Multi-tasking in the Automobile

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While often being reminded to pay full attention while driving an automobile, people regularly engage in a wide variety of multi-tasking activities when they are behind the wheel. Indeed, data from the 2000 US census indicates that drivers spend an average of 25.5 minutes each day commuting to work and there is a growing interest in trying to make the time spent on the roadway more productive (Reschovsky, 2004). Unfortunately, due to the inherent limited capacity of human attention (e.g., Kanheman, 1973; Navon & Gopher, 1979, Wickens, 1984), engaging in these multi-tasking activities often comes at a cost of diverting attention away from the primary task of driving. There are a number of more traditional sources of driver distraction. These "old standards" include talking to passengers, eating, drinking, lighting a cigarette, applying make-up, and listening to the radio (cf. Stutts et al., 2003). However, over the last decade many new electronic devices have been developed and are making their way into the vehicle. In many cases, these new technologies are engaging, interactive information delivery systems. For example, drivers can now surf the Internet, send and receive e-mail or fax, communicate via cellular device, and even watch television. There is good reason to believe that some of these new multi-tasking activities may be substantially more distracting than the old standards because they are more cognitively engaging and because they are often performed over more sustained periods of time.

This chapter focuses on how driving is impacted by cellular communication because this is one of the most prevalent exemplars of this new class of multi-tasking activity. Indeed, the National Highway Transportation Safety Administration estimates that that 8% of drivers on the roadway at any given daylight moment are using their cell phone (Glassbrenner, 2005). Here we summarize research from our laboratory that addresses four interrelated questions related to cell phone use while driving. First, does cell phone use interfere with driving? There is ample anecdotal evidence suggesting that it does. However, multiple resource models of dual-task performance (e.g., Wickens, 1984) have been interpreted as suggesting that an auditory/verbal/vocal cell phone conversation may be performed concurrently with little or no cost with a visual/spatial/manual driving task (e.g., Strayer, Drews, & Johnston, 2003; but see Wickens, 1999). Unfortunately, there is only limited empirical evidence to definitively answer the question (for prior research see Alm & Nilsson, 1995; Briem & Hedman, 1995; Brookhuis, De Vries, & De Waard, 1991; Brown, Tickner, & Simmonds, 1969; McCarley et al., 2004; McKnight & McKnight, 1993; Redelmeier & Tibshirani, 1997; Strayer, Drews, & Johnston, 2003; Strayer & Johnston, 2001). Second, if using a cell phone does interfere with driving, what are the bases of this interference? For example, how much of this interference can be attributed to manual manipulation of the phone (e.g., dialing, holding the phone) and how much can be attributed to the cognitive demands placed on attention by the cell phone conversation itself? This question is of practical importance because if the interference is primarily due to manual manipulation of the phone, then policies such as those enacted by New York State (Chapter 69 of the Laws of 2001, section 1225c State of New York) discouraging drivers from using hand-held devices while permitting the use of hands-free units would be well grounded in science. On the other hand, if significant interference is observed even when all the interference from manual manipulation of the cell phone has been eliminated, then these regulatory policies would not be supported by the scientific data. Third, to the extent that the cell phone conversation itself interferes with driving, what are the mechanisms underlying this interference? One possibility that we explore in this chapter is that the cell phone conversation causes a withdrawal of attention from the visual scene, yielding a form of inattention blindness (Rensink, Oregan, & Clark, 1997; Simons & Chabris, 1999).

Finally, what is the real-world significance of the interference produced by concurrent cell phone use? That is, when controlling for frequency and duration of use, how do the risks compare with other activities commonly engaged in while driving? The benchmark that we employ here is that of the driver who is intoxicated from ethanol at the legal limit (.08 wt/vol). How do the impairments caused by cell phone conversations compare with this benchmark?

Experiment 1

Our first study was an observational one designed to determine the effects of cell phone use on the performance of drivers using their own vehicle who were unaware that their behavior was being monitored.[1] By visual inspection, we observed over 1700 drivers to determine whether or not they were conversing on a cell phone and whether or not each driver came to a complete stop before entering a 4-way intersection with stop signs for all directions of traffic. The resulting 2 X 2 contingency table permitted an assessment of the effects of cell phone use on real-world driving.

Method

Participants. 1748 drivers were observed in naturalistic driving situations in the Avenues residential section of the Salt Lake City, Utah. Observations were made on six occasions for one hour on each occasion, between the hours of 5:00 PM and 6:00 PM. Two of the data collection sessions were on Mondays, two were on Wednesdays, and two were on Fridays. Drivers were not aware that they were being observed.

Stimuli and Apparatus. Three 4-way intersections with stop signs in all directions of traffic were selected in the Avenues residential section of Salt Lake City, Utah. Each location was used twice in the study. The locations were 1) the intersection of E street and 11th avenue, 2) the

1 We would like to thank Henrik Burns and Kyle Strayer for collecting the data reported in Experiment 1.

intersection of I street and 11th avenue, and 3) the intersection of I street and 3rd avenue. The posted speed limit at all locations was 25 MPH. Throughout the observation intervals, the driving conditions were good with normal day time visibility.

Procedures. Observations were made by two research assistants. As each vehicle approached the intersection, the observers recorded whether or not the driver was using a cell phone. If the driver could be seen using a cell phone (i.e., a cell phone was held to the driver's ear), the driver was classified as using a cell phone. If a cell phone was not visibly in use at the time of observation, the driver was classified as not using a cell phone. In addition, the observers determined if the driver came to a complete stop at the intersection. Based on definitions provided by the Salt Lake City Police Department, drivers were required to come to a complete stop at the white stop line painted across the intersection to be classified as stopping at the intersection. If the driver failed to stop at or before the white stop line, then the driver was classified as failing to stop at the intersection.

Results and Discussion

Table 1 presents the data arranged in a 2 X 2 contingency table. Approximately 6% of our sample of drivers was using their cell phone at the time that they approached the intersection and approximately 24% of our sample of drivers failed to come to a complete stop at the intersection. However, it is clear that the ratio of drivers failing to stop at the intersection differed depending on whether or not they were using their cell phone. A logistic regression analysis was used to compare the differential rates of failure to stop at the intersection. For drivers not using a cell phone, the odds ratio for failing to stop at the intersection was 0.27, whereas for cell-phone drivers the odds ratio was 2.93, a ten-fold increase in the odds ratio. The difference in odds ratios was significant

$\chi^2(1)=129.8$, $p<.01$, providing clear evidence for impaired real-world driving when drivers are using their cell phone (see also Redelmeier & Tibshirani, 1997). Thus, these data provide clear-cut evidence that conversing on a cell phone significantly interferes with driving.

However, there are limitations to this observational study. Most notably, while the study established a strong association between cell phone use and failure to stop at intersections, it did not demonstrate a *causal link* between cell phone use and driving impairment. It is possible that self-selection factors underlie the association. For example, people who use their cell phone may be more likely to engage in risky behavior and this increase in risk taking may be the cause of the correlation. To better understand the causal relations between cell phone use and driving impairment, we now turn to a series of controlled laboratory studies using a high-fidelity driving simulator.

Experiment 2

Experiment 1 found that cell-phone drivers were more likely to fail to stop at a 4-way intersection than were drivers who were driving without the distraction caused by cell phone use. One possible interpretation of these findings is that the cell phone conversation reduced the attention paid to information in the external environment. Our second study was designed to examine how cell phone conversations affect the driver's attention to objects that are encountered while driving. We contrasted performance when participants were driving but not conversing (single-task conditions) with that when participants were driving and conversing on a hands-free cell phone (dual-task conditions).

Our second experiment used a 2 alternative forced choice (2AFC) recognition memory paradigm to determine what information in the driving scene participants paid attention to while driving.[2] The procedure required participants to perform a simulated driving task without the foreknowledge that their memory for objects in the driving scene would be subsequently tested. Later, participants were given a surprise 2AFC-recognition memory task in which they were shown objects that were encountered while they were driving and were asked to discriminate these objects from foils that were not in the driving scene. The difference between driving (i.e., single-task) and the driving while conversing on a cell phone condition (i.e., dual-task) provides an estimate of the degree to which attention to visual information in the driving environment is distracted by cell phone conversations.

Method

Participants. Sixty-four undergraduates from the University of Utah participated in the experiment. All had normal or corrected-to-normal vision and a valid driver's license.

Stimuli and Apparatus. A PatrolSim high-fidelity fixed-base driving simulator, manufactured by GE I-Sim and illustrated in Figure 1, was used in the study. The simulator incorporates proprietary vehicle dynamics, traffic scenario, and road surface software to provide realistic scenes and traffic conditions. The dashboard instrumentation, steering wheel, gas, and brake pedal were taken from a Ford Crown Victoria® sedan with an automatic transmission.

The key manipulation in the study was the placement of 30 objects (e.g., cars, trucks, pedestrians, traffic signs, billboards, etc.) along the roadway in the driving scene. Another 30 objects were not presented in the driving scene and served as foils in the 2AFC-recognition memory task. The objects were counterbalanced across participants so that each was used equally often as a

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2 We wish to acknowledge Joel Cooper's assistance in collecting the data reported in Experiment 2.

target and as a foil. Objects in the driving scene were positioned so that they were clearly in view as participants drove past them.

Eye movement data were recorded from 32 of the participants using an Applied Science Laboratories (ASL) eye and head tracker (Model 501). The ASL mobile 501 eye-tracker is a video-based unit that allows free range of head and eye movements, thereby affording naturalistic viewing conditions for the participants as they negotiated the driving environment.

Procedure. When participants arrived for the experiment, they completed a questionnaire that assessed their interest in potential topics of cell phone conversation. Participants were then familiarized with the driving simulator using a standardized 20 minute adaptation sequence. The experiment involved driving two 7-mile sections of an urban highway. One of the scenarios was used in the single-task (i.e., driving only) condition and the other was used in the dual-task (i.e., driving and conversing on a cell phone) condition. The order of single-task and dual-task conditions and driving scenarios were counterbalanced across participants. The participant's task was to drive through each scenario, following all the rules of the road.

The dual-task condition involved conversing on a cell phone with a research assistant. The participant and the research assistant discussed topics that were identified in the pre-experimental questionnaire as being of interest to the participant. To avoid any possible interference from manual components of cell phone use, participants used a hands-free cell phone that was positioned and adjusted before driving began. Additionally, the call was initiated before participants began the dual-task scenarios. Thus, any dual-task interference that we observe must be due to the cell phone conversation itself, because there was no manual manipulation of the cell phone during the dual-task portions of the study.

Immediately following the driving portion of the study, participants performed a 2AFC-recognition memory task in which they attempted to identify which objects had been presented in the driving scenario. On each trial, two objects were presented on a computer display and remained in view until participants made their judgment (i.e., which of the two objects did they see while driving in the simulator?). After the forced choice judgment, participants were also asked to rate the two objects in terms of their relevance to safe driving using a 10-point scale (participants were given an example in which a child playing near the road might receive a rating of 9 or 10, whereas a sign documenting that a volunteer group cleans a particular section of the highway might receive a rating of 1). There was no relationship between the order of presentation of the objects in the driving task and the order of presentation in the 2AFC-recognition memory task. Participants were not informed about the memory test until after they had completed the driving portions of the experiment.

Analysis. Eye-tracking data from 32 participants were analyzed to determine whether or not the participant fixated on each object. To ensure that the image had stabilized on the participant's retinas, we required the eyes to be directed at the center of the object for at least 100 msec for the object to be classified as having been fixated.

Results and Discussion

Objects encountered in single-task conditions were correctly recognized more often than objects from dual-task conditions, $F(1,63)=5.80$, $p<.05$. Corrected for guessing mean recognition probability for the single-task conditions was 0.21 (sd=0.14) and for the dual-task condition was 0.16 (sd=0.11). These data are consistent with the hypothesis that the cell phone conversation disrupts performance by diverting attention from the external environment associated with the driving task to an engaging internal context associated with the cell phone conversation.

We next assessed whether the differences in recognition memory may be due to differences in eye fixations on objects in the driving scene. The eye-tracking data indicated that participants fixated on approximately 61% of the objects in the driving scene. The difference in the probability of fixating on objects from single- to dual-task conditions was not significant, $F(1,31)=0.78$, $p> .40$. Thus, the contribution of fixation probability on recognition memory performance would appear to be minimal. We also measured fixation duration in single- and dual-task conditions to ensure that the observed differences in recognition memory were not due to longer fixation times in single-task conditions. There was a tendency for recognition probability to increase with fixation duration ($r = 0.14$); however, the difference in fixation duration between single- and dual-task conditions was not significant, $F(1,31)=1.63$, $p>.16$. As above, the differences in recognition memory performance that we observed in single- and dual-task conditions do not appear to be due to alterations in visual scanning of the driving environment.

We also computed the conditional probability of recognizing an object given that participants fixated on it while driving. This analysis is important because it specifically tests for memory of objects that were presented where the driver's eyes were directed. The corrected for guessing conditional probability analysis revealed that participants were more likely to recognize objects encountered in the single-task condition (mean=0.25, sd=.15) than in the dual-task condition (mean=0.15, sd=.19), $F(1,31)=5.28$, $p<.05$. Note that dual-task performance was 60% of that obtained in single-task conditions. Estimates of effect size (Cohen's $d = 0.58$) indicate that this is a medium-sized effect. Thus, when we ensured that participants fixated on an object, we found significant differences in recognition memory between single- and dual-task conditions.

Our final analysis focused on participant's rating of each item's relevance in the driving scene in terms of traffic safety. Item relevance ratings ranged from 1.5 to 8 and the overall rating of traffic relevance was 4.1 (sd=1.0). As would be expected given the counterbalancing procedures, the difference in the rating of traffic relevance from single- to dual-task conditions was not significant, $F(1,31)=0.93$, $p> .37$. We conducted a series of regression analyses to determine the extent to which driving relevance affected recognition memory performance in single- and dual-task conditions. The correlation between recognition memory performance and traffic relevance was not significant ($r = .03$) and remained unchanged when the variance associated with single- and dual-task conditions was partialed out. That is, traffic relevance had absolutely no effect on the difference in recognition memory between single- and dual-task conditions. This analysis is important because it demonstrates that participants did not strategically reallocate attention from the processing of less relevant information in the driving scene to the cell phone conversation while continuing to give highest priority to the processing of task-relevant information in the driving scene. In fact, the contribution of an object's perceived relevance to safe driving on recognition memory performance would appear to be negligible.

The results indicate that conversing on a cellular phone disrupts the driver's attention to the visual environment. Even when participants looked directly at objects in the driving scene, they were less likely to create a durable memory of those objects if they were conversing on a cell phone. Moreover, this pattern was obtained for objects of both high- and low-relevance, suggesting that very little semantic analysis of the objects occurs outside the focus of attention. McCarley et al., (2004) also reported that the cell phone conversations of younger adults disrupt the detection of change in complex driving scenes for items of both high- and low-relevance. These data provide strong support for inattention-blindness hypothesis in which the disruptive effects of cell phone conversations on driving are due in large part to the diversion of attention from driving to the phone conversation. We suggest that even when participants are directing their gaze at objects in the driving environment, that they may fail to "see" them their because attention is directed internally to the phone conversation.

Experiment 3

The differences between single- and dual-task recognition memory performance in Experiment 2 are consistent with the inattention-blindness hypothesis in which cell phone conversations interfere with the initial encoding of the objects in the driving scene. However, an alternative possibility is that there were no differences in the initial encoding, but rather differences in the retrieval of the information during the recognition memory test. This distinction is more than academic because the former has direct implications for traffic safety whereas the latter does not (i.e., failing to recognize an item at a later point in time does not necessarily imply an impairment in encoding and reaction to an object in the driving environment).

The purpose of Experiment 3 was to further test the inattention-blindness hypothesis by recording on-line measures of brain activity elicited by events in the driving environment.[3] Prior research has found that the amplitude of the P300 component of the event-related brain potential (ERP) is sensitive to the attention allocated to a task (e.g., Sirevaag, Kramer, Coles, & Donchin, 1989; Wickens, Kramer, Vanasse, & Donchin, 1983) and, further, that memory performance is superior for objects eliciting larger amplitude P300s during encoding (e.g., Fabiani, Karis & Donchin, 1983; Otten & Donchin, 2000). Moreover, Kramer, Sirevaag, and Braune (1987, see also Sirevaag et al., 1993) measured ERPs in a flight simulator and found that the P300 component of

3 We wish to thank Mandi Martinez for assistance in collecting the data reported in Experiment 3.

the ERP discriminated among levels of task difficulty, decreasing as the task demands increased. If the impairments in recognition memory performance observed in Experiment 2 are due to differences in the initial encoding of objects in the driving scene, we predict that P300 amplitude will be smaller in dual-task conditions than in single-task conditions. By contrast, if the recognition memory differences observed in Experiment 2 are due to impaired retrieval of information at the time of the recognition memory test but not at the time of encoding, then we would not expect to find differences in P300 amplitude between single- and dual-task conditions.

We used a car-following paradigm (see also Alm & Nilsson, 1995; Strayer, Drews, & Johnston, 2003) in which participants drove on a multi-lane freeway in single-task (i.e., driving only) and dual-task (i.e., driving and conversing on a cell phone) conditions. Participants followed a pace car that would brake at random intervals and ERPs were time-locked to the onset of the pace car brake lights in both single- and dual-task conditions. Do cell phone conversations suppress the traffic-related brain activity as predicted by the inattention-blindness hypothesis?

Method

Participants. Thirty-two undergraduates, recruited as friend dyads from the University of Utah participated in this study. One participant out of each dyad was randomly selected to be the driver while the other was selected to be the conversing partner. All had normal or corrected-to-normal visual acuity and a valid driver’s license.

Stimuli and Apparatus. The PatrolSim high-fidelity driving simulator used in Experiment 2 was also used in the current study. A freeway road database simulated a 24-mile multi-lane beltway with on and off-ramps, overpasses, and two and three-lane traffic in each direction. A pace car, programmed to travel in the right-hand lane, braked intermittently throughout the scenario.

Distractor vehicles were programmed to drive between 5% and 10% faster than the pace car in the left lane, providing the impression of a steady flow of traffic. Unique driving scenarios, counterbalanced across participants, were used for each condition in the study.

Electroencephalographic (EEG) activity, time-locked to the onset of the pace car brake lights, was recorded from three midline sites (Fz, Cz, Pz, according to the international 10-20 system; Jasper, 1958). Bipolar vertical and horizontal Electrooculographic (EOG) activity was simultaneously recorded to ensure that eye movements did not contaminate the EEG records. MED 10-mm diameter Ag/AgCl biopotential electrodes were used at all electrode sites and electrode impedance did not exceed 10 KOhms. EEG and EOG signals were amplified with a Grass model 12 Neurodata Acquisition System. Both EEG and EOG were sampled every two msec and the digitized data were stored on disk for subsequent analysis. EOG artifacts were corrected off-line with a procedure described by Gratton, Coles, and Donchin (1983).

Procedure. When participants arrived for the experiment, they completed a questionnaire assessing their interest in potential topics of cell phone conversation. Participants were then familiarized with the driving simulator, using a standardized 20-minute adaptation sequence. Participants then drove four ten-mile sections on a multi-lane highway. Half of the scenarios were used in the single-task driving condition and half were used in the dual-task (i.e., driving and cell phone conversation) condition. The order of conditions and scenarios was counterbalanced across participants using a Latin square design, with the constraint that both single-and dual-task conditions were performed in the first half of the experiment and both single-and dual-task conditions were performed in the last half of the experiment.

The participant's task was to follow a pace car that was driving in the right-hand lane of the highway. When the participant stepped on the brake pedal in response to the braking pace car, the pace car released its brake and accelerated to normal highway speed. If the participant failed to depress the brake, they would eventually collide with the pace car. That is, like real highway stop and go traffic, the participant was required to react in a timely and appropriate manner to vehicles slowing in front of them.

The dual-task condition involved conversing on a cell phone with the driver's friend. The driver and friend discussed topics that were identified in the pre-experimental questionnaire as being of interest to both parties (cf. Drews, Pasupathi, & Strayer, 2004). To avoid any possible interference from manual components of cell phone use, participants used a hands-free cell phone that was positioned and adjusted before driving began. Additionally, the call was initiated before participants began the dual-task scenarios. As before, any dual-task interference that we observe must therefore be due to the cell phone conversation itself, because there was no manual manipulation of the cell phone during the dual-task portions of the study.

Results and Discussion

The average ERPs recorded at the parietal electrode site are presented in Figure 2. In the figure, the solid line represents ERPs recorded in the single-task condition and the dotted line represents the ERPs recorded in the dual-task condition. Inspection of the figure reveals a large positive potential between 250 and 750 msec (the P300 component of the ERP). It is evident that the P300 component of the ERPs is larger in single- than in dual-task conditions. P300 amplitude was quantified by computing the area under the curve between 250 msec and 750 msec post-stimulus onset for each subject/condition. A correlated t-test indicated that the difference between single- and dual-task conditions was significant, $t(15)=4.41$, $p<.01$. Estimates of effect size (Cohen's $d = 0.46$)

indicate that this is a medium-sized effect.

We also measured the peak latency of the P300 component, as this has been taken as an index of the time for stimulus evaluation processes largely uncontaminated by response mechanisms (e.g., Kutas, McCarthy, & Donchin, 1977; McCarthy & Donchin, 1981; Magliero, Bashore, Coles, & Donchin, 1984). The peak latency of the P300, estimated using a single trial peak picking algorithm (Fabiani, Gratton, Karis, & Donchin, 1988), was greater in dual- than in single-task conditions, $t(15)=6.32$, $p<.01$. Estimates of effect size (Cohen's $d = 0.89$) indicate that this is a large-sized effect. The delay in P300 latency in dual-task conditions provides good evidence that the initial processing of information necessary for the safe operation of a motor vehicle is impaired when drivers were conversing on a cell phone (i.e., these differences cannot be attributed to differences in response criteria in single- and dual-task conditions).

The reduced P300 amplitude in dual-task conditions provides strong evidence for the inattention-blindness hypothesis. In particular, the data support an interpretation in which the initial encoding of information in the driving environment is interfered with by the cell phone conversation. In Experiment 2, we suggested that cell-phone drivers looked but often failed to see objects in the driving environment. The ERP data further indicate that when drivers converse on a cell phone, the brain activity associated with processing information necessary for the safe operation of a motor vehicle is suppressed. Thus, drivers using a cell phone fail to see information in the driving scene because they do not encode it as well as they do when they are not distracted by the cell phone conversation. In situations where the driver is required to react with alacrity, these data suggest that those using a cell phone will be less able to do so because of the diversion of attention from driving to the phone conversation.

Experiment 4

Our fourth study was designed to evaluate the real-world risks associated with conversing on a cell phone while driving. [4] One way to evaluate these risks is by comparison with other activities commonly engaged in while driving (e.g., listening to the radio, talking to a passenger in the car, etc). The benchmark that we used in our final study was driving while intoxicated from ethonol at the legal limit (.08 wt/vol). We selected this benchmark because there are well established societal norms and laws regarding drinking and driving. Indeed, the World Health Organization recommended that the behavioral effects of an activity should be compared to alcohol under the assumption that performance should be no worse than when operating a motor vehicle at the legal limit (Willette & Walsh, 1983). How does conversing on a cell phone compare with the drunk driving benchmark?

Redelmeier and Tibshirani (1997) used an epidemiological approach and concluded that “the relative risk [of being in a traffic accident while using a cell-phone] is similar to the hazard associated with driving with a blood alcohol level at the legal limit” (p. 465). If this finding can be substantiated in a controlled laboratory experiment, then these data would be of immense importance for public safety. Here we directly compared the performance of drivers who were conversing on a cell-phone with the performance of drivers who were legally intoxicated with ethanol. We used the car-following paradigm described in Experiment 3. Three conditions were studied: single-task driving (baseline condition), driving while conversing on a cell-phone (cell-phone condition), and driving with a blood alcohol concentration of 0.08 wt/vol (alcohol condition).

Method

4 We thank Amy Alleman, Joel Cooper, and Danica Nelson for collecting the data reported in Experiment 4.

Participants. Forty adults, recruited via advertisements in local newspapers, participated in the study. All had normal or corrected-to-normal vision and a valid driver's license. A further requirement for inclusion in the study was that participants were social drinkers, consuming between three to five alcoholic drinks per week. The experiment lasted approximately 10 hours (across the three days of the study) and participants were remunerated at a rate of $10 per hour.

Stimuli and Apparatus. The PatrolSim high-fidelity driving simulator used in Experiment 2 was used in the current study. Measures of real-time driving performance, including driving speed, distance from other vehicles, and brake inputs, were sampled at 30 Hz and stored for later analysis. Blood alcohol concentration levels were measured using an Intoxilyzer 5000, manufactured by CMI Inc.

Procedure. The experiment was conducted in three sessions on different days. The first session familiarized participants with the driving simulator using a standardized adaptation sequence. The order of subsequent alcohol and cell-phone sessions was counterbalanced across participants. In these latter sessions, the participant's task was to follow the intermittently braking pace car driving in the right-hand lane of the highway.

In the alcohol session, participants drank a mixture of orange juice and vodka (40% alcohol by volume) calculated to achieve a blood alcohol concentration of 0.08 wt/vol. Blood alcohol concentrations were verified using infrared spectrometry breath analysis immediately before and after the alcohol driving condition. Participants drove in the 15-minute car-following scenario while legally intoxicated. Average blood alcohol concentration before driving was 0.081wt/vol and after driving was 0.078 wt/vol.

In the cell-phone session, three counterbalanced conditions, each 15 minutes in duration, were included: single-task baseline driving, driving while conversing on a hand-held cell phone, and driving while conversing on a hands-free cell phone. In both cell-phone conditions, the participant and a research assistant engaged in naturalistic conversations on topics that were identified on the first day as being of interest to the participant. The task of the research assistant in our study was to maintain a dialog in which the participant listened and spoke in approximately equal proportions. To minimize interference from manual components of cell phone use, the call was initiated before participants began driving.

Results and Discussion

Table 2 presents the nine performance variables that were measured to determine how participants reacted to the vehicle braking in front of them. *Brake reaction time* is the time interval between the onset of the pace car's brake lights and the onset of the participant's braking response (i.e., defined as a minimum of 1% depression of the participant's brake pedal). *Braking force* is the maximum force that the participant applied to the brake pedal in response to the braking pace car (expressed as a percentage of maximum). *Speed* is the average driving speed of the participant's vehicle (expressed in miles per hour). *Mean following distance* is the distance prior to braking between the rear bumper of the pace car and the front bumper of the participant's car. *SD following distance* is the standard deviation of following distance. *Time to collision (TTC),* measured at the onset of the participant's braking response, is the time that remains until a collision between the participant's vehicle and the pace car if the course and speed were maintained (i.e., had the participant failed to brake). Also reported are the frequency of trials with TTC values below 4 seconds, a level found to discriminate between cases where the drivers find themselves in dangerous situations from cases where the driver remains in control of the vehicle (e.g., Hirst & Graham, 1997). *Half-recovery time* is the time for participants to recover 50% of the speed that was lost during braking (e.g., if the participant's car was traveling at 60 MPH before braking and decelerated to 40 MPH after braking, then half-recovery time would be time taken for the participant's vehicle to return to 50 MPH). Also shown in the table is the total number of collisions in each phase of the study. We used a Multivariate Analysis of Variance (MANOVA) followed by planned contrasts to provide an overall assessment of driver performance in each of the experimental conditions.

We performed an initial comparison of driving while using a hand-held versus hands-free cell phone. Both hand-held and hands-free cell-phone conversations impaired driving. However, there were no significant differences in the impairments caused by these two modes of cellular communication (all p's $> .25$). Therefore, we collapsed across the hand-held and hands-free conditions for all subsequent analyses reported in this chapter. The observed similarity between hand-held and hands-free cell-phone conversations is consistent with earlier work *(*e.g., Mazzae et al., 2004; Patten et al., 2004; Redelmeier & Tibshirani, 1997; Strayer & Johnston, 2001) and calls into question driving regulations that prohibit hand-held cell phones and permit hands-free cell phones.

MANOVAs indicated that both cell-phone and alcohol conditions differed significantly from baseline ($F(8,32)=6.26$, $p<.01$ and $F(8,32)=2.73$, $p<.05$, respectively). When drivers were conversing on a cell phone, they were involved in more rear-end collisions, their initial reaction to vehicles braking in front of them was slowed by 9%, and the variability in following distance increased by 24%, relative to baseline. In addition, compared to baseline, it took participants who were talking on a cell phone 19% longer to recover the speed that was lost during braking.

By contrast, when participants were intoxicated, neither accident rates, nor reaction time to vehicles braking in front of the participant, nor recovery of lost speed following braking differed significantly from baseline. Overall, drivers in the alcohol condition exhibited a more aggressive driving style. They followed closer to the pace vehicle, had twice as many trials with TTC values below 4 seconds, and braked with 23% more force than in baseline conditions. Importantly, our study found that accident rates in the alcohol condition did not differ from baseline; however, the increase in hard braking and the increased frequency of TTC values below 4 seconds are predictive of increased accident rates over the long run (e.g., Brown, Lee, & McGehee, 2001; Hirst & Graham, 1997).

The MANOVA also indicated that the cell-phone and alcohol conditions differed significantly from each other, $F(8,32)=4.06$, $p<.01$. When drivers were conversing on a cell phone, they were involved in more rear-end collisions and took longer to recover the speed that they had lost during braking than when they were intoxicated. Drivers in the alcohol condition also applied greater braking pressure than drivers in the cell-phone condition.

Finally, the accident data were analyzed using a non-parametric Chi Square statistical test. The Chi Square analysis indicated that there were significantly more accidents when participants were conversing on a cell phone than in the baseline or alcohol conditions. $\chi^2(2)=6.15$, $p<.05$.

Taken together, we found that both intoxicated drivers and cell-phone drivers performed differently from baseline and that the driving profiles of these two conditions differed. Drivers using a cell phone exhibited a delay in their response to events in the driving scenario and were more likely to be involved in a traffic accident. Drivers in the alcohol condition exhibited a more aggressive driving style, following closer to the vehicle immediately in front of them, necessitating braking with greater force. With respect to traffic safety, the data suggest that the impairments associated with cell-phone drivers may be as great as those commonly observed with intoxicated drivers.

Conclusions

Cell phone conversations alter how drivers perceive and react to information in the driving environment. We found cell-phone drivers were more likely to fail to stop at 4-way intersections and more likely to be involved in rear-end collisions than drivers not using a cell phone. In fact, even when cell-phone drivers were directing their gaze at objects in the driving environment they often failed to see them because attention was directed elsewhere. Moreover, we found that cell phone conversations suppress the ERPs elicited by traffic-related information. We suggest that talking on a cell phone creates a form of inattention blindness, muting driver's awareness of important information in the driving scene.

We also compared hand-held and hands-free cell phones and found that the impairments to driving are identical for these two modes of communication. There was no evidence that hands-free cell phones were any safer to use while driving than hand-held devices. In fact, we consistently found significant interference even when we removed any possible interference from manual components of cell phone use (e.g., by having drivers place a call on a hands-free cell phone that was positioned and adjusted before driving began). Although there is good evidence that manual manipulation of equipment (e.g., dialing the phone, answering the phone, etc.) has a negative impact on driving (Mazzae et al., 2004), the distracting effects of cell phone conversation persist even when these manual sources are removed. Moreover, the duration of a typical phone conversation is often significantly greater than the time required to dial or answer the phone. Thus, these data call into question driving regulations that prohibit hand-held cell-phones and permit hands-free devices, because no differences were found in the impairments caused by these two modes of cellular communication.

Finally, what is the real-world risk associated with using a cell phone while driving? An important epidemiological study by Redelmeier and Tibshirani (1997) found that cell phone use was associated with a 4-fold increase in the likelihood of getting into an accident and that this increased risk was comparable to that observed when driving with a blood alcohol level at the legal limit. Our simulator-based research controlling for time on task and driving conditions found that driving performance was more impaired when drivers were conversing on a cell phone than when these same drivers were intoxicated at .08 wt/vol. Taken together, these observations provide clear-cut evidence indicating that driving while conversing on a either a hand-held or hands-free cell phone poses significant risks both to the driver and to the general public.

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Table 1. Cell frequencies for Experiment 1.

	Failed to Stop at Intersection	Stopped Properly at Intersection	
On Cell Phone	82	28	110
Not Using Cell Phone	352	1286	1838
	434	1314	1748

Table 2. Means and standard errors (in parentheses) for the Alcohol, Baseline, and Cell-Phone conditions of Experiment 4.

	Alcohol	Baseline	Cell Phone
Total Accidents	0	0	3
Brake Reaction Time (msec)	779 (33)	777 (33)	849 (36)
Maximum Braking Force	69.8 (3.7)	56.7 (2.6)	55.5 (3.0)
Speed (MPH)	52.8 (2.0)	55.5 (0.7)	53.8 (1.3)
Mean Following Distance (meters)	26.0 (1.7)	27.4 (1.3)	28.4 (1.7)
SD Following Distance (meters)	10.3 (0.6)	9.5 (0.5)	11.8 (0.8)
Time to Collision (seconds)	8.0 (0.4)	8.5 (0.3)	8.1 (0.4)
Time to Collision < 4 seconds	3.0 (0.7)	1.5 (0.3)	1.9 (0.5)
½ Recovery Time (seconds)	5.4 (0.3)	5.3 (0.3)	6.3 (0.4)

Figure 1. A participant talking on a cell phone while driving in the GE I-SIM driving simulator.

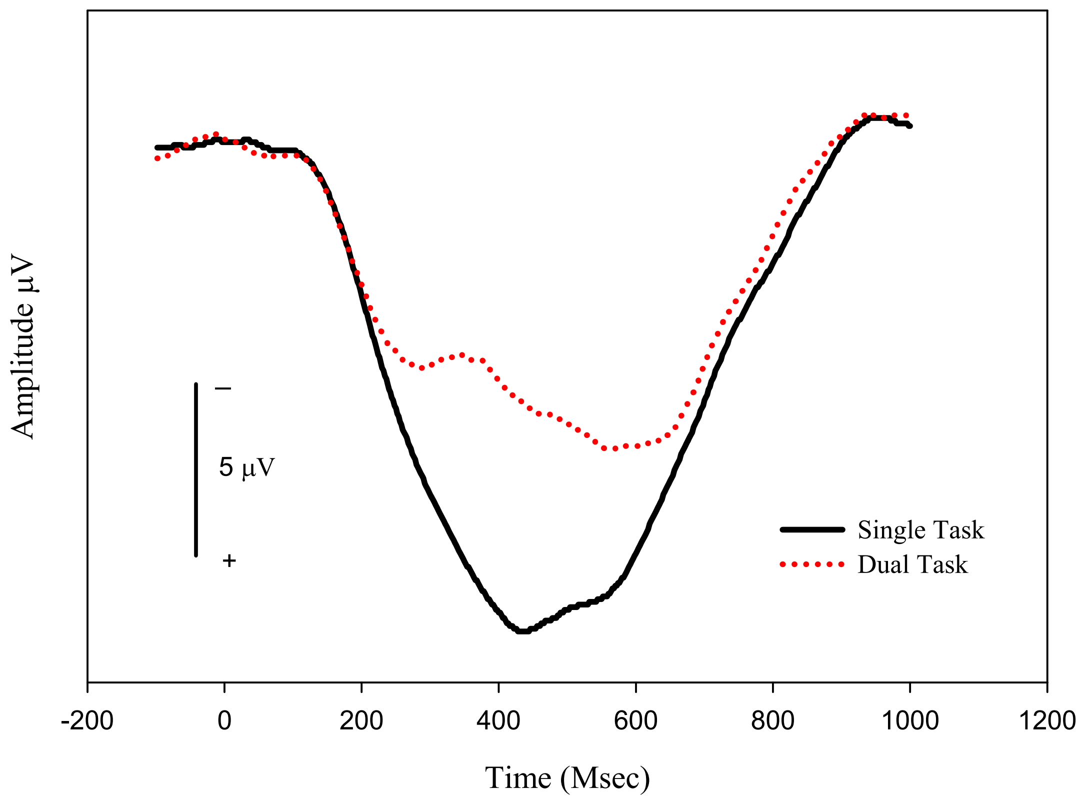

Figure 2. ERPs elicited by the onset of the pace car brake light in Experiment 3 (recorded at Pz)