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Why Do Cell Phone Conversations Interfere With Driving?

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While often being reminded to pay full attention to driving, people regularly engage in a wide variety of multi-tasking activities when they are behind the wheel. Indeed, as the average time spent commuting increases, there is a growing interest in trying to make the time spent on the roadway more productive. Unfortunately, due to the inherent limited capacity of human attention, 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, **or** listening to the radio (Stutts et al., 2003). However, over the last 5-10 years many new electronic devices have been developed and are making their way into the vehicle. In most 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 performed over longer 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. Here we summarize research from our lab (e.g., Strayer & Johnston, 2001; Strayer, Drews, & Johnston, 2003; Strayer, Drews, & Crouch, in press), that addressed four interrelated questions related to cell phone use while driving. First, does cell phone use interferes with driving? There is ample anecdotal evidence suggesting that it does. However, multiple resource models of dual-task performance (e.g., Wickens, 1984; but see Wickens 1999) can be 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. Unfortunately, there is a paucity of empirical evidence to definitively answer the question. 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 demands placed on attention by the cell phone conversation itself? This question is of practical importance; If the interference is primarily due to manual manipulation of the phone, then policies such as those recently 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 explored 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 employed is that of the driver who is intoxicated from ethanol at the legal limit (.08 wt/vol). Do the impairments caused by cell phone conversations rise above this benchmark?

Background

In their seminal article, Redelmeier and Tibshirani (1997) evaluated the cellular records of 699 individuals involved in motor vehicle accidents. It was found that 24% of these individuals were using their cell phone within the 10-minute period preceding the accident, and this was associated with a four-fold increase in the likelihood of getting into an accident. Moreover, these authors suggested that the interference associated with cell phone use was due to attentional factors rather than to peripheral factors such as holding the phone. However, there are several limitations to this study. First, while the study established a strong association between cell phone use and motor vehicle accidents, it did not demonstrate a *causal link* between cell phone use and increased accident rates. For example, there may be self-selection factors underlying the association: People who use their cell phone may be more likely to engage in risky behavior. It may also be the case that a person’s emotional state may simultaneously increase the likelihood of using a cell phone and driving erratically. Finally, limitations on establishing the exact time of the accident lead to uncertainty regarding the precise relationship between talking on a cell phone while driving and increased traffic accidents.

Other researchers have established that the manual manipulation of equipment (e.g., dialing the phone, answering the phone, etc.) has a negative impact on driving (e.g., Brookhuis, De Vries, & De Waard, 1991; Briem & Hedman, 1995). However, the effects of the phone *conversation* on driving are not as well understood, despite the fact that the duration of a typical phone conversation is often significantly greater than the time required to dial or answer the phone. Briem & Hedman (1995) reported that simple conversations did not adversely affect the ability to maintain road position. On the other hand, several studies have found that working memory tasks (Alm & Nilsson, 1995; Briem & Hedman, 1995), mental arithmetic tasks (McKnight & McKnight, 1993), and reasoning tasks (Brown, Tickner, & Simmonds, 1969) disrupt simulated driving performance.

Experiment 1

Our first study was designed to contrast the effects of hand-held and hands-free cell phone conversations on responses to traffic signals in a simulated driving. We also included control groups who either listened to the radio or listened to a book on tape while performing the driving task. As participants performed the driving task, occasional red and green lights were flashed on the computer display. If participants saw a green light, they were instructed to continue as normal. However, if a red light was presented they were to make a braking response as quickly as possible. This manipulation was included to determine how quickly participants could react to the red light as well as to determine the likelihood of detecting simulated traffic signals under the assumption that these measures would contribute significantly to any increase in the risks associated with driving and using a cell phone.

Method

Participants. Sixty-four undergraduates (32 male, 32 female) from the University of Utah participated in the experiment. Participants ranged in age from 18 to 30. All had normal or corrected-to-normal vision and a valid driver's license. Participants were randomly assigned to one of the radio control, book-on-tape control, hand-held cell phone, or hands-free cell phone groups.

Stimuli and Apparatus. Participants performed a pursuit tracking task in which they used a joystick to maneuver the cursor on a computer display to keep it aligned as closely as possible to a moving target. The target position was updated every 33 msec and was determined by the sum of three sine waves (0.07 hz, 0.15 hz, and 0.23 hz). The target movement was smooth and continuous, yet essentially unpredictable. At intervals ranging from 10 to 20 sec (mean = 15 sec), the target flashed red or green and participants were instructed to press a “brake button” located in the thumb position on top of the joystick as rapidly as possible when they detected the red light. Red and green lights were equiprobable and were presented in an unpredictable order.

Procedure. An experimental session consisted of three phases. The first phase was a warm-up interval that lasted 7 minutes and was used to acquaint participants with the tracking task. The second phase was the single-task portion of the study and was comprised of the 7.5 minute segment immediately preceding and the 7.5 minute segment immediately following the dual-task portion of the study. During the single-task phase, participants performed the tracking task by itself. The third phase was the dual-task portion of the study, lasting 15 minutes. Dual-task conditions required the participant to engage in a conversation with a confederate (or listen to a radio broadcast of their choosing or a book on tape) while concurrently performing the tracking task. The confederate’s task was to facilitate the conversation and also to ensure that the participant listened and spoke in approximately equal proportions during the dual-task portions of the experiment. Participants in the radio control group listened to a radio broadcast of their choice during the dual-task portions of the experiment. Participants in the book-on-tape control group listened to selected portions from a book on tape during the dual-task portions of the experiment.

Results and Discussion

A preliminary analysis of detection rates and reaction times to traffic signals indicated that there were no reliable differences between hands-free and hand-held cell phone groups (all p’s > .8). Neither were there reliable differences between radio control and book-on-tape control groups (all p’s > .3). Therefore, the data were aggregated to form a 2 (Group: Cell Phone vs. Control) X 2 (Task: Single vs. Dual) factorial design. Table 1 presents both the probability of missing simulated traffic signals and the reaction time to the simulated traffic signals that were detected. Overall, miss rates were low; however, the probability of a miss significantly increased when participants were engaged in conversations on the cell phone, F(1,31)=8.8, p<.01. By contrast, the difference between single and dual-task conditions was not reliable for the control group, *F*(1,31)=0.9, *p*>.3. Analysis of the RT data revealed that participants in the cell phone group responded slower to simulated traffic signals while engaged in conversation on the cell phone, *F*(1,31)=29.8, *p*<.01. There again was no indication of a dual-task decrement for the control group, *F*(1,31)=2.7, *p*>.1.

These data demonstrate that the phone conversation itself resulted in significant slowing in the response to simulated traffic signals, as well as an increase in the likelihood of missing these signals. Moreover, the fact that hand-held and hands-free cell phones resulted in equivalent dual-task deficits indicates that the interference was not due to peripheral factors such as holding the phone while conversing. These findings also rule out interpretations that attribute the deficits associated with a cell phone conversation to simply attending to verbal material, because dual-task deficits were not observed in the book-on-tape and radio controls. Active engagement in the cell phone conversation appears to be necessary to produce the observed dual-task interference.

Experiment 2

Experiment 1 found that participants driving and conversing on a cell phone missed more traffic signals than when they were driving without the distraction caused by cell phone use. One possible interpretation of these findings is that participants using a cell phone detected the imperative signals, but that their responses to them were suppressed. However, a potentially more dangerous possibility is that the cell phone conversation actually inhibited attention to 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).

Experiment 2 used an incidental recognition memory paradigm to determine what information in the driving scene participants attended while driving. 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, the participants were given a surprise recognition memory task in which they were shown objects that were presented while they were driving and were asked to discriminate these objects from foils that were not in the driving scene. The difference in incidental recognition memory between single- and dual-task conditions provides an estimate of the degree to which attention to visual information in the driving environment is distracted by cell phone conversations.

Method

Participants. Twenty undergraduates (15 male, 5 female) from the University of Utah participated in the experiment. Participants ranged in age from 18 to 23. All had normal or corrected-to-normal vision and a valid driver’s license.

Stimuli and Apparatus. A PatrolSim high-fidelity driving simulator, 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.

A key manipulation in the study was the placement of 5 billboards in each of the scenarios. The billboards were positioned so that they were clearly in view as participants drove past them. A total of 45 digital images of real-world billboards were created using a digital camera. A random assignment of billboards to conditions and locations within the scenarios was created for each participant.

Eye movement data were recorded using an Applied Science Laboratories eye and head tracker (ASL 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 were familiarized with the driving simulator using a standardized 20 minute adaptation sequence. The experiment involved driving six 1.2-mile sections of a suburban section of a city. Half of the scenarios were used in the single-task condition and half were used in the dual-task condition. Single- and dual-task conditions were blocked and both task order (single- vs. dual-task) and driving scenario were counterbalanced across participants. For data analysis purposes, the data were aggregated across scenario in both the single- and dual-task conditions.

The participant’s task was to drive through each scenario, following all the rules of the road. Participants were given directions to turn left or right at intersections by using left or right arrow signs that were placed in clear view of the roadway. Within each scenario, participants made an average of 2 left-hand and 2 right-hand turns.

The dual-task condition involved conversing on a cell phone with a confederate. 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 an incidental recognition memory task in which they judged whether each of the 45 billboards had been presented in the driving scenario (15 of the billboards had been presented in the single-task condition, 15 in the dual-task condition, and 15 were control billboards that had not been presented in the driving portion of the study). Each billboard was presented separately on a computer display and remained in view until the participants made their old/new judgment. There was no relationship between the order of presentation of the billboards in the driving task and the order of presentation in the recognition memory task. Participants were not informed about the recognition memory test until after they had completed the driving portions of the experiment.

Analysis. Eye-tracking data were analyzed to determine whether or not the participant fixated on each billboard. We required the participant's eyes to be directed at the center of the billboard for at least 100 msec for the billboard to be classified as having been fixated.

Results and Discussion

Table 2 presents the recognition memory data. The classification of control billboards as "old" was infrequent, indicating a low base rate of guessing. Billboards presented in single-task conditions were correctly recognized more often than billboards from dual-task conditions, $t(19)=4.53$, $p<.01$. 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. However, it is possible that the impaired recognition memory performance may be due, at least in part, to a disruption of the visual scanning of the driving environment while conversing on the cell phone. This possibility is addressed in the following analyses.

We next assessed whether the differences in recognition memory may be due to differences in eye fixations on billboards. The eye-tracking data indicated that participants fixated on approximately two-thirds of the billboards and that the difference in the probability of fixating on billboards from single- to dual-task conditions was not significant, $t(19)=0.76$, $p>.4$. Thus, the contribution of fixation probability on recognition memory performance would appear to be negligible. We also measured total 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. The difference in fixation duration between single- and dual-task conditions was also not significant, $t(19)=0.75$, $p>.4$. Thus, the differences in recognition memory performance that we observed in single- and dual-task conditions cannot be attributed to alterations in visual scanning of the driving environment.

Finally, we computed the conditional probability of recognizing a billboard 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 conditional probability analysis revealed that participants were more than twice as likely to recognize billboards presented in the single-task condition than in the dual-task condition, $t(19)=4.53$, $p<.01$. That is, when we ensured that participants fixated on a billboard, we found significant differences in recognition memory between single- and dual-task conditions.

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 environment, they were less likely to have explicit memory of those objects if they were conversing on a cell phone. The data are consistent with an inattention-blindness hypothesis whereby 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.

Experiment 3

To more thoroughly evaluate the inattention-blindness hypothesis, our third study measured the implicit perceptual memory for words that were presented at fixation during the pursuit-tracking task originally used in Experiment 1. Perceptual memory was measured immediately after the tracking task using a dot-clearing procedure. In the dot-clearing procedure, words were initially masked by an array of dots and then slowly faded into view as the dots were gradually removed. We estimated the perceptual memory for an item by the time taken by participants to correctly report the identity of that item. One advantage of the dot-clearing task is that it does not rely on the participant's explicit memory of objects in the driving scene. Indeed, evidence for implicit perceptual memory has been obtained even when observers have no explicit memory for old items (Johnston, Dark, & Jacoby, 1985). However, this form of memory is obtained only if attention is directed to fixated words (Hawley & Johnston, 1991). Thus, the dot-clearing task is thought to provide an index of the initial data-driven processing of the visual scene.

Method

Participants. Thirty undergraduates (17 male and 13 female) from the University of Utah participated in the experiment. Participants ranged in age from 18 to 25. All had normal or corrected-to-normal vision and a valid driver’s license.

Stimuli and Apparatus. The task was adapted from that used in Experiment 1 as follows. At intervals ranging from 10 to 20 sec (mean = 15 sec), a four-to-five letter word, selected without replacement from the Kucera and Francis (1967) word norms, was presented at the location of the target. Each word subtended an approximate visual angle of 0.5 degrees vertically and 2.0 degrees horizontally. Altogether, 200 words were presented during the driving task and an additional 100 words were presented as new words in the subsequent dot-clearing phase. A random assignment of words to conditions was generated for each participant. The latencies of responses in the dot-clearing phase were measured with msec precision using a voice-activated response device and response accuracy was manually recorded.

Procedure. The tracking portion of the study was identical to Experiment 1 with the exception that during the tracking task words were presented for 500 msec at the center of fixation. Participants were asked to press a button on the joystick if the word was an animal name. Only three percent of the words were animal names and these items were excluded from the dot-clearing phase of the experiment.

Immediately following the tracking task, participants performed the dot-clearing task. The dot-clearing procedure was used to measure the perceptual memory for old words, that is, those previously presented in the single- and dual-task conditions. New words that had not been previously presented were included to provide a baseline against which to assess perceptual memory for the old words. In the dot-clearing task, words were initially masked with random pixels and the mask was gradually removed pixel by pixel until participants could report the identity of the word. A pixel from the mask was removed every 33 msec, rendering the word completely in view after 5 seconds. The words from the three categories (i.e., single-task, dual-task, and control) were presented in a randomized order in the dot-clearing phase of the study.

Results and Discussion

Participants named old words from the single-task condition faster than control words, *t*(29)=4.97, *p*<.01 ($\underline{M}_{Control}$=3252 msec, $\underline{M}_{Single}$=3114 msec), replicating prior demonstrations of implicit perceptual memory. Old words from the dual-task condition were also identified faster than control words, *t*(29)=2.31, *p*<.05 $\underline{M}_{Control}$=3252 msec, $\underline{M}_{Dual}$=3175 msec). However, most importantly, identification was slower for old words from the dual-task condition than those from the single-task condition, *t*(29)=2.39, *p*<.05 ($\underline{M}_{Single}$= 3114 msec, $\underline{M}_{Dual}$=3175 msec)These data indicate that cell phone conversations reduce attention to external inputs, even of those presented at fixation.

Experiment 4

Our fourth study was designed to evaluate the real-world risks associated with conversing on a cell phone while driving. 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 the current 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. How does conversing on a cell phone compare with the drunk driving benchmark?

Redelmeier and Tibshirani (1997) 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 report the result of a controlled study that 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 a car-following paradigm in which participants followed an intermittently braking pace car while they were driving on a multi-lane freeway. 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

Participants. Forty-one adults (26 male and 15 female) participated in the study. Participants ranged in age from 22 to 45. All had normal or corrected-to-normal vision and a valid driver's license.

Stimuli and Apparatus. The PatrolSim high-fidelity driving simulator used in Experiment 2 was used in the 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. 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. 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 a vehicle slowing in front of them.

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. Participants then drove in the car-following scenario while legally intoxicated.

In the cell-phone session, three counterbalanced conditions 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. The call was initiated before participants began driving to minimize interference from manual components of cell phone use.

Performance Variables. Six performance variables, presented in Table 3, were measured to determine how participants reacted to the vehicle braking in front of them. *Brake-onset time* is the time interval between the onset of the pace car's brake lights and the onset of the participant's braking response (expressed in milliseconds). *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). *Following distance* is the distance between the pace car and the participant's car (expressed in meters). *Half-recovery time* is the time for participants to recover 50% of the speed that was lost during braking (expressed in seconds). Also shown in Table 3 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.

Results and Discussion

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, $F(5,36)=1.33$, $p>.3$. 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 the preceding experiments and suggests that the impairments to driving are mediated by a withdrawal of attention from the processing of information in the driving environment necessary for safe operation of a motor vehicle

MANOVAs indicated that both cell-phone and alcohol conditions differed significantly from the single-task baseline, $F(5,36)=3.44$, $p<.01$ and $F(5,36)=3.90$, $p<.01$, respectively. When drivers were conversing on a cell-phone, they were involved in more rear-end collisions and their initial reaction to vehicles braking in front of them was slowed by 8.4%, relative to baseline. In addition, compared to baseline it took participants who were talking on the cell phone 14.8% longer to recover the speed that was lost during braking. Drivers using a cell phone attempted to compensate for their increased reaction time by driving 3.1% slower than baseline and increasing their following distance by 4.4%.

By contrast, when participants were legally 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 3.0% closer to the pace vehicle and braked with 23.4% more force than in baseline conditions. Most importantly, our study found that accident rates in the alcohol condition did not differ from baseline; however, the increase in hard braking that we observed is likely to be predictive of increased accident rates in the long run (e.g., Lee, Vaven, Haake, & Brown, 2001).

The MANOVA also indicated that the cell-phone and alcohol conditions differed significantly from each other, $F(5,36)=4.66$, $\boldsymbol{p}<.01$. When drivers were conversing on a cell-phone, they were involved in more rear-end collisions, had a 7.5% greater following distance, and took 14.8% longer to recover the speed that they had lost during braking than when they were legally intoxicated. Drivers in the alcohol condition also applied 26.1% greater braking pressure than drivers in the cell-phone condition.

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 in the cell-phone condition exhibited a sluggish behavior (i.e., slower reactions) which they attempted to compensate for by increasing their following distance. Drivers in the alcohol condition exhibited a more aggressive driving style, in which they followed closer, necessitating braking with greater force. With respect to traffic safety, our data are consistent with Redelmeier and Tibshirani’s (1997) earlier estimates. In fact, when controlling for driving difficulty and time on task, cell-phone drivers may actually exhibit greater impairments (i.e., more accidents and less responsive driving behavior) than legally intoxicated drivers.

General Discussion

Our research provided a controlled laboratory environment for assessing the impact of cell phone conversations on driving. We found that when drivers talk on a cell phone, their reactions to imperative events (e.g., braking in response to traffic lights or a decelerating vehicle) were significantly slower than when they were not talking on the cell phone. In several cases, the driver's reactions were impaired to such an extent that they were involved in a traffic accident. By contrast, listening to radio broadcasts or books on tape did not impair driving performance. Together, these findings are important because they demonstrate that listening to auditory or verbal material, by itself, is not sufficient to produce the interference associated with using a cell phone while driving. The data indicate that when drivers become involved in a cell phone conversation, attention is withdrawn from the processing of the information in the driving environment necessary for safe operation of a motor vehicle.

We found that cell phone conversations alter how well drivers perceive the driving environment. For example, cell-phone drivers were more likely to miss traffic signals and often failed to see billboards and other signs in the driving environment. In our studies, we used an eye-tracking device to measure exactly where drivers were looking while driving. We found that even when drivers were directing their gaze at objects in the driving environment that they often failed to see them because attention was directed elsewhere. Thus, talking on a cell phone creates a form of inattention blindness, making drivers less aware 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 have 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, 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 significant differences were found in the impairments caused by these two modes of cellular communication.

What is the real-world risk associated with using on 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. In a similar vein, 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 legally intoxicated. Taken together, these observations provide converging 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.

We have found it useful to conceptualize the problem of driver distraction along several dimensions, because not all multi-tasking activities are equal in distraction. First, is the source of interference from manual manipulation of equipment or from cognitive distraction? While few activities are exclusively manual or cognitive, the primary source of interference often stems from one source or the other and methods to combat such distraction are likely to differ. Second, is the multi-tasking activity relevant to the primary goal of driving or is the secondary task less relevant to driving? Some activities may be higher in task-relevance (e.g., using an electronic navigation system) whereas others may be quite low in relevance to driving (e.g., surfing the Internet). Third, what are the time constraints imposed by these multi-tasking activities? Some tasks can be accomplished quickly, such as changing radio stations, whereas others may take place over extended periods of time, like cell phone conversations. The difference in timing can significantly compromise the ability of the driver to schedule these secondary activities during lulls in traffic. Fourth, what is the frequency of use in real life? Some activities may be quite risky, but low in frequency, such as changing clothes while driving. By contrast, other activities may be lower in risk, but engaged in by a large segment of the public (e.g., NHTSA estimates that at any point in time that 3% of drivers are using their cell phone while driving). Together, the frequency, duration, task relevance, and basis of interference combine to determine the impact of a particular source of distraction on traffic safety.

In sum, our research indicates that the use of cell phones disrupts driving performance by diverting attention from the information processing immediately associated with the safe operation of a motor vehicle. Similar patterns of interference were observed for hand-held and hands-free cell phones. These findings suggest that policies that restrict hand-held devices but permit hands-free devices are not well grounded in science. We are often asked what our position is on regulatory issues concerning cell-phone induced driver distraction. Clearly, the safest course of action is to pull over and park in a safe location before one makes or takes a call. However, regulatory issues are best left to legislators who are provided with the latest scientific evidence. We caution, however, that as more cognitively engaging technology makes **its** way into the vehicle, the potential for even more severe driver distraction will increase. In the long run, skillfully crafted regulation and better driver education addressing driver distraction will be essential to keep our roadways safe.

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Table 1. The probability of missing the simulated traffic signals and the mean reaction time to the signals that were detected in single and dual-task conditions for the cell phone and control groups in Experiment 1. Standard errors are presented in parentheses.

Probability of Missing Signal	Single-Task	Dual-Task
Cell Phone	0.028 (.009)	0.070 (.015)
Control	0.027 (.007)	0.034 (.007)
Reaction Time (msec)		
Cell Phone	534 (12)	585 (16)
Control	543 (12)	533 (12)

Table 2. Recognition memory performance for Experiment 2. Standard errors are presented in parentheses.

	Single-Task	Dual-Task	Control
Number of Billboards Classified as Old	6.9 (0.5)	3.9 (0.6)	1.2 (0.5)
Fixation Probability	0.66 (0.06)	0.62 (0.06)	
Fixation Duration (msec)	1122 (99)	1009 (115)	
Conditional Probability of Recognition | Billboard Fixation	0.50 (0.05)	0.24 (0.04)	

Table 3. Means for the Alcohol, Baseline, and Cell-phone conditions of Experiment 4. Standard errors are in parentheses.

	Alcohol	Baseline	Cell Phone
Total Accidents	0	0	3
Brake Onset Time (msec)	888 (51)	943 (58)	1022 (61)
Braking Force (% of maximum)	69.6 (3.6)	56.4 (2.5)	55.2 (2.9)
Speed (MPH)	52.8 (.08)	54.9 (.08)	53.2 (.07)
Following Distance (meters)	26.5 (1.7)	27.3 (1.3)	28.5 (1.6)
½ Recovery Time (sec)	5.4 (0.3)	5.4 (0.3)	6.2 (0.4)

Figure 1. The PatrolSim Driving Simulator Used In Experiments 2 and 4.