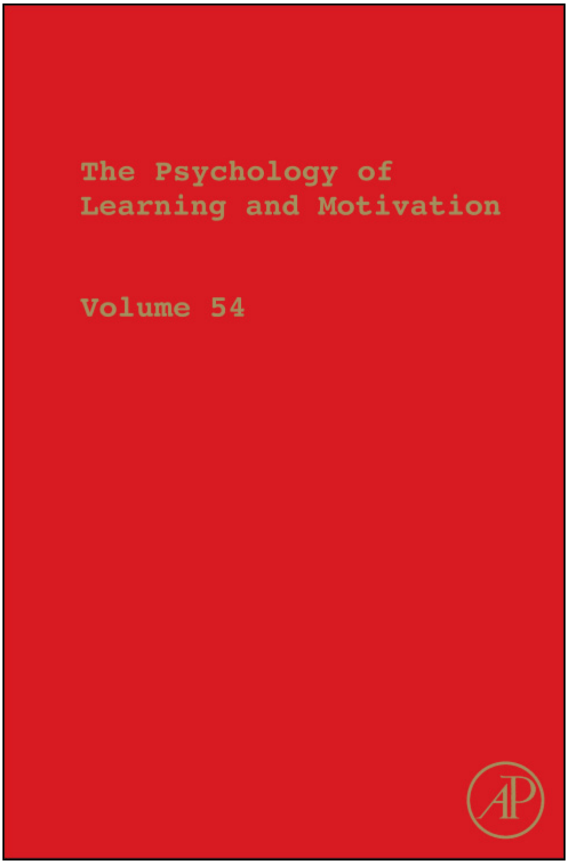

From: David L. Strayer, Jason M. Watson, and Frank A. Drews, Cognitive Distraction While Multitasking in the Automobile. In Brian Ross, editor: *The Psychology of Learning and Motivation,* Vol. 54, Burlington: Academic Press, 2011, pp. 29-58.
ISBN: 978-0-12-385527-5

CHAPTER TWO

Cognitive Distraction While Multitasking in the Automobile

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Contents

Abstract

Driver distraction is a significant source of motor-vehicle accidents. This chapter begins by presenting a framework for conceptualizing the different sources of driver distraction associated with multitasking. Thereafter, the primary focus is on cognitive sources of distraction stemming from the use of a cell phone while driving. We present converging evidence establishing that concurrent cell phone use significantly increases the risk of a motor-vehicle accident. Next, we show that using a cell phone induces a form of inattention blindness, where drivers fail to notice information directly in their line of sight. Whereas cell-phone use increases the crash risk, we show that passenger conversations do not. We also show that real-world cell-phone interference cannot be practiced away and conclude by considering individual differences in multitasking ability. Although the vast majority of individuals cannot perform this dual-task combination without impairment, a small group of "supertaskers" can, and we discuss the neural regions that support this ability.

Most of the time we take driving for granted. But operating an automobile is the riskiest activity that most readers of this chapter engage in on a regular basis. In fact, motor-vehicle crashes were the leading cause of accidental deaths in the US in 2008 and are the leading cause of all deaths for people between the age of 1 and 35. The National Safety Council White Paper (2010) recently noted that driver distraction had joined alcohol and

Psychology of Learning and Motivation, Volume 54
ISSN 0079-7421, DOI: 10.1016/B978-0-12-385527-5.00002-4

speeding as leading factors in fatal and serious injury crashes. In this chapter, we will focus on driver distraction and some of the underlying causes that contribute to driving impairment.

There are indeed many sources of driver distraction. Some "old standards" include talking to passengers, eating, drinking, lighting a cigarette, shaving, applying makeup, and listening to the radio (Stutts et al., 2003). However, the last decade has seen an explosion of new wireless "nomadic" devices that have made their way into the automobile, enabling a host of new sources of driver distraction (e.g., sending and receiving e-mail or text messages, communicating via cellular device, watching video movies, using the internet, etc.). It is likely that these new sources of distraction are more impairing than the old standards because they are more cognitively engaging and are often performed over more sustained periods of time. The primary focus of this chapter is on how driving is impacted by cellular communication (i.e., talking on a cell phone), because this is one of the most prevalent exemplars of this new class of multitasking activity. In fact, in 2010, the NSC estimated that the 28% of all crashes on the roadway were caused by the use of a cell phone to talk, dial, or text while driving (National Safety Council White Paper, 2010).

Our chapter begins with a theoretical framework for understanding the different sources of driver distraction. Thereafter, our main focus will be on cognitive sources of distraction, with cell-phone use as the primary exemplar of this type of interference. Next, we will review evidence from our laboratory and elsewhere that establishes that driving is impaired with the concurrent use of a cell phone. Understanding why cell phones impair driving is important, and we will show that the use of a cell phone induces a form of inattention blindness, causing the drivers to fail to see critical information in their field of view. We also consider whether all forms of verbal communication impair driving and whether a driver can become sufficiently skilled at using a cell phone that they are no longer impaired by this activity (the answer to both questions is "NO"). Finally, we examine individual differences in this multitasking behavior. We will show that the majority of individuals suffer significant impairment when they use a cell phone while driving. However, there is a small percentage of individuals who have extraordinary multitasking ability and do not exhibit interference in the cell phone/driving dual-task combination. We show that these "supertaskers" exhibit a generalizable ability to multitask and present neuroimaging data that establish that frontal brain regions support this extraordinary ability.

1. A Framework for Understanding the Sources of Driver Distraction

Figure 1 presents a framework for discussing the sources of driver distraction. Impairments to driving can arise from a competition for visual processing, wherein the driver takes their eyes off the road to interact with a

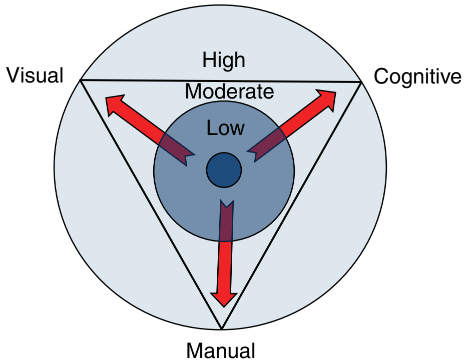

Figure 1 A framework for conceptualizing the sources of driver distraction.

device. Impairments can also arise from manual interference, as in cases where drivers take their hands off the steering wheel to manipulate a device. Finally, cognitive sources of distraction occur when attention is withdrawn from the processing of information necessary for the safe operation of a motor vehicle. These three sources of distraction can operate independently; that is, interacting with different devices can result in competition from one, two, or all the three sources.

Figure 1 illustrates three hypothetical multitasking situations. The small blue inner circle represents a situation in which the driver engages in a concurrent activity that places low levels of demand on the visual, manual, or cognitive resources. An activity such as listening to a preprogrammed radio station at normal volume would be an example of low demand, in that it places little or no demand on visual, manual, or cognitive processing resources. The middle circle represents a situation in which the driver engages in a concurrent task that places moderate levels of demand on visual, manual, and cognitive resources. The outer circle represents situations in which the driver engages in a concurrent task that places high levels of demand on visual, manual, and cognitive resources. An example of this high level of interference might involve a driver using a touchscreen device to access information on the internet (e.g., a recent case we reviewed involved a younger driver who was killed when his vehicle collided into a semitractor trailer while he was manipulating information on his Facebook page using his cell phone). This interaction placed heavy demands on visual, manual, and cognitive resources, and activities such as these will inevitably end in a bad outcome. Holding other factors constant, the crash risk is higher for multitasking activities in the outer circle than for multitasking activities in the inner circle.

There are two additional factors that are important to consider in discussions concerning driver distraction and crash risk. The first factor is the duration of an activity that is concurrently performed while driving. In many instances, drivers attempt to multitask when they perceive the demands of driving to be low (e.g., while stopped at a traffic light). But, as the duration of interaction with a device increases, the ability of a driver to accurately predict the driving demands decreases. For example, changing a radio station may place demands on visual and manual resources, but the duration of that impairment is relatively short (e.g., 5 s or so). By contrast, a cell-phone conversation may extend for several minutes, and the conditions that were in effect at the beginning of a call may change considerably over this interval. In general, dual-tasking activities that tie up resources for longer periods of time will create greater cumulative impairments than activities with shorter durations.

The second factor to consider is the exposure rate of an activity. The more drivers that engage in a distracting activity, the greater the impact to public safety. For example, below we will demonstrate that the risk of being in a motor-vehicle accident increases by a factor of 4 when drivers are talking on a cell phone. What compounds the risk to public safety is that at any daylight hour it is estimated that over 10% of drivers on US roadways talk on their cell phone (Glassbrenner, 2005). While there are many activities engaged in while driving that are associated with an equal or higher crash risk, few if any have the same exposure as using a cell phone.

For the remainder of this chapter, we will examine cognitive sources of distraction, with a particular focus on the role that cell phones play in driver distraction. The cell phone is a relatively modern invention that has been in common use for less than 20 years. Over this period, use has skyrocketed, and as of 2010, more than 90% of the US population now carries a cell phone. Using a cell phone while driving has become commonplace, with 85% of drivers reporting that they use a cell phone while concurrently operating a motor vehicle (National Highway Transportation Safety Administration, 2006). And, as mentioned above, current estimates suggest that at any time during the day, more than 10% of drivers on the roadway talk on their cell phone. Even more alarming is that 2 out of 10 drivers who use a cell phone report that they have bumped into a person or object because they were distracted (Pew Internet and American Life Project, 2010).

From a theoretical perspective, understanding the mechanisms underlying dual-task performance has been an important endeavor in psychology for over 60 years, and certain patterns of interference may prove useful for evaluating cognitive theory. In fact, several of the findings we discuss below prove challenging for current theories of attention and dual-task processing (e.g., see Strayer & Drews, 2007; Watson & Strayer, 2010). From an applied perspective, this issue is important as legislators attempt to craft legislation that addresses the safety concerns associated with multitasking. For example, at least six US States now have regulations that prohibit the use of hand-held cell phones while driving but permit the use of hands-free devices

(IIHS, 2010). Implicit in this regulation is the assumption that a major source of the interference stems from the manual manipulation of the phone (i.e., holding the phone to listen and talk). We will see that this assumption is not supported by the empirical research.

2. Do Cell-Phone Conversations Increase the Crash Risk?

There are several methodologies that have been used to address this question. Each methodology has strengths and weaknesses. Converging evidence from the different techniques provides a definitive answer to the question ("YES").

The simplest method uses naturalistic observations to see how their driving behavior is altered with the concurrent use of a cell phone to dial, talk, or text. In one such study, we observed over 1700 drivers as they approached a residential intersection with four-way stop signs. We determined through observation whether the drivers were or were not using their cell phone as they approached the intersection and whether they came to a complete stop (as required by law) before proceeding through the intersection.[1] The resulting data are presented in Table 1.

For drivers not using a cell phone, the majority stopped in accordance with traffic laws. By contrast, for the drivers who were observed talking on their cell phone as they approached the intersection, the majority failed to stop in accordance with traffic laws. For drivers not using a cell phone, the odds ratio for failing to stop was 0.27, whereas the odds ratio for failing to stop for drivers who were using their cell phone was 2.93. This 10-fold increase in failing to stop was significant ($\chi^2(1) = 129.8$, $p < 0.01$).

Table 1 Frequency Totals for the 2 (Cell Phone in Use Vs. Cell Phone Not in Use) $\times$ 2 (Stopping Violation Vs. No Violation) Observational Study of Four-Way Stop Sign Compliance.

	Stopping violation	No violation	
On cell	82	28	110
Not on cell	352	1286	1638
	434	1314	1748

[1] This simple observational study has now become a standard used in research method courses at the University of Utah. It is a sure-fired way to ensure that students get significant and meaningful data that can be used for their class writing assignments (see www.psych.utah.edu/cellphonestudy/).

Observational studies have a high validity. After all, it is real driving and if a cell phone is in use, it is a real conversation. But one important limitation of the observational approach is that it cannot establish a *causal link* between the use of a cell phone and impaired driving. For example, it is possible that those drivers who regularly use a cell phone are willing to engage in more risky activities and that this increase in risk taking also leads drivers to engage in more risky driving behaviors such as running stop signs.

Epidemiological studies provide another method for assessing the crash risk associated with using a cell phone while driving. Redelmeier and Tibshirani (1997) obtained the cell phone records of 699 drivers who were involved in a noninjury motor-vehicle collision. They used a case-crossover design in which the same driver was evaluated to see whether they were using a cell phone at several comparison intervals (e.g., same day of the week). The authors found that the odds of a crash were over four times higher when drivers were using their cell phone. McEvoy et al. (2005) replicated this procedure, but instead used crashes that required the driver to be transported to a hospital for medical care. Similar to Redelmeier and Tibshirani (1997), the odds of crashing were over four times higher when drivers were using their cell phone.

As with observational studies, epidemiological studies have high face validity and establish a real-world association between use of a cell phone and crashes. However, like observational studies, this method does not establish a causal link between cell-phone use and crashes. Note that establishing a causal link between driving impairment and the concurrent use of a cell-phone is important if the research is to advance our theoretical understanding of driver distraction.

The final method that we consider in detail involves the use of high-fidelity driving simulators to establish a causal relationship between the use of a cell phone and driving impairment. Figure 2 shows a participant using our driving simulator. The simulator is composed of five networked microprocessors and three high-resolution displays providing a 180° field of view. It 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. For the majority of our studies, the simulator used a freeway road database simulating a 24-mile multilane highway with on- and off-ramps, overpasses, and two- and three-lane traffic in each direction.

Our first simulator study used a car-following paradigm to determine how driving performance is altered by conversations over a cell phone. The participant's task was to follow a periodically braking 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

Figure 2 A participant driving in the Patrol-Sim driving simulator.

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.

Car following is an important requirement for the safe operation of a motor vehicle. In fact, failures in car following account for ~30% of police-reported accidents (e.g., National Highway Transportation Safety Administration, 2001). In our study, the performance of a nondistracted driver was contrasted with the performance of that same driver when they were conversing on either a hand-held or hands-free cell phone. We were particularly interested in examining the differences in driving performance of the hand-held cell-phone driver with that of the hands-free cell-phone driver, because six US States currently prohibit the former while allowing the latter form of cellular communication. To preview, our analyses will show that the performance of drivers engaged in a cell-phone conversation differs significantly from that of the nondistracted driver and that there is no safety advantage for hands-free over hand-held cell phones.

Figure 3 presents a typical sequence of events in the car-following paradigm. Initially, both the participant's car (solid line) and the pace car (long-dashed line) were driving at about 62 MPH with a following distance of 40 m (dotted line). At some point in the sequence, the pace car's brake lights illuminated for 750 ms (short-dashed line) and the pace car began to decelerate at a steady rate. As the pace car decelerated, following distance decreased. At a later point in time, the participant responded to the decelerating pace car by pressing the brake pedal. The time interval between the onset of the pace car's brake lights and the onset of the participant's brake response defines the brake reaction time. Once the participant depressed the brake, the pace car began to accelerate at which point the participant removed his foot from the brake and applied pressure to the gas pedal.

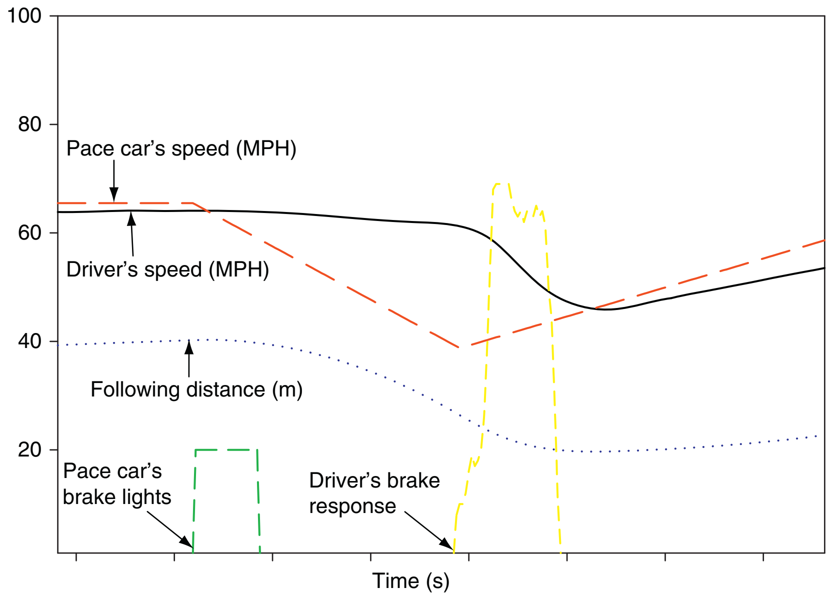

Figure 3 A typical sequence of events in the car-following paradigm.

Note that in this example, following distance decreased by about 50% during the braking event.

Here, we report three parameters associated with the participant's reaction to the braking pace car. *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., a 1% depression of the brake pedal). *Following distance* is the distance between the rear bumper of the pace car and the front bumper of the participant's car. *Speed* is the average driving speed of the participant's vehicle.

Figure 4 presents the brake reaction time Vincentized cumulative distribution functions (CFFs) as participants reacted to the pace car's brake lights. In Figure 4, the reaction time at each decile of the distribution is plotted, and it is evident that the functions for the hand-held and hands-free cell-phone conditions are displaced to the right, indicating slower reactions, compared to the single-task condition. Analysis indicated that RT in each of the dual-task conditions differed significantly from the single-task condition at each decile of the distribution, whereas the distributions for hand-held and hands-free conditions did not differ significantly across the deciles. A companion analysis of median brake reaction time found that braking reactions were significantly slower in dual-task conditions than in single-task conditions, $F(2,78) = 13.0$, $p < 0.01$. Subsidiary pair-wise t-tests indicated that the single-task condition differed significantly from the hand-held

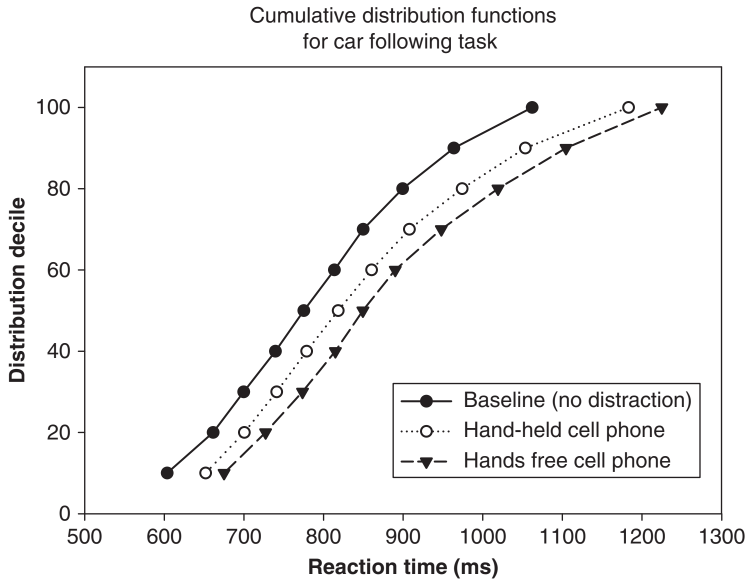

Figure 4 **RT Cumulative Frequency Distributions (CDFs) for the single-task baseline condition and the hand-held and hands-free dual-task cell-phone conditions.**

and hands-free cell-phone conditions, and the difference between hand-held and hands-free conditions was not significant.

In order to better understand the changes in driving performance with cell-phone use, we examined driver performance profiles in response to the braking pace car. Driving profiles were created by extracting 10 s epochs of driving performance that were time-locked to the onset of the pace car's brake lights. That is, each time that the pace car's brake lights were illuminated, the data for the ensuing 10 s were extracted and entered into a 32 × 300 data matrix (i.e., on the *j*th occasion that the pace car brake lights were illuminated, data from the 1st, 2nd, 3rd, . . ., and 300th observations following the onset of the pace car's brake lights were entered into the matrix $X_{[j,1]}$, $X_{[j,2]}$, $X_{[j,3]}$, . . ., $X_{[j,300]}$; where j ranges from 1 to 32 reflecting the 32 occasions in which the participant reacted to the braking pace car). Each driving profile was created by averaging across j for each of the 300 time points.

Figure 5 presents the average driving speed profile, time-locked to the onset of the pace car's brake lights, for the three conditions in the study. Over the 10-s epoch, participants in the single-task condition drove at a faster rate of speed than when they were conversing on a cell phone, $F(2,78) = 3.3$, $p < 0.05$; however, vehicle speed during the prebraking interval did not differ significantly between conditions. Driving speed

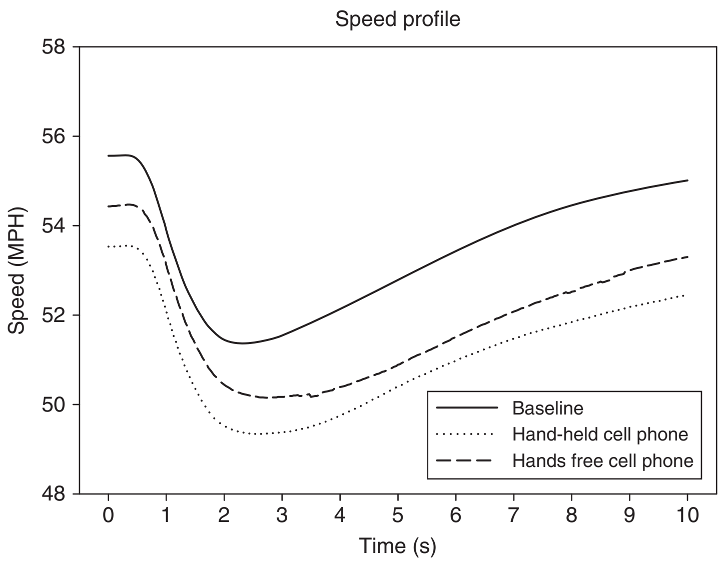

Figure 5 **The driving speed profile plotted as a function of time. The single-task baseline condition is presented with the hand-held and hands-free dual-task cell-phone conditions.**

reached the nadir between 2 and 3 s after the onset of the pace car's brake lights whereupon the participant's vehicle reaccelerated toward prebraking speed. The difference in overall speed was primarily determined by the time it took participants to recover the speed lost during braking. In particular, the time that it took participants to recover 50% of the speed lost during the braking episode was significantly shorter in the single-task condition than the hand-held or the hands-free cell-phone conditions, $F(2,78) = 4.4$, $p < 0.01$. Subsidiary pair-wise *t*-tests indicated that single-task recovery was significantly faster than either the hand-held or the hands-free cell-phone conditions and that the rate of recovery time did not differ for the two cell-phone conditions. This sluggish behavior appears to be a key characteristic of the driver distracted by a cell-phone conversation, and such a pattern of driving is likely to have an adverse impact on the overall flow of dense highway traffic (see Cooper, Vladisavljevic, Medeiros-Ward, Martin, & Strayer, 2009).

Figure 6 cross-plots driving speed and following distance to illustrate the relationship between these two variables over the braking episode. In the figure, the beginning of the epoch is indicated by a left-pointing arrow, and the relevant symbol (circle, triangle, or square) is plotted every third of a second in the time series. The distance between the symbols provides an indication of how each function changes over time (i.e., on a

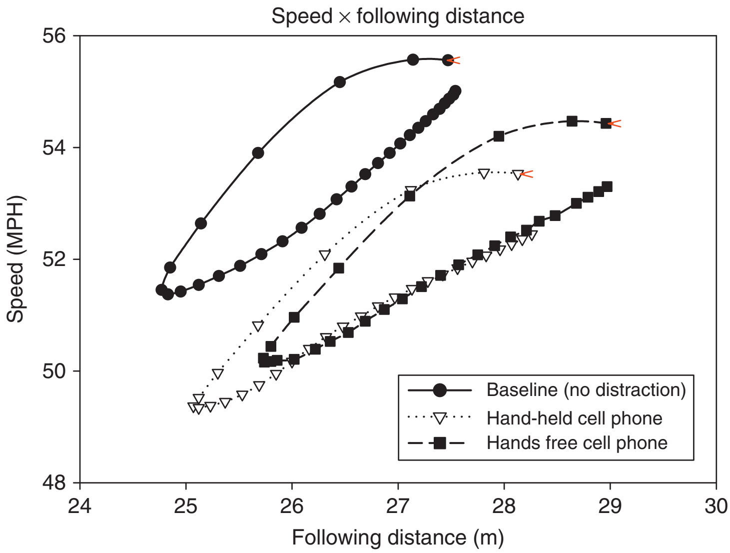

Figure 6 A cross-plot of driving speed and following distance plotted as a function of time. The single-task baseline condition is presented with the hand-held and hands-free dual-task cell-phone conditions.

given function, symbols closer together indicate a slower change over time than symbols farther apart). The figure clearly illustrates that the relationship between driving speed and following distance is virtually identical for the driver distracted by either a hand-held or hands-free cell phone. By contrast, the performance of the participant in single-task conditions provides a qualitatively different pattern than what is seen in the dual-task conditions. In particular, the functions representing the dual-task conditions are displaced toward the lower right quadrant, indicative of a driver operating the vehicle more conservatively (i.e., somewhat slower and with a greater following distance from the pace car) than in single-task conditions.

Figure 6 also illustrates the dynamic stability of driving performance following a braking episode. From a dynamic systems perspective, driving performance in single- and dual-task conditions can be characterized as operating in different speed-following distance basins of attraction with performance returning to equilibrium following each braking perturbation. Note also that the curves in Figure 6 for the nondistracted driver and the driver conversing on a cell phone did not intersect. This suggests that the basin of attraction created with either the hand-held or hands-free cell-phone conversations was sufficiently "deep" that participants returned to their respective prebraking set points after a braking episode had perturbed their position in the speed/following-distance space.

Taken together, the data demonstrate that conversing on a cell phone impaired driving performance and that the distracting effects of cell-phone conversations were equivalent for hand-held and hands-free devices. Compared to single-task conditions, cell-phone drivers' brake reaction times were slower and they took longer to recover the speed that was lost following braking. The cross-plot of speed and following distance showed that drivers conversing on a cell phone tended to have a more cautious driving profile, which may be indicative of a compensatory strategy to counteract the delayed brake reaction time. Elsewhere, Brown, Lee, & McGehee (2001) found that the sluggish brake reactions, such as the ones described herein, can increase the likelihood and severity of motor-vehicle collisions.

Another 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 second study was driving while intoxicated from ethanol at the legal limit (0.08 wt/vol). We selected this benchmark because the epidemiological study by Redelmeier and Tibshirani (1997) noted 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 claim can be substantiated in a controlled laboratory experiment, then these data would be of immense importance for public safety. In particular, 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?

Here, we directly compared the performance of 40 drivers who were conversing on a cell phone with the performance of these same drivers who were legally intoxicated with ethanol. Three counterbalanced 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, verified using an Intoxilyzer 5000).

Table 2 presents nine performance variables that were measured to determine how participants reacted to the vehicle braking in front of them. Three of the variables (*brake reaction time*, *speed*, and *following distance*) were used in our first study. We also added several new variables to provide a more fine-grained comparison between drunk driving and cell-phone conditions.[2] *Braking force* is the maximum force that the participant applied to the brake pedal in response to the braking pace car. *SD following distance* is

[2] These additional parameters did not differ between the hand-held and hands-free cell phone conditions in the first study.

Table 2 Driving Performance Measures Obtained in the Alcohol, Baseline, and Cell-Phone Driving Conditions.

	Alcohol	Baseline	Cell phone
Total accidents	0	0	3
Brake reaction time (ms)	779 (33)	777 (33)	849 (36)
Speed (MPH)	52.8 (2.0)	55.5 (0.7)	53.8 (1.3)
Following distance (m)	26.0 (1.7)	27.4 (1.3)	28.4 (1.7)
Maximum braking force percentage of max	69.8 (3.7)	56.7 (2.6)	55.5 (3.0)
SD following distance (m)	10.3 (0.6)	9.5 (0.5)	11.8 (0.8)
Time to collision (s)	8.0 (0.4)	8.5 (0.3)	8.1 (0.4)
Time to collision < 4 s	3.0 (0.7)	1.5 (0.3)	1.9 (0.5)
Half-recovery time (s)	5.4 (0.3)	5.3 (0.3)	6.3 (0.4)

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 is the frequency of trials with TTC values below 4 s, 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. 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.

MANOVAs indicated that both cell phone and alcohol conditions differed significantly from single-task baseline ($F(8,32) = 6.26$, $p < 0.01$ and $F(8,32) = 2.73$, $p < 0.05$, 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, and the variability in following distance increased. In addition, compared to the single-task baseline, it took participants who were talking on a cell phone 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 single-task baseline. Overall, drivers in the alcohol condition exhibited a more aggressive driving style. They followed closer to the pace vehicle and braked with more force than in the single-task baseline condition. Unexpectedly, our study found that accident rates in the alcohol condition did not differ from baseline; however, the increase in hard braking is predictive of increased accident rates over the long run (e.g., Brown et al., 2001; Hirst & Graham, 1997).

The MANOVA also indicated that the cell-phone and alcohol conditions differed significantly from each other, $F(8,32) = 4.06$, $p < 0.01$. 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 indicated that there were significantly more accidents when participants were conversing on a cell phone than in the single-task baseline or alcohol conditions. $\chi^2(2) = 6.15$, $p < 0.05$.

Taken together, we found that both intoxicated drivers and cell-phone drivers performed differently from the single-task 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 when controlling for driving conditions and time on task, the impairments associated with cell-phone drivers may be as great as those commonly observed with intoxicated drivers.

3. Why Does Talking on a Cell Phone Impair Driving?

The epidemiological studies establish that talking on a cell phone while driving increases the crash risk by a factor of 4. Moreover, several lines of evidence suggest that the crash risk is the same for hand-held and hands-free cell phones. For example, simulator-based studies reviewed above found that hands-free cell phones had the same impairment profile as that of hand-held devices. In addition, a recent analysis from the Highway Loss Data Institute compared US States that imposed a ban on driving while using a hand-held cell phone with comparable States that did not institute a ban and found no safety advantage for prohibiting hand-held cell phones (HLDI, 2009).

Given that hands-free cell phones produce the same level of impairment as held-held units, it suggests that the source of interference is cognitive in nature. This follows because hands-free cell phones allow drivers to have their eyes on the road (i.e., little or no visual interference) and their hands on the wheel (i.e., little or no manual interference). We have suggested that using a cell phone induces a form of inattention blindness whereby the cell-phone conversation diverts attention from processing the information necessary to safely operate a motor vehicle (Strayer & Drews, 2007; Strayer, Drews, & Johnston, 2003; Strayer & Johnston, 2001).

To test the inattention blindness hypothesis, we examined how cell-phone conversations affect the driver's attention to objects that are encountered while driving. The study used an incidental recognition memory paradigm to assess what information in the driving scene participants attended while driving. The procedure required participants to perform the driving task without the foreknowledge that their memory for objects in the driving scene would be tested. Later, the participant was 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. Differences in recognition memory between single- and dual-task conditions provide an estimate of the degree to which attention to visual information in the driving environment is distracted by cell-phone conversations. In this study, we also monitored eye fixation using an Applied Science Laboratories mobile 501 eye-tracker that allowed a free range of head and eye movements, thereby affording naturalistic viewing conditions for the participants as they negotiated the driving environment.

Figure 7 presents the conditional probability of recognizing an object in the driving scene given that participants fixated on it while driving. This analysis specifically tests for memory of objects that were presented where the driver's eyes were directed. That is, based on the eye tracking data, we

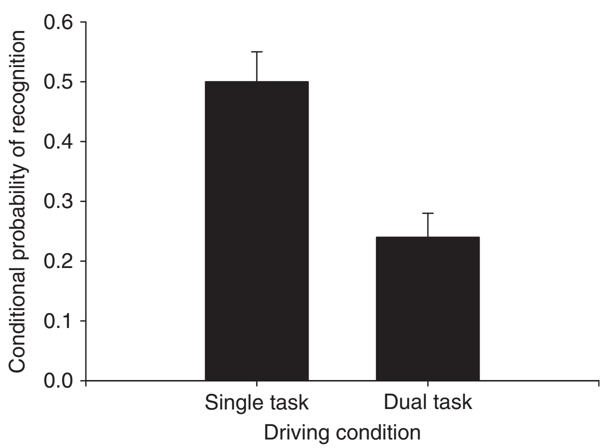

Figure 7 Recognition memory in the single-task and dual-task conditions.

know that the driver's eyes were on the road (directed at objects in the driving environment). Moreover, because we used a hands-free cell phone and the call was initiated before driving began, there was no manual interference when drivers were talking on the phone. Thus, any interference that is observed can be attributed entirely to cognitive interference. We restricted our analysis to objects that were fixated upon during the drive. In addition, we used hierarchical linear regression to statistically control for any differences in fixation duration. The analysis revealed that participants were more than twice as likely to recognize objects encountered in the single-task condition than in the dual-task condition, $t(19) = 4.53$, $p < 0.01$. That is, when we ensured that participants fixated on objects in the driving scene, significant differences in recognition memory between single- and dual-task conditions were found. Even when the participant's eyes were directed at objects in the driving environment for the same duration, they were less likely to remember them if they were conversing on a cellular phone.

In a follow-up study, we asked participants to rate the objects in the driving scene 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). Safety relevance ratings ranged from 1.5 to 8, with an average of 4.1. A series of regression analyses found that traffic relevance had absolutely no effect on the difference in recognition memory between single-task and dual-task conditions. This finding is important because it establishes that drivers do 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.

Figure 8 illustrates how the driving environment might be perceived by a driver who is not talking on a cell phone (panel A) and for that same driver when they are talking on a cell phone (panel B). In this example, the encoding of important objects (e.g., the flagman and the bicyclist) is impaired by the use of a cell phone. In fact, we have reviewed several real-world crashes where drivers report failing to see critical information such as stop signs and pedestrians that result in motor-vehicle accidents.

Thus far, our studies assessing inattention blindness have relied on explicit memory measures to test the hypothesis that cell-phone conversations interfere with the initial encoding of information in the driving scene. However, an alternative possibility is that there are no differences in the initial encoding, but rather differences in the retrieval of the information during subsequent memory tests. This distinction is important because the former has direct implications for traffic safety, whereas the latter does not. To differentiate between encoding and retrieval deficits, we recorded

Figure 8 **A representation of what a driver might perceive when they are not talking on the phone (left panel) and when they are talking on a hands-free cell phone (right panel).**

on-line measures of brain activity elicited by braking events in the driving environment. Prior research has found that the amplitude of the P300 component of the event-related brain potential (ERP) is sensitive to initial encoding conditions and that memory performance is superior for objects eliciting larger amplitude P300s during initial encoding (e.g., Fabiani, Karis, & Donchin, 1986; Otton & Donchin, 2000).

We asked participants to follow 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. The dual-task condition involved talking to a confederate on a hands-free cell phone. If the impairments in memory performance are due to differences in the initial encoding of objects in the driving scene, then P300 amplitude should be smaller in the dual-task condition than in the single-task condition. By contrast, if the memory differences 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 the single-task and the dual-task conditions.

The average ERPs recorded at the parietal electrode site are presented in Figure 9. Visual inspection reveals a large positive potential between 250 and 750 ms (the P300 component of the ERP). Statistical analysis indicated that the P300 component of the ERPs was significantly larger in the single-task than in the dual-task condition, $t(15) = 4.41$, $p < 0.01$. In fact, P300 amplitude was reduced by 50% when the drivers were talking on the cell phone.

These ERP data provide strong evidence for the inattention-blindness hypothesis. In particular, the brain activity associated with processing the information necessary for the safe operation of a motor vehicle is suppressed when drivers talk on a cell phone. Thus, drivers using a cell phone fail to see information in the driving scene because they do not encode it as well as

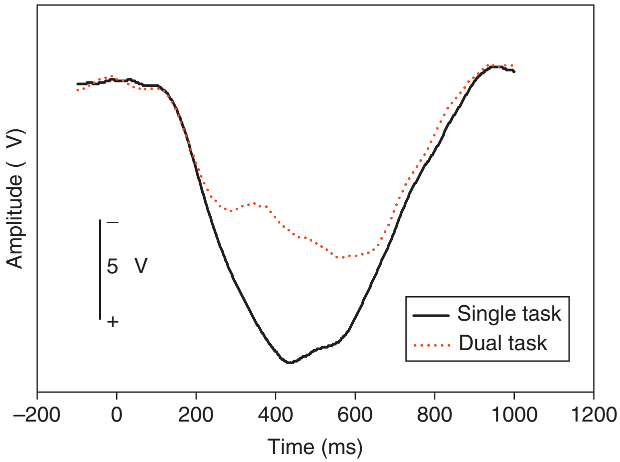

Figure 9 **Event-related brain potentials elicited by the onset of brake lights in single-task and dual-task conditions.**

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 drivers using a cell phone will be less able to do so because of the diversion of attention from driving to the phone conversation. It is important to note that the demonstrations of inattention blindness described herein provide a pure measure of cognitive interference, because the participant's eyes were on the road and they were not manually manipulating the phone in dual-task conditions.

The studies assessing the inattention-blindness hypothesis tested memory for objects that were at fixation, ensuring that participants actually looked at objects in the driving scene. However, cell phones can also induce a form of tunnel vision, whereby drivers tend to direct their gaze directly ahead and tend to look less often in the periphery. The consequence of this tendency to fixate centrally is that drivers talking on a cell phone are less likely to see objects in the periphery (pedestrians, cars, roadside hazards) and make fewer glances at traffic signals at intersections (Harlbluk, Noy, Trbovich, & Eizenman, 2007). Alarmingly, some drivers talking on a cell phone do not even look at the traffic signals!

In an unpublished study, Noy (2009) recorded eye movements in an instrumented vehicle when drivers were and were not talking on a hands-free cell phone. Figure 10 provides a visual illustration of the areas scanned by the driver as they operated a motor vehicle. The left panel illustrates visual scanning under normal conditions and the right panel illustrates visual scanning when drivers were talking on a hands-free cell phone. In this example, the driver talking on a cell phone would fail to see the bicyclist

Figure 10 An illustration of how visual scanning is disrupted when drivers are talking on a hands-free cell phone. The left panel represents the scanning pattern of an undistracted driver and the right panel represents the scanning pattern when the driver is talking on a hands-free cell phone.

until it was too late to react. Note also that a driver talking on a cell phone suffers from both impaired visual scanning and inattention blindness, which helps to explain the high-crash rates associated with this activity.

In sum, cell-phone conversations compete for attention with driving. The result is that visual processing is substantially impaired when drivers are talking on a cell phone (either hand-held or hands-free). This is seen both in the visual scanning of the driving environment (leading to tunnel vision) and in the extraction of information that is at fixation (leading to inattention blindness).

4. Are All Conversations Harmful to Driving?

The preceding sections document that cell-phone conversations impair driving. But what about other conversations engaged in while driving? In particular, do in-vehicle conversations impair driving to the same extent as cell-phone conversations? One way to examine this issue is to compare the crash risk while conversing on a cell phone (established above as a fourfold increase) with the crash risk when there is another adult in the vehicle. Epidemiological evidence (Reuda-Domingo et al., 2004; Vollrath, Meilinger, & Kruger, 2002) indicates that the crash rate drops below 1.0 when there is an adult passenger in the vehicle (i.e., there is a slight safety advantage for having another adult passenger in the vehicle). Given that in many instances the passenger and the driver are conversing, these findings would seem to be at odds with the suggestion that any conversation task diverts attention from driving. However, there are also situations where the passenger and the driver are not engaged in conversation, so a more precise analysis is needed.

To provide a more formal comparison of the differences between passenger and cell-phone conversations, my colleagues and I returned to the driving simulator (Drews, Pasupathi, & Strayer, 2008). We recruited pairs of participants who knew each other before the study and randomly assigned one participant as the driver and the other as an interlocutor (a) on a cell phone or (b) as a passenger seated next to the driver in the vehicle. In single-task conditions, the driver was asked to drive down a multilane highway and take an exit at a rest stop located approximately 8 miles down the road. In dual-task conditions, the driver was asked to perform the same task while they were also engaged in a conversation with their friend.

In all cases, the driver's task was to exit the highway at the rest stop and park the vehicle. Drivers in single-task conditions had no trouble complying with this task, with a successful completion rate of 96%. However, there was a striking difference between cell-phone and passenger conversations in dual-task conditions. Passenger conversations (with a successful completion rate of 88%) did not significantly differ from single-task conditions, whereas 50% of the drivers engaged in a cell-phone conversation failed to take their exit. The difference between these two conversation conditions was significant, $\chi^2(1) = 7.9$, $p < 0.05$, providing clear evidence that the impairments to driving are not the same for all forms of conversation.

We also examined the ability of drivers to maintain their lane position as they drove down the highway. We used an RMS error measure to determine variations in lane position. Single-task conditions did not differ from dual-task conditions involving an in-vehicle conversation (RMSe = 0.45 vs. 0.40, respectively), whereas cell-phone conversations resulted in significantly greater lane deviation than passenger conversations (RMSe = 1.0 vs. 0.4, respectively), $t(39) = 2.1$, $p < 0.01$.

To understand *why* passenger conversations differ from cell-phone conversations, we performed a detailed analysis of the conversations. Video analysis revealed that with in-vehicle conversations, the passenger often actively engaged in supporting the driver by pointing out hazards, helping to navigate, and reminding the driver of the task (i.e., exiting at the rest stop). In other cases, the conversation was temporally halted during a difficult section of driving and then resumed when driving became easier. These real-time adjustments to the conversation based on the demands of driving were not evident in cell-phone conversations. In effect, the passenger acted as another set of eyes that helped the driver control the vehicle, and this sort of activity is not afforded by cell-phone conversations.

Another factor differing between passenger and cell-phone conversation is the content of the conversation. For example, a content analysis of the conversation revealed that there were significantly more references to traffic with passenger conversations (3.8) than with cell-phone conversations (2.1),

$t(46) = 3.0$, $p < 0.01$. This finding suggests that both the driver and the passenger share an awareness of the driving conditions, something that was significantly less likely with cell-phone conversations.

Taken together, the epidemiological and simulator studies establish that not all conversations in the vehicle lead to impairments in driving. In particular, because the driver and an adult passenger adjust their conversation based upon the real-time demands of driving, in-vehicle conversations do not increase the odds of an accident. However, if that same conversation is performed over a cell phone, the conversation diverts the driver's attention from the road and drivers are significantly more likely to be involved in a crash.

5. Can the Interference Be Practiced Away?

Practice improves performance in some, but not in all contexts. A necessary condition for improvement is a consistency in the environment that can be capitalized upon with practice (Schneider & Shiffrin, 1977). If performance in the cell-phone–driving combination improves with practice, then it is possible that the impairments would diminish over time and the issues of cell phone-based driver distraction would abate as more and more drivers became proficient with this dual-task skill. However, an important aspect of driving involves reacting to unexpected events (e.g., a child running across the street, a deer darting across the road, road construction, a novel driving route, etc.), making it unlikely that driving can become automatic. Moreover, cell-phone conversations, by their very nature, vary from call to call. As a consequence, the consistency necessary to become an "expert" in talking on a cell phone while driving would appear to be missing.

We tested to see if drivers could become expert cell-phone drivers with practice. The procedure involved identifying 30 individuals who used the cell phone regularly while driving (i.e., the experts who reported using the phone on 41% of their trips) and 30 drivers who did not use their phone while driving (novices). We tested these drivers in both single-task and dual-task conditions in both city driving and highway driving scenarios (Cooper & Strayer, 2008). We found no differences between the experts and novices ($F < 1$); both groups exhibited significant (and equivalent) impairment in dual-task conditions $F(3,55) = 10.7$, $p < 0.01$. Thus, real-world experience using a cell phone while driving did not make the so-called experts any better at multitasking than the novices.

We also used the driving simulator to test a "Groundhog Day"[3] variation in which participants drove a scenario with the same event sequences

[3] In the 1993 movie "Groundhog Day," the actor Bill Murray plays weatherman Phil Connors who finds himself living the same day over and over.

for 4 days in a row (e.g., a pedestrian stepping out at a particular location). Our rationale was that the unexpected events would become more predictable and that the impairments to driving while using a cell phone would diminish with practice. This is exactly what happened. With practice, the number of collisions diminished from the first day (41 collisions) to the fourth day (18 collisions) of training, $\chi^2(1) = 9.94$, $p < 0.01$; however, even on the fourth day of practice, there were still twice as many collisions in dual-task conditions (12 vs. 6 for dual-task and single-task, respectively).

To see if the improvements from Day 1 to 4 reflected a generalizable improvement in the ability to talk on a cell phone while driving, the participants were then transferred to a novel driving scenario. In the transfer phase, we observed significantly more crashes in dual-task conditions (26 collisions) than in single-task conditions (10 collisions), $\chi^2(1) = 6.35$, $p < 0.05$. In fact, the collision rates at transfer did not differ significantly from that observed on the first day of training. What the transfer analyses tell us is that the improvements observed with "Groundhog Day" training were specific to the training sequences, and when drivers were exposed to novel events at transfer, the pattern of dual-task impairment returned to the levels observed on the first day of training.

Neither real-world practice nor simulator training made drivers perform better in novel dual-task conditions. There was no evidence that drivers became experts at the dual-task combination of talking on a cell phone while driving. We suggest that the dynamic nature of both driving and conversing on a cell phone precludes the possibility of practicing away the dual-task costs of this concurrent activity.

6. Is Everyone Impaired by Using a Cell Phone While Driving?

A final issue to which we turn examines individual differences in the ability to concurrently talk on a cell phone while driving. We have provided clear evidence based upon group averages that using a cell phone while driving impairs performance. In fact, the evidence indicates that the interference is bidirectional, that is, not only does cell-phone use impair driving performance, but driving also interferes with the quality of the cell-phone conversation. But are there individual differences in the ability to multitask while driving? And, more importantly, are there "supertaskers" in our midst, individuals who can drive while simultaneously conversing on a cell phone without noticeable impairment? If so, what allows them to exhibit behavior that seemingly violates cognitive scientists' current understanding of attention and dual-task control?

To identify individuals with extraordinary multitasking ability, we paired the task of driving with an auditory version of the Operation Span (OSPAN) task. The OSPAN task involves maintaining the task goal of memorizing items and recalling them in the correct serial order while concurrently performing distracting math problems. Individual differences in OSPAN performance have been shown to predict behavior on a wide range of cognitive tasks thought to require frontal executive attention.

Two hundred participants performed the driving and OSPAN tasks in combination and also performed each of the tasks separately. We predicted that most individuals would show substantial performance declines in driving and OSPAN when performed together compared to the single-task baseline measures. By contrast, individuals with extraordinary multi-tasking ability, if they exist, might be able to perform these two tasks in combination without impairment.

The group-level data are presented in Figure 11. Dual-task performance was inferior to single-task performance for brake reaction time, $F(1,199) = 51.3$, $p < 0.01$, following distance, $F(1,199) = 10.2$, $p < 0.01$, OSPAN memory performance, $F(1,199) = 66.4$, $p < 0.01$, and OSPAN math performance $F(1,199) = 30.6$, $p < 0.01$. This pattern of performance is consistent with the well-established pattern of dual-task performance decrements associated with limited capacity attention.

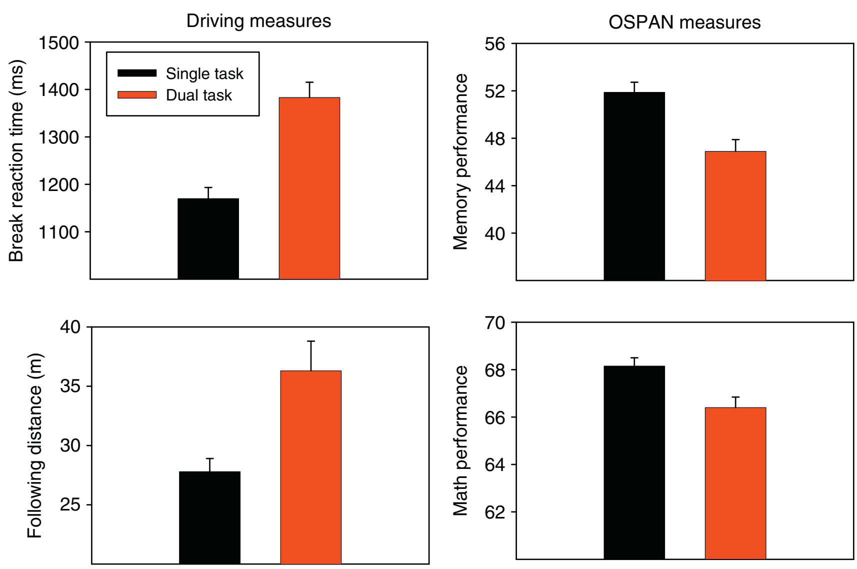

Figure 11 The group-level data for single-task and dual-task conditions.

Moreover, the data indicate bidirectional interference such that both driving and OSPAN measures suffered in dual-task conditions.

Further scrutiny revealed a small subset of participants ($N = 5$; 3 males and 2 females) scoring in the upper quartile of the OSPAN memory task (i.e., "high spans") and showing no performance decline from single-task to dual-task across all the dependent measures. We used a stringent set of criteria for classifying participants as a "supertasker." The first requirement was that performance on each of the four dependent measures was in the top 25% of the single-task scores for that variable, ensuring that the absence of dual-task costs could not be attributed to "sandbagging" in single-task conditions. The second requirement was that dual-task performance could not differ from single-task levels by more than the single-task standard error of the mean for that measure. Participants received a score ranging from 0 to 4, reflecting the number of measures in which they showed no dual-task decrement. Participants who earned a score of 3 ($N = 4$) or 4 ($N = 1$) were classified as supertaskers (i.e., participants who performed *both* tasks at the same time with high levels of proficiency on each task) and those earning a score of 0–2 were classified as controls. Note that a score of 2 or lower indicates that one or both of the tasks were not performed as well in dual-task conditions as in single-task conditions.

As illustrated in Figure 12, the dual-task cost for these supertaskers was zero; they performed as well, if not better, in the dual-task condition than

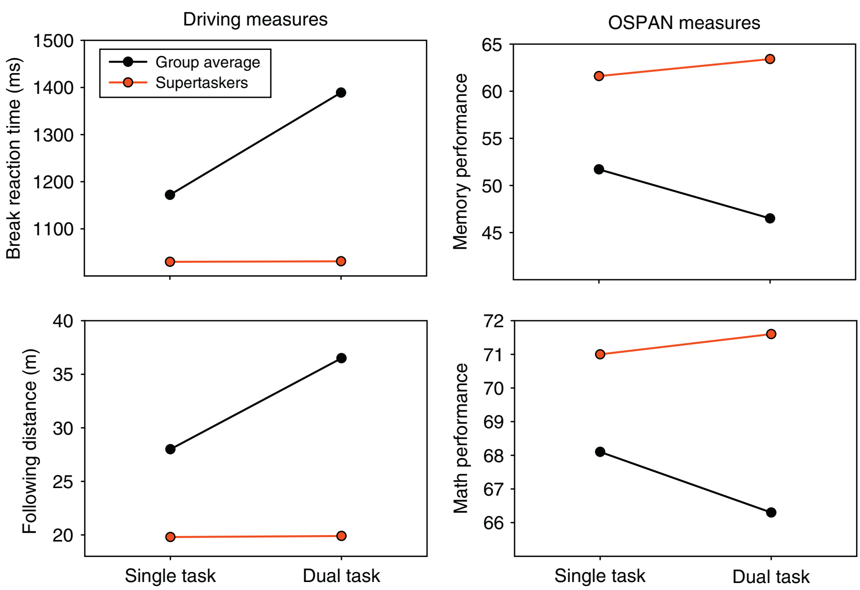

Figure 12 A comparison of control and supertasker performance.

they did in the single-task conditions. Independent sample *t*-tests comparing the difference between single-task and dual-task conditions indicated significantly smaller costs for supertaskers than for controls in brake reaction time, $t(198) = 5.0$, $p < 0.01$; following distance, $t(198) = 3.1$, $p < 0.01$; OSPAN memory performance, $t(198) = -4.6$, $p < 0.01$, but OSPAN math performance did not differ ($p > 0.10$). We also compared the performance of supertaskers with the subset of participants who scored in the top quartile of the OSPAN task (i.e., high spans). Independent sample *t*-tests comparing the difference between single-task and dual-task revealed significantly smaller costs for supertaskers in brake reaction time $t(49) = 3.5$, $p < 0.01$. and OSPAN memory performance $t(49) = 4.8$, $p < 0.01$. There was also a trend for smaller costs in following distance for supertaskers $t(49) = 1.9$, $p < 0.06$, whereas the costs in OSPAN math performance did not differ ($p > 0.20$). Note also that the supertaskers began in single-task conditions in the upper quartile of the distribution and became an even more extreme outlier in dual-task conditions.

To ensure that this pattern of data did not arise by chance alone, we performed a Monte Carlo simulation in which randomly selected single–dual-task pairs of variables from the existing data set were obtained for each of the four dependent measures and then subjected to the same algorithm that was used to classify the supertaskers. The Monte Carlo procedure simulated 100,000 participants, and we found that by chance alone, 0.16% of the cases resulted in performance criteria that matched those of the supertaskers (compared to the obtained 2.5% of cases; a 15-fold difference). Logistic regression found that the frequency of supertaskers was significantly greater than chance $\chi^2(1) = 17.9$, $p < 0.01$. Given that this pattern cannot be attributed to chance, it suggests that an important individual difference variable underlies the effect. We have suggested that this individual difference is associated with differences in executive attention as mediated, at least in part, by the frontal cortex (Watson & Strayer, 2010).

To test the hypothesis that the extraordinary multitasking behavior of supertaskers is mediated by differences in the frontal cortex, we invited our supertaskers plus three individuals who met the supertasker criteria in subsequent studies (making a total of eight supertaskers) and a control group matched on working memory capacity (assessed using the OSPAN task), age, handedness, and gender back for additional testing. This testing took place at least a month after the initial screening and involved having the participants perform a challenging *N*-back task while their brains were scanned using functional magnetic resonance imaging (fMRI). Participants were also retested on a single-task variant of the OSPAN task.

In the dual *N*-back task, participants were instructed to respond when the letter and/or position of the square matched the stimuli *N*-times back (i.e., 1 time back in the 1-back condition, 2 times back in the 2-back condition, and so on). The *N*-back was administered as a dual task in that visual/spatial and auditory/verbal stimuli were presented simultaneously, requiring participants to process both modalities independently (Jaeggi et al., 2007). Participants completed the dual *N*-back task in two separate fMRI sessions in a Siemens 3T Trio MR scanner with a standard head coil.

With the accuracy data, there was a significant effect of *N*-back load, with accuracy decreasing as load increased, $F(3,30) = 4.06$, $p < 0.01$. More importantly, there was also a significant effect of group, $F(1,10) = 10.67$, $p < 0.01$. The latter effect indicates that the supertaskers performed the dual *N*-back task more accurately than the controls. In addition, the test–retest reliability of the OSPAN task was higher for the supertaskers than for the controls, indicating a high level of stability for supertaskers. The stability of the OSPAN performance across several months reflects a reliable ability difference, and the superior performance in the dual *N*-back task suggests that the ability of supertaskers generalizes beyond the driving/OSPAN dual-task combination used for classification by Watson and Strayer (2010). That is, the supertasker classification reflects a reliable and generalizable ability difference.

The fMRI analyses found several brain regions that differed for supertaskers and controls as they performed the dual *N*-back task. Of these, three frontal areas were of particular importance because they have been implicated in prior research on multitasking: frontopolar prefrontal cortex (FP-PFC), dorsolateral prefrontal cortex (DL-PFC), and anterior cingulate cortex (ACC). In all cases, the supertaskers had *less* activity at higher levels of load than controls. These neuroimaging findings provide an important biobehavioral marker of supertaskers' performance and suggest that they are more efficient, achieving higher levels of accuracy in the dual *N*-back task with less metabolic activity (i.e., fewer resources). Note, however, that in terms of working memory capacity, supertaskers and controls did not differ, that is, there is something specific about multitasking that makes supertaskers unique. In other words, the dissociative pattern indicates that supertaskers excel at multitasking, but it is not the case that supertaskers are necessarily "smarter" across the board.

Supertaskers have a remarkable ability to successfully perform two attention-demanding tasks that over 97% of the population cannot perform without incurring substantial costs in performance. Paradoxically, a recent study examining multitasking ability found that individuals who report multitasking more frequently do so *less* well than those who are less frequent multitaskers (Ophir, Nass, & Wagner, 2009). Indeed, our studies over the last decade have found that a great many people have the belief that the laws of attention do not apply to them (e.g., they have seen other drivers who are impaired while multitasking, but they believe that they are the exception to the rule), which is consistent with the general overconfidence of beliefs about one's ability. In fact, some readers may also be wondering whether they too are supertaskers; however, we suggest that the odds of this are against them. The illusion that people harbor about their superior multi-tasking ability is likely to be driven by inattention blindness, whereby attention is diverted from sources of evidence that would indicate that their driving behavior is impaired.

The discussion of supertaskers begs an interesting question: Why are we all not supertaskers? We suggest two possibilities. First, there may be some cost associated with being a supertasker. People are often faced with a stability/plasticity dilemma in which they must strike a delicate balance between being overly rigid and overly flexible in their processing style. Indeed, many clinical disorders are associated with an imbalance, being either overly rigid or overly flexible (DSM-IV, 1994). It may be that supertaskers excel at multitasking at the expense of other processing abilities. Second, there may be few costs (and possibly benefits) associated with being a supertasker, but the environmental and technological demands that favor this ability are relatively new, and any selective advantage for being a supertasker has yet to propagate throughout the population. Indeed, it has only been in the last few generations that technology has placed high value on multitasking ability. This time-scale is too short for any selective advantage to spread through the population.

Together, these individual differences in multitasking behavior provide clear evidence for cognitive distraction (for the majority of us) and help to localize the areas of the brain (i.e., frontal cortex) that become overloaded when drivers attempt to talk on a cell phone while driving. In particular, these findings help to bridge the gap between applied cognition and cognitive neuroscience. Ultimately, we believe that the differences between supertaskers and controls can be leveraged to provide theoretical insight into why cognition does (or does not) break down for dual-task combinations beyond cell phones and driving.

7. Conclusions and Future Directions

This chapter took an applied cognitive neuroscience approach to driver distraction, integrating methods and theories from cognitive science and cognitive neuroscience into the study of driving. Considering the ubiquity of driving and the fact that motor-vehicle crashes are the leading cause of accidental deaths in the United States, we believe that this work can have a significant impact. We focused on cognitive distraction and showed that for the most prevalent exemplar, driving while conversing on a cell phone, impairments can be as profound as operating a motor vehicle at the legal limit of alcohol. We showed that using a cell phone induces a form of inattention blindness and provided evidence using eye tracking and ERP methodologies of this impairment. We also used state-of-the-art neuroimaging methods (fMRI) to identify several regions of the frontal cortex that are overloaded in multitasking situations. We also showed that talking on a cell phone differs in important ways from other forms of verbal communication (e.g., talking to an adult passenger in the vehicle).

Translational research is often used to help guide public policy, and this has been the case with the research described herein. Members of our research team have participated in two National Distracted Driving Summits and briefed members of both the US House and Senate on the science of driver distraction. Given the explosion of new technologies that are making their way into the vehicle, the issues of driver distraction are likely to get much worse in the coming years. Unfortunately, there will be thousands of additional lives lost because a driver was multitasking instead of paying full attention to the road.

We suggest two important directions for further research. First, a theoretically sound and methodologically rigorous technique should be developed to determine the distraction potential of a device *before* it is used while driving (and this is particularly true if the device is installed by the auto manufacturer). We suggest that it is unwise and unethical to integrate a device into the vehicle without first proving that it does not cause harm. By comparison, a drug company cannot market a drug unless it has gone through a rigorous set of evaluations to ensure that it causes no harm. This research need not be *atheoretical*. That is, not only will this research help to improve safety on the roads, but also it has the potential for helping to refine cognitive theory (as was the case for the research on supertaskers; for other examples, see Strayer et al., 2003).

Second, it is important to understand why people continue to engage in a distracting activity when they acknowledge that it is risky. For example, surveys indicate that large segments of the driving public support legislation restricting or prohibiting the use of cell phones to talk or text. Yet, these same surveys also indicate that 85% of adult drivers talk on their cell while driving and 47% of adults report text messaging while driving. There is clearly a disconnect in that people support legislation that would restrict the activities in which they regularly engage. Understanding the bases for this disconnect is likely to be important both theoretically and in the process of helping to better translate our scientific understanding of driver distraction into good public policy.

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