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University of Utah
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Profiles in Driver Distraction: Effects of Cell Phone Conversations on Younger and Older Drivers

David L. Strayer and **Frank A. Drews,** University of Utah, Salt Lake City, Utah

Our research examined the effects of hands-free cell phone conversations on simulated driving. We found that driving performance of both younger and older adults was influenced by cell phone conversations. Compared with single-task (i.e., driving-only) conditions, when drivers used cell phones their reactions were 18% slower, their following distance was 12% greater, and they took 17% longer to recover the speed that was lost following braking. There was also a twofold increase in the number of rear-end collisions when drivers were conversing on a cell phone. These cell-phone-induced effects were equivalent for younger and older adults, suggesting that older adults do not suffer a significantly greater penalty for talking on a cell phone while driving than compared with their younger counterparts. Interestingly, the net effect of having younger drivers converse on a cell phone was to make their average reactions equivalent to those of older drivers who were not using a cell phone. Actual or potential applications of this research include providing guidance for recommendations and regulations concerning the use of mobile technology while driving.

INTRODUCTION

Summarizing the literature on aging and dual-task performance, Kramer and Larish (1996; see also Craik, 1977, and Hartley, 1992, for similar conclusions) noted that "one of the best exemplars of a mental activity in which large and robust age-related differences have been consistently obtained is dual-task processing" (p. 106). Given that driving is a complex activity involving the combination of a number of task-relevant activities (navigating; maintaining lane position, following distance, and speed; reacting to unexpected events, etc.) and task-irrelevant activities (using a cell phone, adjusting the radio, conversing with passengers, eating, lighting a cigarette, shaving, applying makeup, etc.), it is not surprising that older adults exhibit deficiencies in driving.

In fact, there is a U-shaped function relating fatality rates with age (U.S. Department of Transportation, 2000). Fatality rates systematically decline from teenage years to middle-aged years, followed by a steady increase in fatality rates

beginning with sexagenarians. The U-shaped function relating fatality rates with age appears to be multiply determined. On the one hand, younger drivers have less experience, take greater risks, and have a higher likelihood of being intoxicated as compared with drivers in the 35- to 60-year age range. On the other hand, drivers over 65 years of age tend to have more experience, take fewer risks, and are more likely to use seat belts, and they have the lowest proportion of intoxication of all adults. In general, older drivers are also more likely to succumb to the health complications associated with an accident than are younger drivers.

The purpose of the current research is to test the hypothesis that age-related differences in the ability to divide attention between tasks commonly engaged in while driving contributes significantly to the impairments in driving performance associated with senescence. Our current research focuses on a dual-task activity that is currently engaged in by more than 100 million drivers in the United States: the concurrent use of cell phones while driving (Goodman et al.,

1997; see also the Cellular Telecommunications Industry Association Web site, http://www.wow-com.com/).

It is now well established that cell phone use impairs the driving performance of younger adults (Alm & Nilsson, 1995; Briem & Hedman, 1995; Brookhuis, De Vries, & De Waard, 1991; Brown, Tickner, & Simmonds, 1969; Goodman et al., 1997; McKnight & McKnight, 1993; Redelmeier & Tibshirani, 1997; Strayer, Drews, & Johnston, 2003; Strayer & Johnston, 2001). For example, drivers are more likely to miss critical traffic signals (stop signs, traffic lights, a vehicle braking in front of the driver, etc.), slower to respond to the signals that they do detect, and more likely to be involved in rear-end collisions when they are conversing on a cell phone (D. L. Strayer, Drews, & Johnston, 2003; K. Strayer & Burns, 2004). In addition, even when participants directed their gaze at objects in the driving environment, they often failed to "see" them when they were talking on a cell phone because their attention was directed away from the external environment and toward an internal, cognitive context associated with the phone conversation.

In this article, we explore the extent to which older adults are penalized by this real-world dual-task activity. Based on the aging and dual-task literature, we predict that as the dual-task demands increase, the driving performance of older adults will deteriorate more rapidly than that of younger drivers.

We used a car-following paradigm (see also Alm & Nilsson, 1995; Lee, Vaven, Haake, & Brown, 2001; Strayer, Drews, & Johnston, 2003) in which participants drove on a multilane freeway in single-task (i.e., driving only) and dual-task (i.e., driving and conversing on a cell phone) conditions. Participants followed a pace car that would brake at random intervals. We measured a number of performance variables (driving speed, following distance, brake onset time, etc.) that have been shown to affect the likelihood and severity of rear-end collisions (Brown, Lee, & McGehee, 2001; Lee et al., 2001). We predict that these performance variables will be altered given the cognitive basis of distraction associated with cell phone conversations. For example, prior research suggests that both brake onset time and following distance will be lengthened when drivers are talking on a cell phone (Strayer, Drews, & Johnston, 2003).

METHOD

Participants

The participants were 20 older adults and 20 younger adults. The younger participants ranged in age from 18 to 25 years, with an average age of 20 years. Older participants ranged in age from 65 to 74 years, with an average age of 70 years. Table 1 reports several demographic and psychometric measures for the two age groups. Older adults scored significantly lower in both digit symbol and maze tracing tasks, indicating a decrease in processing speed for this cohort. All participants were in good health, had normal or corrected-to-normal visual acuity, normal color vision (Ishihara, 1993), and a valid driver's license.

TABLE 1: Psychometric and Demographic Measures for Younger and Older Adults

	Younger Adults	Older Adults	$F(1, 39)$
Age (years)	20.2 (0.4)	69.6 (0.6)	4299*
Gender	13 men, 7 women	14 men, 6 women	0.2, ns
Digit symbol	84.6 (4)	59.1 (2.4)	32.1*
Schooling (years)	9.6 (1.4)	15.5 (0.5)	17.1*
Maze tracing	15.1 (1)	8.1 (1)	34.5*

Note. Standard errors are presented in parentheses.

*$p < .05$.

Stimuli and Apparatus

A PatrolSim high-fidelity driving simulator, illustrated in Figure 1, was used in the study. (Simulator information is available on the MPRI Ship Analytics Web site, http://www.shipanalytics.com/STS/patrolsimii+.asp.) The simulator incorporates proprietary vehicle dynamics, traffic scenario, and road surface software to provide realistic scenes and traffic conditions. The dashboard instrumentation, steering wheel, and gas and brake pedals were taken from a Ford Crown Victoria® sedan with an automatic transmission.

The simulator used a freeway road database simulating a 24-mile (38.6-km) multilane highway 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. Four unique driving scenarios, counterbalanced across participants, were used in the study. In each scenario, the pace car was programmed to brake at 32 randomly distributed locations. 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.

Procedure

When participants arrived for the experiment, they completed a questionnaire assessing health status, psychometric information, and their interest in potential topics of cell phone conversation. Participants were then familiarized with the driving simulator using a standardized 20-min adaptation sequence. Participants then drove four 10-mile (16.1-km) sections on a multilane highway. The duration of each scenario was approximately 10 min but varied as a function of the driving speed of each participant. Half of the scenarios were used in the single-task driving condition and half were used in the dual-task (i.e., driving and cell phone conversation) condition. The order of conditions and scenarios was counterbalanced across participants using a Latin square design, with the constraint that both single- and dual-task conditions were performed in the first half of the experiment and both single- and dual-task conditions were performed in the last half of the experiment. For data analysis purposes, we aggregated the data across scenario for both the single- and dual-task conditions.

Figure 1. The PatrolSim Driving Simulator.

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

The dual-task condition involved conversing on a cell phone with a research assistant. The participant and the research assistant discussed topics that were identified in the questionnaire as being of interest to the participant. These naturalistic conversations were unique to each participant, and the research assistant was instructed to maintain a dialog in which the participant spoke and listened in approximately equal proportions. (In hindsight, it would have been useful to have recorded and analyzed these conversations; however, because they were not recorded a detailed analysis of the conversations was precluded. Consequently, aside from our research assistant ensuring that the participant was engaged in the conversation and spoke and listened in approximately proportions, we cannot make comments on the content and specific nature of the conversations.) 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 observed must be attributable to the cell phone conversation itself, because there was no manual manipulation of the cell phone during the dual-task portions of the study.

Dependent Measures

We examined four parameters associated with the participant's reaction to the braking pace car. *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 (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. *Half-recovery time* is the time for participants to recover 50% of the speed that was lost during braking (e.g., if the pace car was traveling at 60 mph before braking and decelerated to 40 mph after braking, then half-recovery time would be the time taken to return to a speed of 50 mph).

Figure 2 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 (100 kph) 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. Sometime later 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 onset time. Once the participant depressed the brake, the pace car began to accelerate, at which point the participant removed his or her foot from the brake and applied pressure to the gas pedal. Note that in this example, following distance decreased by about 50% during the braking event.

Design and Statistical Analysis

The design was a 2 (age: younger vs. older adults) × 2 (task: single vs. dual task) factorial. Age was a between-subjects factor and the single- versus dual-task condition was a within-subjects factor. We used a multivariate analysis of variance (MANOVA) to provide an overall measure of driver performance as a function of experimental conditions. We also performed univariate analyses on each of the dependent measures using a 2 (age: younger vs. older adults) × 2 (task: single vs. dual task) split-plot analysis of variance (ANOVA). A significance level of $p < .05$ was adopted for all inferential tests, and Cohen's d was used to estimate effect size for significant effects in the univariate analyses. Cohen (1988) provided a heuristic for interpreting measures of d, in which a small effect size would have a value of .20, a medium effect size would have a value of .50, and a large effect size would have a value of .80.
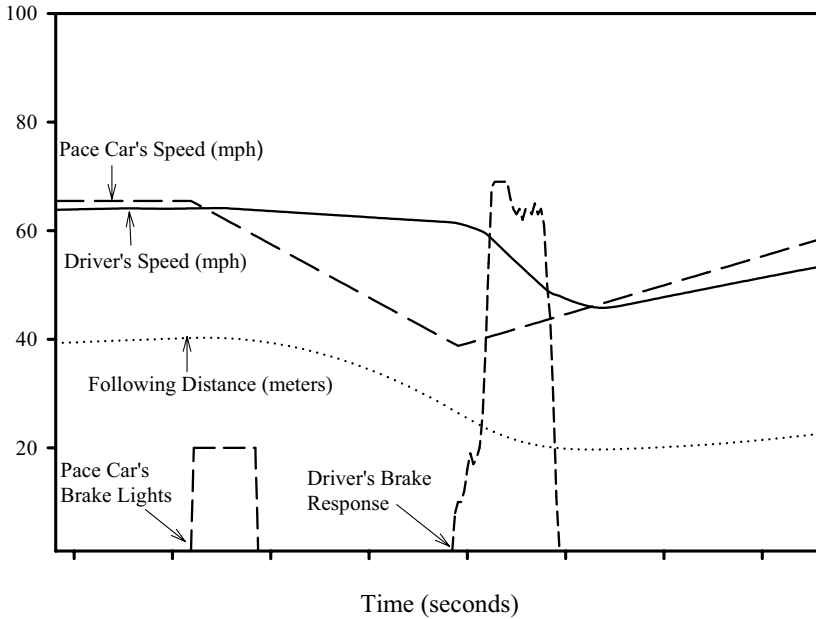
Figure 2. An example of the sequence of events occurring in the car-following paradigm.

RESULTS

Table 2 presents the four driving performance measures described earlier. The MANOVA indicated significant main effects of age, $F(4, 35) = 8.74$, $p < .01$, and single versus dual task, $F(4, 35) = 11.44$, $p < .01$. However, the Age × Single- versus Dual-Task interaction was not significant, $F(4, 35) = 1.46$, $p > .23$. This latter finding suggests that older adults do not suffer a significantly greater penalty for talking on a cell phone while driving than do their younger counterparts.

In order to better understand the changes in driving performance with age and 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 jth 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 $X_{[j,1]}, X_{[j,2]}, X_{[j,3]}...X_{[j,300]}$, in which 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. We created profiles of the participant's braking response, following distance, and driving speed.

Figure 3 presents the average braking profile,

TABLE 2: Driving Performance Measures as a Function of Age and Single- Versus Dual-Task Conditions

	Younger Adults		Older Adults	
	Single Task	Dual Task	Single Task	Dual Task
Brake onset time (ms)	780 (49)	912 (83)	912 (49)	1086 (83)
Following distance (m)	22.7 (3)	26.4 (2)	37.1 (3)	40.7 (2)
Driving speed (mph)	63.3 (2)	62.1 (1)	52.4 (2)	53.7 (1)
½ Recovery time (s)	4.6 (0.4)	5.9 (0.4)	6.4 (0.4)	7.0 (0.4)

Note. Standard errors are presented in parentheses.
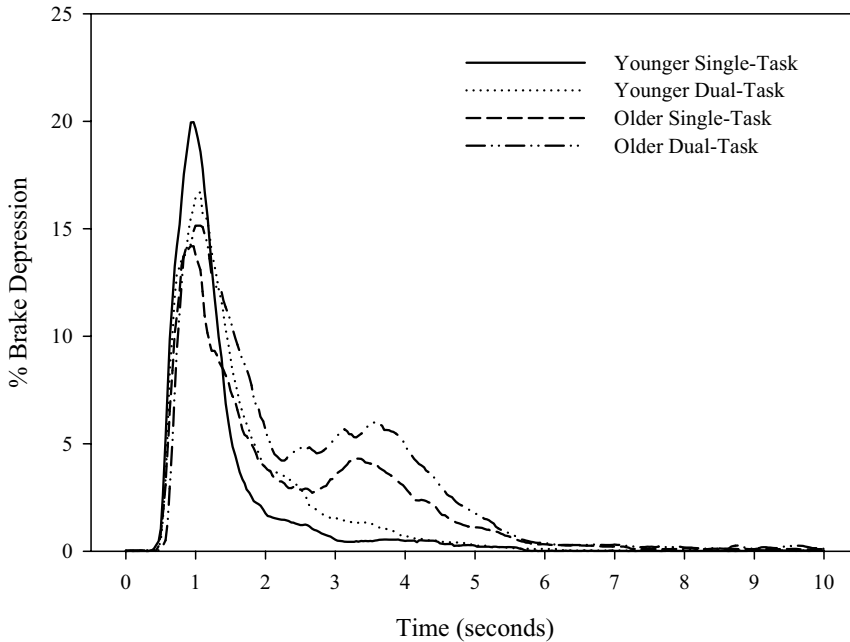
Braking Profile

Figure 3. Participant's time-locked braking profile in response to the braking pace car.

time locked to the onset of the pace car's brake lights, for each of the conditions in the experiment. Inspection of the figure reveals that participants initiated their braking response within 1 s of the onset of the pace car's brake lights and that they continued to depress the brake for several seconds following brake onset. Older drivers also exhibited a second peak in the braking profile, approximately 4 s after the onset of the pace car's brake lights, and this was most pronounced in dual-task conditions. Unlike the braking profile, the distribution of brake onset times did not exhibit this bimodal pattern. Because the brake onset time was defined as the interval between the pace car's brake lights and the initial depression of the brake pedal by the participant, subsequent changes in the braking response will not affect this performance measure. However, the extended braking observed for older adults does contribute to the longer recovery time following braking; see Figure 4.

Statistical analysis of brake onset times revealed slower reactions in dual-task than in single-task driving conditions, $F(1, 38) = 12.96$, $p < .01$, $d = 1.17$. However, the main effect of

age was only marginally reliable, $F(1, 38) = 3.13$, $p < .08$, $d = 0.57$, and the Age × Single-versus Dual-Task interaction was not significant, $F(1, 38) = 0.26$, $p > .64$. Interestingly, the difference in average reaction time between the dual- and single-task conditions was exactly the same magnitude (153 ms) as that between older and younger adults (153 ms). That is, cell phone conversations slowed participants' reactions by 18%, an amount comparable to the average slowing observed with senescence (although the variability in reaction time associated with age was greater than the variability associated with using a cell phone).

Figure 5 presents the average following distance profile, time locked to the onset of the pace car's brake lights, for each of the conditions in the experiment. Inspection of the figure indicates that following distance decreased as the pace car began to decelerate and then increased as the participant applied his or her brakes. Analysis of following distance revealed that older adults drove with a greater following distance than did younger drivers, $F(1, 38) = 21.97$, $p < .01$, $d = 1.52$. Following distance was also
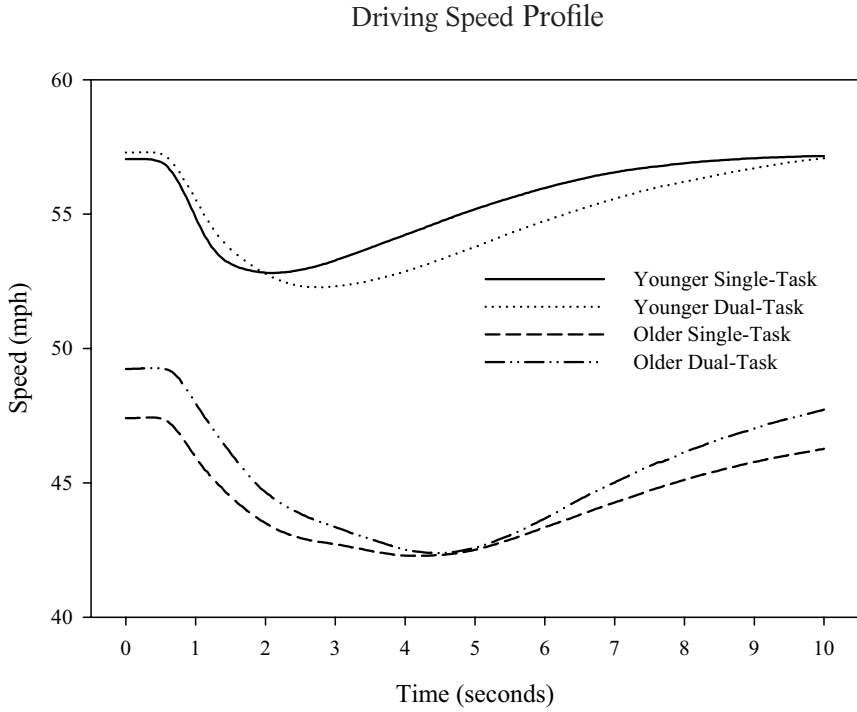
Driving Speed Profile

Figure 4. Participant's time-locked driving speed profile in response to the braking pace car.
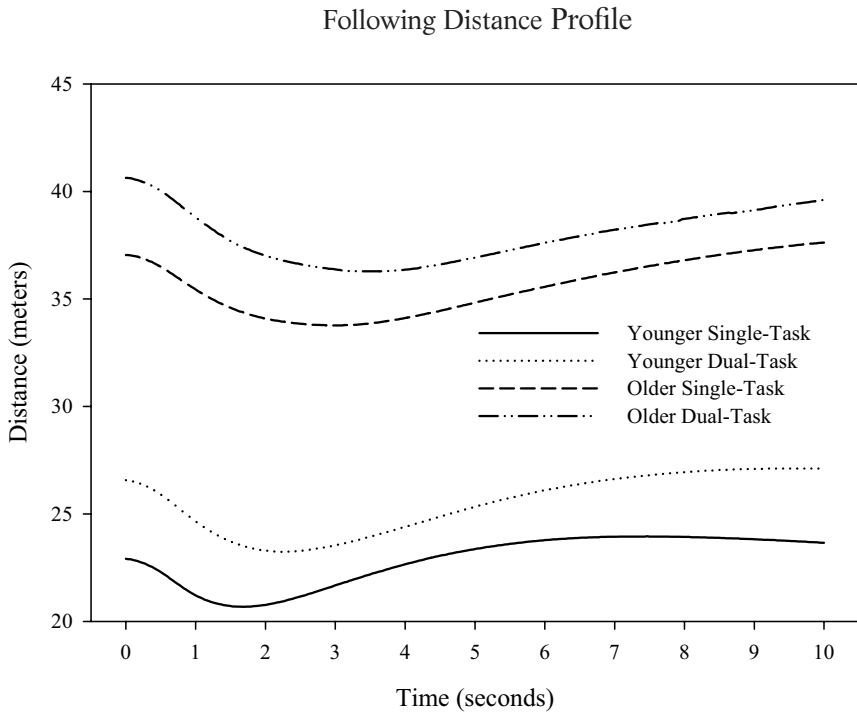
Following Distance Profile

Figure 5. Participant's time-locked following distance profile in response to the braking pace car.

greater in dual- than in single-task conditions, although this effect was only marginally significant, $F(1, 38) = 3.80$, $p < .06$, $d = 0.63$. The Age × Single versus Dual-Task interaction was not significant, $F(1, 38) = 0.01$, $p > .98$.

Figure 4 presents the average driving speed profile, time locked to the onset of the pace car's brake lights, for each of the conditions in the experiment. Inspection of the figure indicates that the vehicle began to decelerate approximately 1 s after the pace car's brake lights illuminated. For younger drivers, the deceleration lasted approximately 1 s, whereupon the participant's vehicle began to accelerate to prebraking speeds. For older adults, the deceleration lasted approximately 3 s, and the return to prebraking speeds took longer than that for younger adults. Analysis of driving speed revealed that older adults drove slower than younger adults did, $F(1, 38) = 21.86$, $p < .01$, $d = 1.52$. Neither the main effect of single versus dual task, $F(1, 38) = 0.01$, $p > .97$, nor the Age × Single- versus Dual-Task interaction were significant, $F(1, 38) = 1.53$, $p > .22$. Further analysis of driving speed indicated that it took older adults longer to recover 50% of the speed that was lost following braking, $F(1, 38) = 9.07$, $p < .01$, $d = 0.98$, and the recovery time was greater in dual-task than in single-task conditions, $F(1, 38) = 21.43$, $p < .01$, $d = 1.50$. One reason for the longer recovery time for older adults is that they tended to keep their foot on the brake longer than the younger drivers did (see Figure 3). The Age × Single-versus Dual-Task interaction was not significant, $F(1, 38) = 2.58$, $p > .12$.

Six of the participants in the study were involved in a collision while driving. Although many factors contribute to an accident, it is noteworthy that two accidents occurred in single-task conditions (1 older adult and 1 younger adult) and four accidents occurred in dual-task conditions (1 older adult and 3 younger adults). Although the low frequency of accidents in this study precludes traditional statistical analysis, this twofold increase is likely to have important consequences for traffic safety (see Loftus, 1996).

We have also used this car-following paradigm in two other published studies (Strayer, Drews, & Crouch, 2003; Strayer, Drews, & Johnston, 2003), and when we aggregate the data from those earlier studies with the current data, definitive statements regarding the impact of cell phone use on accident rates can be made. Taken together, a total of 121 participants performed in both single- and dual-task conditions. Of these, 2 were involved in rear-end collisions when driving in single-task conditions and 10 were involved in rear-end collisions when driving in dual-task conditions. The difference in accident rates was significant, $\chi^2(1) = 5.61$, $p < .02$, providing clear evidence that drivers using a cell phone were more likely to be involved in a collision than when these same drivers were not using a cell phone.

Elsewhere, Brown et al. (2001) demonstrated that increases in brake onset time, such as those observed in our study, can increase the likelihood and severity of a rear-end collision. The fact that older adults were involved in fewer collisions can be attributed, at least in part, to the greater following distance and slower driving speed of this cohort.

DISCUSSION

Taken together, the data demonstrate that conversing on a hands-free cell phone influenced driving performance and that the distracting effects of cell phone conversations were equivalent for older and younger adults. As compared with drivers in single-task conditions, drivers using cell phones had 18% slower brake onset times, had a 12% greater following distance, and took 17% longer to recover the speed that was lost following braking. Drivers talking on the cell phone were also involved in more rear-end collisions. However, our study found that older drivers did not suffer a greater penalty talking on the phone while driving than did younger drivers. Interestingly, the average reaction time of younger drivers talking on the cell phone was equivalent to the average reaction time of older drivers who were not using the cell phone.

It appears that participants using a cell phone may have attempted to compensate for their slower reactions by increasing the following distance from the vehicle immediately in front of them. We have observed similar compensatory strategies in our naturalistic observations of drivers on the highway. In one particularly

compelling case, the position of the mirrors in the vehicle allowed us to determine that the driver was switching attention between tasks. At regular intervals the driver would glance out the windshield to assess her driving performance and then shift her gaze back to a mirror in the sun visor. This driver exhibited an information sampling strategy that appeared to be based on an assessment of how often things were changing in the driving scene. To provide a greater interval between shifts of attention, she increased the separation between her vehicle and the one immediately ahead of her. Unfortunately for the driver, another vehicle merged into her lane while she was not attending to driving. When she returned her attention to driving and noticed this new vehicle, she abruptly applied the brakes, nearly causing an accident.

Thus the compensatory strategy of increasing following distance may give drivers an additional buffer for responding to unpredictable events, but in many cases the compensation may be inadequate (e.g., Strayer, Drews, & Johnston, 2003). Moreover, Brown et al. (2001; see also Lee et al., 2001) recently showed that a slowing of the driver's reactions is likely to increase the severity of impact during collision, especially when driving at highway speeds.

The absence of age-related differences between single- and dual-task performance would appear to contradict findings from laboratory-based studies showing "large and robust age-related differences...in dual-task processing" (Kramer & Larish, 1996, p. 106). However, one important difference between the current research and much of the earlier laboratory-based studies is that our task used a high-fidelity driving simulator to study a skill that older adults have performed for 50 years. It may be that highly practiced, real-world skills such as driving are less sensitive to the dual-task impairments normally associated with aging. If this hypothesis is correct, then it implies that novel laboratory-based tasks may significantly overestimate the age-related dual-task deficits (but see Ball et al., 2003, for an example in which age-related differences in the useful field of view are predictive of crash frequency). At this juncture, more research is needed to test this proposition.

Nevertheless, the epidemiological evidence clearly indicates that older drivers, on average, are more likely to be involved in fatal traffic accidents (U.S. Department of Transportation, 2000). Another possibility for our failure to find a significant Age × Single- versus Dual-Task task interaction is that the older adults in our study may have had better mental and physical fitness than is the case among the general population of older drivers. Our participants were recruited from advertisements in local papers, and all were in good health and exercised regularly. It may be that the older drivers who are at greater risk for accidents are less likely to participate in driving-related research. Although we cannot rule out this possibility, we note that this is a potential problem for all cross-sectional aging research.

It is also important to note that performance decrements for cell-phone drivers were obtained even when there was no possible contribution from the manual manipulation of the cell phone. Therefore, legislation that restricts handheld devices but permits hands-free devices (e.g., State of New York Laws of 2001, Chapter 69, Section 1225c) is not likely to eliminate the problems associated with using cell phones while driving because these problems can be attributed in large part to the distracting effects of the phone conversations themselves.

A final comment concerns the nature of the cell phone conversations in our study. Unlike earlier research using working memory tasks (Alm & Nilsson, 1995; Briem & Hedman, 1995), mental arithmetic tasks (McKnight & McKnight, 1993), reasoning tasks (Brown et al., 1969), or simple word generation (Strayer & Johnston, 2001), the conversations in our current study were designed to be naturalistic, casual conversations centering on topics of interest to the participant. As would be expected with any naturalistic conversation, they were unique to each participant. The research assistant in our study was trained to maintain a dialog in which the participant listened and spoke in approximately equal proportions. One problem with comparing the performance of older and younger drivers is that there is no clear way to ensure that the cognitive loads imposed by these naturalistic conversations were equivalent. Although older and younger participants received identical instructions and the subjective estimates of our

research assistant did not indicate any systematic difference between the age groups, we cannot rule out the possibility that the older adults may have allocated attention to the conversation in a manner different from that of the younger adults.

In sum, our research found that the driving performance of both younger and older adults is significantly impaired when they are conversing on a hands-free cell phone. These dual-task impairments were equivalent in magnitude for younger and older adults. Our data further indicate that the net effect of having a younger driver converse on a cell phone was to make his or her reactions similar to those of older drivers who were not using a cell phone.

ACKNOWLEDGMENTS

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David L. Strayer is a professor of psychology at the University of Utah. He received his Ph.D. in psychology from the University of Illinois at Urbana-Champaign in 1989.

Frank A. Drews is an assistant professor of psychology at the University of Utah. He received his Ph.D. is psychology at the Technical University of Berlin, Germany, in 1999.