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Engrossed in conversation: The impact of cell phones on simulated driving performance

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Abstract

The current study examined the effects of cognitively distracting tasks on various measures of driving performance. Thirty-six college students with a median of 6 years of driving experience completed a driving history questionnaire and four simulated driving scenarios. The distraction tasks consisted of responding to a signal detection task and engaging in a simulated cell phone conversation. Driving performance was measured in terms of four categories of behavior: traffic violations (e.g., speeding, running stop signs), driving maintenance (e.g., standard deviation of lane position), attention lapses (e.g., stops at green lights, failure to visually scan for intersection traffic), and response time (e.g., time to step on brake in response to a pop-up event). Performance was significantly impacted in all four categories when drivers were concurrently talking on a hands-free phone. Performance on the signal detection task was poor and not significantly impacted by the phone task, suggesting that considerably less attention was paid to detecting these peripheral signals. However, the signal detection task did interact with the phone task on measures of average speed, speed variability, attention lapses, and reaction time. The findings lend further empirical support of the dangers of drivers being distracted by cell phone conversations.

Keywords: Attention; Distracted driving; Reaction time; Traffic violations

1. Introduction

Technological advancements have resulted in the incorporation of electronic devices in automobiles that compete for the attention of drivers. Cellular phones have been the most popular addition, with more than 55% of the total U.S. population currently owning one (CTIA, 2004; U.S. Bureau of the Census, 2004). Research has shown that those who talk on a phone while driving are four times more likely to have an accident when compared to those who do not talk on a phone (Redelmeier and Tibshirani, 1997). In fact, an estimated 330,000 driving related injuries and 2600 fatalities per year could be attributed to the use of cell phones (Cohen and Graham, 2003). In addition to phones, equipment such as computers and dashboard-navigation systems, have been added to the already attention-demanding task of driving. Even a task as common as changing the radio station requires the driver to divert attention from the road and may lead to an accident. The purpose of the current study was to identify specific driving subtasks that suffer while concurrently performing a secondary task.

Driving alone, without engaging in distracting activities, requires the successful time-sharing of concurrently performed tasks. There are two general groups of tasks involved with driving: immediate and peripheral. The immediate tasks, which are crucial to driving, include staying on the roadway, maintaining forward motion, continuing on the intended course, and identifying and reacting to changing events that can impact the driver (Seppelt and Wickens, 2003). Peripheral tasks are somewhat less important to the overall success of driving, and include monitoring speed, viewing both inside the car and the surrounding environment, and processing static signs or objects in the periphery.

Both immediate and peripheral driving tasks suffer when individuals engage in phone conversations while driving. In terms of the immediate tasks, results have shown that drivers make more frequent and larger steering corrections (Reed and Green, 1999) and have more intense, though delayed braking patterns (Hancock et al., 2003). Drivers engaged in a phone conversation have also been found to miss (Strayer and Johnston, 2001) or react slower to critical signals (Consiglio et al., 2003) and changing stop lights (Hancock et al., 2003). In terms of

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peripheral tasks, drivers have been found to compensate for the attentional overload by reducing their driving speed (e.g., Alm and Nilsson, 1994; Brown et al., 1969; Haigney et al., 2000; Reed and Green, 1999) as well as reducing both the frequency (Harbluk et al., 2002) and duration (McCarley et al., 2001) of glances in the driving scene. Drivers engaged in phone conversations have also been found to leave dangerously small gaps between themselves and other drivers (Brown et al., 1969; Haigney et al., 2000).

Research has demonstrated that the adverse effects of driving while talking are most likely not related to the motor control issues of manipulating a hand-held phone (Consiglio et al., 2003; Redelmeier and Tibshirani, 1997; Strayer and Johnston, 2001) or driving experience (Redelmeier and Tibshirani, 1997). Rather, it is believed that the effects are a result of competition for limited cognitive resources. In one of the initial studies on this topic, using a radiophone minimally interfered with automated driving tasks, but severely impacted the drivers' decision-making processes (Brown et al., 1969). Consistent with Wickens et al. (1998), it was concluded that the combination of phone usage and decision making in demanding driving situations (controlled processes) creates a potentially hazardous competition for a driver's attention.

The current study investigates the impact of engaging in a cellular phone conversation and/or divided attention task (i.e., signal detection) on various aspects of driving performance. To focus on the cognitively distracting nature of the cell phone, rather than the physical limitations caused by dialing or holding a cell phone while driving, the current study simulates a hands-free cell phone interaction.

2. Methods

2.1. Participants

Thirty-six undergraduate students at the University of West Florida served as participants. The investigator recruited volunteers from psychology classes with the permission of faculty members. Participants were offered extra credit for their participation.

Participants ranged in age from 20 to 53 years with a median of 22.50 years. All participants possessed a valid driver's license. Participants reported having a license for a median of 6 years and driving a median of 724 km (450 miles) in a typical month.

2.2. Instruments and materials

2.2.1. Driving performance

Driving performance was measured using STISIM Drive software by Systems Technology Inc. (STI) from Hawthoren, CA. STISIM Drive is an interactive program that records numerous performance measures. The program allows for investigator control over development of the driving scenario, ensuring that all participants encountered the same events and conditions while driving.

The simulated driving program operated on a standard desktop computer with a Pentium IV processor and Nividia GeForce FX 5200 graphic card. Participants were seated in a stationary chair at a large desk. A 61 cm (24 in.) Samsung LCD monitor was located on top of the desk, and a large black curtain barrier was placed behind the desk to minmize environmental distractions. A Logitech Wingman steering wheel was mounted to the front of the desk, and gas and brake pedals were placed on the floor. The steering wheel had four buttons on the front and two buttons on the back. Two of the front buttons, used for viewing the right and left side of the roadway, were located on the right and left side of the top of the steering wheel face. Two of the buttons, used for responding to the signal task, were located on the right and left side of the face of the steering wheel. Finally, two buttons, used for turn signal indicators, were located on the back of the right and left side of the wheel. A Logitech THX sound system, that included a subwoofer and four speakers, was used in the present study. The sound from the front two speakers was projected directly into a set of headphones and the sound for the back two speakers was projected at a low decibel level to the experimental lab. Participants wore the headphones, which were equipped with a speaking piece, during all of the driving scenarios.

2.3. Distraction conditions

2.3.1. Signal detection

The provision of a secondary signal detection task (included as part of the STISIM Drive software) was intended to increase the demands of the driving task. The divided attention symbol (i.e., right or left red arrows) appeared in the lower right or left side of the computer monitor. The changing arrows replaced a diamond of the same color and size. Ten signals were included in each of the two divided attention signal scenarios. The signals began to change after the participants drove approximately 914 m (3000 ft). After that, the signals appeared at seemingly random intervals distributed throughout the scenario. The participants responded to the changing signals by pressing the buttons on the side of the steering wheel that corresponded with the location of the signal. The driving scenario continued regardless of the participants' responses.

2.3.2. Telephone task

Participants received a telephone call in two conditions of the study and engaged in a conversation with a pre-recorded confederate. Participants were fitted with a headset equipped with a speaking piece. The conversations were programmed into the STISIM Drive scenario as individual wav files and began after participants drove 945 m (3100 ft). These wav files presented various questions and statements and were synchronized with the simulator to be played when participants reached particular locations within the scenarios.

The conversations in the two talking conditions were similar in terms of cognitive demand. Both conversations were primarily visuo-spatial in nature requiring the participants to engage in mental imagery (e.g., "How do I get to the mall from your house?" or "I'm looking for a new home with lots of sunlight, how many windows do you have in your home?"). This type of conversation was used because of its greater likelihood of competing with the cognitive resources used for driving. However, declarative questions were also included to enhance the conversational flow (e.g., “What is your favorite restaurant?”).

2.4. Measures

A short questionnaire was developed to gather basic information on the participants’ demographics, cellular phone usage, driving history, and driving behaviors. Participants’ driving performance was assessed in four categories: violations, driving maintenance, attention lapses, and reaction time.

Types of violations recorded by the simulator included speeding [i.e., speed surpassed posted limit by 8 kph (5 mph)], running stop signs and traffic lights, and lane violations (i.e., crossing centerline or road edge).

Driving maintenance was assessed via the recording of three driving behaviors. These behaviors were speed, speed variability (i.e., standard deviation of speed) and lane maintenance (i.e., standard deviation of lane position). Data were sampled at a rate of every 30.5 m (100 ft) traveled.

Attention lapses were operationally defined, then recorded manually by a research assistant reviewing the simulation replays of each participant. An attention lapse was recorded when one of the following *a priori* criteria were met: (a) driver failed to scan the intersection at a stop sign; (b) driver stopped completely in the absence of a stop sign; (c) driver, who initially stopped at a red light, proceeded into the intersection prior to the light turning green, but did not go far enough for the computer to register it as a traffic light violation; (d) driver stopped at a green light.

Response times were taken for various driving events. These events included the mean length of time participants waited to begin driving after a red traffic light turned green, after being stopped at a stop sign, and the mean time to step on the brake in response to two reaction time events occurring in each scenario. These last reaction time events were surprise occurrences in which a stop sign instantly (and randomly from the driver’s perspective) appeared on the monitor and filled the driver’s field of view.

2.5. Procedures

An initial pilot study was conducted to determine whether adjustments in the protocol were necessary and to ensure that the equipment was working properly. The scenarios were standardized prior to testing. In the experimental series, participants completed the informed consent form and the Demographic and Driving History Questionnaire then performed the driving task while sometimes engaged in a cell phone conversation and/or engaged in a signal detection task. The study was a 2 (signal detection task: on versus off) × 2 (distraction: phone versus none) completely within subjects design. Each of the four testing conditions lasted approximately 15 min. Participants completed a practice scenario that lasted approximately 18 min prior to beginning the experimental scenarios. The driving conditions were counterbalanced across participants to control for carryover effects.

Each of the four experimental driving conditions contained the same events including intersections, buildings, pedestrians, cars, and other obstacles, though in different orders. Within each driving scenario, the traffic lights varied in color as the participant approached and the stop signs varied in terms of being a two- or four-way, but the number of each was constant across scenarios. The speed limit indicated in posted signs, varied from 35 to 45 mph (56.32–72.42 kph) within each scenario. All of the roadways had two 3.66 m (12 ft) lanes in each direction. The traffic scene visible through the simulated windshield (including car hood, roads, traffic, buildings, pedestrians, etc.), dashboard (including speedometer, tachometer, and trip odometer), and signal task was displayed on the LCD monitor.

Participants were instructed to drive as they normally would. Emphasis was given to obeying all traffic laws, following the speed limit, stopping at red lights and stop signs, using the turn signal as an indicator, and avoiding accidents with other cars, objects, and pedestrians. Drivers were notified with a siren wav file if their speed was in excess of 8 kph (5 mph) above the posted limit or if they failed to stop at a stop sign or red light. Instructions were given to stay on the current road, rather than turning at intersections.

When the participant reached 8.69 km (28,500) feet the scenario automatically ended. Participants took brief breaks between each experimental condition while the scenarios loaded onto the computer. At the conclusion of the driving task, participants were afforded the opportunity to ask questions pertaining to the study.

3. Results

3.1. Driving history

Data from the driving history questionnaire revealed that 67% of the current participants reported having been involved in at least one accident, though only 41% stated that they were found to be at fault. As a whole, the current sample of participants reported having received an average of 1.7 traffic tickets each, with speeding tickets accounting for 68% of those violations. When asked about their driving behaviors, more than half of the participants (58%) indicated that they dialed a cell phone while driving in a typical week (4.4 times on average). Nearly 80% reported that they engaged in at least one hand-held cell phone conversation while driving in a typical week with the average number of hand-held cell phone conversations being 8.4 at an average of 7 min per day. Participants reported driving approximately 24.1 km (15 miles) on average per day. Further, engaging in cell phone conversations was the second most often reported distraction to changing the radio station, compact disk or audio tape ($M = 13.7$ times per week).

3.2. Traffic violations

Because of the relatively infrequent occurrence of the individual types of violations in the driving simulator, total traffic violations were summed for analysis. A main effect of cell phone use on commission of traffic violations was observed,

Table 1
Means and standard deviations for total violations

	Without phone	With phone	Total
Without signal task			
M	3.81	5.33	4.57
S.D.	2.84	3.44	3.14
With signal task			
M	2.89	5.03	3.96
S.D.	2.32	3.44	2.88
Total			
M	3.35	5.19	
S.D.	2.58	3.44	

$F(1, 35) = 20.51$, $p < 0.001$. Drivers committed more violations during scenarios in which they engaged in a simulated cell phone conversation than in conditions without that distraction (see Table 1). The signal detection task had little impact on this aspect of driving performance, $F(1, 35) = 2.24$, $p = 0.06$ and the two distracting tasks did not have an interactive effect. However, signal detection performance was poor overall whether drivers were on the cell phone or not. Participants averaged just 4.53 (S.D. = 2.65) correct detections out of 10 during the cell phone driving condition and 4.42 (S.D. = 2.74) when driving was the only other task, $F(1, 35) < 1.0$. Reaction times (in seconds) to the signal detection task for correct detections were similarly poor in both the cell phone condition ($M = 1.33$, S.D. = 0.40) and driving-only condition ($M = 1.24$, S.D. = 0.38), $F(1, 35) = 1.46$, $p > 0.05$.

3.3. Driving maintenance

Driving speed was not significantly impacted by the cell phone task, $F(1, 35) = 2.37$, $p > 0.05$, but participants did drive a bit faster with the signal task than without it, $F(1, 35) = 10.69$, $p < 0.01$ (see Table 2). However, an interaction effect was observed, $F(1, 35) = 24.43$, $p < 0.001$, indicating that the effect of the signal detection task on speed was only evident when the scenario included a phone conversation. That is, for the phone conversation scenarios participants drove at a higher average speed when they were also engaged in the signal detection task. No significant main effects of the tasks on variability of speed were found, but the two tasks had an interactive effect, $F(1, 35) = 13.63$, $p < 0.01$, in that speed varied the most when participants were not engaged in either non-primary task. The two distraction tasks had similar effects in decreasing the variability of drivers' lane maintenance behavior. Participants deviated less from their lane position when they were engaged in either a cell phone conversation, $F(1, 35) = 16.62$, $p < 0.001$, or a signal detection task, $F(1, 35) = 12.77$, $p < 0.01$. No significant interaction was found.

Whereas, the small number of lane violations (crossing centerline or road edge; overall $M = 1.21$, S.D. = 1.54) could not by itself account for the large deviations in lane position, the number of lane changes made could help explain this finding. Therefore, an additional analysis was conducted to examine whether the number of lane changes varied by condition. Engaging in either

Table 2
Means and standard deviations for driving maintenance behaviors

	Without phone	With phone	Total
Speed, kph (mph)			
Without signal task			
M	34.36 (21.35)	33.67 (20.92)	34.02 (21.14)
S.D.	3.32 (2.06)	2.83 (1.76)	3.07 (1.91)
With signal task			
M	34.15 (21.22)	35.49 (22.05)	34.83 (21.64)
S.D.	2.95 (1.83)	2.64 (1.64)	2.80 (1.74)
Total			
M	34.26 (21.29)	34.58 (21.49)	
S.D.	3.14 (1.95)	2.74 (1.70)	
Speed variability, kph (mph)			
Without signal task			
M	22.48 (13.97)	21.95 (13.64)	22.21 (13.80)
S.D.	1.66 (1.03)	1.74 (1.08)	1.71 (1.06)
With signal task			
M	21.81 (13.55)	22.05 (13.70)	21.92 (13.62)
S.D.	1.64 (1.02)	1.59 (.99)	1.63 (1.01)
Total			
M	22.14 (13.76)	22.00 (13.67)	
S.D.	1.66 (1.03)	1.67 (1.04)	
Lane position S.D., m (ft)			
Without signal task			
M	1.61 (5.27)	1.45 (4.77)	1.53 (5.02)
S.D.	0.29 (0.95)	0.34 (1.10)	0.31 (1.03)
With signal task			
M	1.40 (4.59)	1.23 (4.05)	1.32 (4.32)
S.D.	0.40 (1.31)	0.52 (1.69)	0.46 (1.50)
Total			
M	1.50 (4.93)	1.34 (4.41)	
S.D.	0.34 (1.13)	0.43 (1.40)	
Lane changes			
Without signal task			
M	7.25	4.64	5.94
S.D.	3.12	3.32	3.22
With signal task			
M	4.42	3.53	3.97
S.D.	3.60	3.36	3.48
Total			
M	5.83	4.08	
S.D.	3.36	3.34	

the cell phone conversation, $F(1, 35) = 20.72$, $p < 0.001$, or the signal detection task, $F(1, 35) = 25.33$, $p < 0.001$, decreased the number of times drivers changed lanes. The phone and signal detection task had an interactive effect on this driving measure, $F(1, 35) = 4.91$, $p < 0.05$. That is, when participants were not required to engage in the cell phone task, the signal task greatly reduced the number of lane changes. However, when participants were engaged in conversation, the additional impact of the signal detection task was much smaller.

3.4. Attention lapses

Because attention lapses are manifested in the context in which they occur (i.e., may have different outcomes based on the specific situation at the time) the four different types of lapses were treated equally and combined for the purpose of analysis. Both the phone conversation task, $F(1, 35) = 19.28$,

Table 3
Means and standard deviations for attention lapse behaviors

	Without phone	With phone	Total
Without signal task			
M	1.56	2.17	1.87
S.D.	3.70	3.13	3.42
With signal task			
M	1.36	3.64	2.50
S.D.	3.67	4.41	4.04
Total			
M	1.46	2.90	
S.D.	3.69	3.77	

$p < 0.001$, and the signal detection task, $F(1, 35) = 4.22$, $p < 0.05$, significantly increased the number of attention lapses committed (see Table 3). The significant interaction of these two tasks was evident in that the increase in the number of attention lapses committed in the phone conditions (as compared to the non-phone conditions) was greater when participants also had to perform the signal task, $F(1, 35) = 6.97$, $p < 0.05$.

3.5. Reaction times

Drivers waited approximately one-third of a second longer to begin driving after arriving at a stop sign when they were in the phone conversation conditions than when they were not, $F(1, 35) = 4.31$, $p < 0.05$ (see Table 4). The signal detection task did not affect drivers' response times following the stop signs, $F(1, 35) < 1$. No significant interaction was observed. Response times to the changing of red to green traffic lights did not follow the same pattern as that for stop signs. Whereas, main effects demonstrated that delays were longer for participants engaged in phone conversation, $F(1, 35) = 30.62$, $p < 0.001$, the delays were shorter when drivers were engaged in a signal detection task, $F(1, 35) = 5.65$, $p < 0.05$. The significant interaction, $F(1, 35) = 19.60$, $p < 0.001$, reveals that the phone conversation delayed participants' responses more when they were not also engaged in the signal detection task. In response to the pop-up stop signs (i.e., reaction time events), participants hit their brakes an average of 0.03 s sooner when in the phone conversation conditions. Though this difference was relatively small, it was significant, $F(1, 35) = 4.61$, $p < 0.05$. The signal detection task had no significant impact on reaction times to these events, $F(1, 35) < 1$, but did interact with the cell phone, $F(1, 35) = 7.77$, $p < 0.01$. That is, when not involved in the signal task, the phone had little impact on reaction times, but when engaged in the this task reaction times for those on the phone were faster than those not on the phone. However, it should be noted that signals did not appear at the same time as the pop-up stop signs.

4. Discussion

4.1. Driving performance

Results from this study demonstrate some of the potential dangers of engaging in a secondary task (particularly one that is cognitively demanding) while driving. Drivers in the current study showed a significant increase in traffic violations and attention lapses while talking on a phone, despite the investigator's instructions emphasizing careful driving and the fact that the phone used was hands-free as to not interfere with the driver's manual control of the vehicle. This is likely an indication that participants lacked situation awareness, rather than decreased motor control.

Table 4
Means and standard deviations for response time data

	Without phone	With phone	Total
Stop sign delay (s)			
Without signal task			
	6.83	7.41	7.12
	1.72	1.72	1.72
With signal task			
	6.98	7.07	7.03
	1.17	1.73	1.45
Total			
	6.90	7.24	
	1.45	1.73	
Traffic light delay (s)			
Without signal task			
	1.37	1.79	1.58
	0.41	0.43	0.42
With signal task			
	1.41	1.46	1.44
	0.33	0.45	0.39
Total			
	1.39	1.62	
	0.37	0.44	
Reaction time event (s)			
Without signal task			
	0.83	0.84	0.84
	0.11	0.15	0.13
With signal task			
	0.88	0.81	0.85
	0.10	0.07	0.09
Total			
	0.86	0.83	
	0.11	0.11	

The results regarding lane maintenance behaviors were counter to that which was anticipated, but in retrospect, consistent with Seppelt and Wickens (2003) findings. That is, participants likely protected their lane keeping by shedding peripheral tasks in order to maintain a straighter course in the presence of the distracter tasks. For instance, drivers not engaged in either secondary task changed lanes the most frequently. When participants were in the other conditions, simplifying their driving behaviors (e.g., fewer lane changes and less deviations in speed) may have allowed them to focus more on their phone conversations.

Performance on the divided attention (signal detection) task was inconsistent with what was anticipated. The poor performance on the relatively easy signal detection task and the fact that few of the driving measures were adversely affected by that task may indicate that participants often ignored that task in favor of the cell phone or driving tasks. In fact, the number of signals detected was nearly the same whether participants were on the phone or not. Unlike the introduction of static, but highly salient, objects like stop signs (which were often missed), the signals changed physically. Identifying potential hazards by noticing changing objects is considered to be a primary and immediate task of driving (Wickens et al., 1998). The inability to spot stimulus changes (e.g., a child running into the street) in an actual highway setting could have serious negative consequences for safety.

Overall results from the current study suggest that when drivers were overloaded with a cognitively demanding conversation they tended to overlook some peripheral driving tasks. Disregarding the "extra" tasks enabled the drivers to devote more attentional resources to the successful completion of the two presumed primary tasks of driving and talking on the phone. The tendency to shed tasks became apparent in the current study from the participants' increased traffic violations, attention lapses, and decreased lane position standard deviation. The task shedding and driving behaviors provide further support for the notion that participants engrossed in cell phone conversations lacked situation awareness. That is, participants appeared to be either completely unaware of, or failed to process, vital information in their driving environment. Some traffic violations (in particular, stop sign infractions) increased by as much as three-fold when drivers were talking on the phone. All of the participants answered the conversational questions in the two talking scenarios; therefore, it can be argued that the attentional resources were reallocated to engaging in the conversation while driving.

One theoretical explanation for the impact of cell phones on driving performance comes from the concept of cross-modal interference in the time sharing of cognitive resources. According to Wickens and Hollands (2000), cross-modal time-sharing (e.g., visual and auditory input) can be accomplished more effectively than intra-modal time-sharing (e.g., visual and visual input). Whereas, the sensory inputs used to drive (primarily visual) and converse (typically auditory) may often be used concurrently without interference, conversations that tap into visual resources (such as many of the questions asked in the current study) may produce a great deal of interference. The competing visual-spatial demands of the driving task and conversation (e.g., describing physical aspects of your home, or providing map directions) resulted in the likely reduction of attention given to processing visual cues in the periphery. It appears from this and other studies on the topic of driving while talking that cross-modal interference occurs when cognitive demands are high (e.g., busy intersections, or responding to complicated questions).

Results from the current study revealed a larger picture of the behavioral tendencies of those participating in a phone conversation while driving. In previous research where fewer variables were examined, singular behavioral patterns emerged (e.g., increased lane deviations and decreased driving speed) when talking on the phone while driving. In the current study, where multiple variables were examined together, a tendency to shed peripheral tasks (e.g., lane maintenance and scanning of intersections) and attend to primary tasks emerged. Though some results were contradictory to previous findings, the study revealed a larger behavioral picture of the effects of dual-task or distracted driving.

4.2. Conclusion

The adverse effects of talking while driving were clear in the present study. Participants coped with the demands of engaging in a phone conversation while driving by narrowing their attention, shedding peripheral tasks (e.g., signal detection task), and focusing on more immediate tasks. In the talking conditions, participants committed more traffic violations, committed more attention lapses, changed lanes less frequently, but reacted more quickly to events occurring directly in the line of sight. The current results add to the growing literature on the effects of distracted driving, though more research on the effects of varying the driving conditions is needed. For instance, future studies should explore the effects that varying time-on-task, driving environment and stimulation level, and conversation types have on dual-task driving performance. Whereas, the current study helps to identify the potential dangers of cell phones (or other distracters) in vehicles, additional research is warranted to establish the generalizability of the results. The current data add support for the recent attempts by some states to limit or ban the use of cell phones in vehicles. However, the findings also suggest that a ban on cell phone use should include hands-free phones; not just hand-held phones.

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