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A comparison of the effect of mobile phone use and alcohol consumption on driving simulation performance

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Abstract

Objective: The present study compared the effects of a variety of mobile phone usage conditions to different levels of alcohol intoxication on simulated driving performance and psychomotor vigilance. Methods: Twelve healthy volunteers participated in a crossover design in which each participant completed a simulated driving task on 2 days, separated by a 1-week washout period. On the mobile phone day, participants performed the simulated driving task under each of 4 conditions: no phone usage, a hands-free naturalistic conversation, a hands-free cognitively demanding conversation, and texting. On the alcohol day, participants performed the simulated driving task at four different blood alcohol concentration (BAC) levels: 0.00, 0.04, 0.07, and 0.10. Driving performance was assessed by variables including time within target speed range, time spent speeding, braking reaction time, speed deviation, and lateral lane position deviation. Results: In the BAC 0.07 and 0.10 alcohol conditions, participants spent less time in the target speed range and more time speeding and took longer to brake in the BAC 0.04, 0.07, and 0.10 than in the BAC 0.00 condition. In the mobile phone condition, participants took longer to brake in the natural hands-free conversation, cognitively demanding hands-free conversation and texting conditions and spent less time in the target speed range and more time speeding in the cognitively demanding, hands-free conversation, and texting conditions. When comparing the 2 conditions, the naturalistic conversation was comparable to the legally permissible BAC level (0.04), and the cognitively demanding and texting conversations were similar to the BAC 0.07 to 0.10 results. Conclusion: The findings of the current laboratory study suggest that very simple conversations on a mobile phone may not represent a significant driving risk (compared to legally permissible BAC levels), whereas cognitively demanding, hands-free conversation, and particularly texting represent significant risks to driving

Keywords

mobile, phone, alcohol, comparison, consumption, effect, driving, simulation, performance

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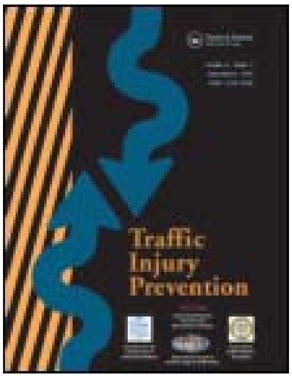

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A Comparison of the Effect of Mobile Phone Use and Alcohol Consumption on Driving Simulation Performance

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Objective: *The present study compared the effects of a variety of mobile phone usage conditions to different levels of alcohol intoxication on simulated driving performance and psychomotor vigilance.*

Methods: *Twelve healthy volunteers participated in a crossover design in which each participant completed a simulated driving task on 2 days, separated by a 1-week washout period. On the mobile phone day, participants performed the simulated driving task under each of 4 conditions: no phone usage, a hands-free naturalistic conversation, a hands-free cognitively demanding conversation, and texting. On the alcohol day, participants performed the simulated driving task at four different blood alcohol concentration (BAC) levels: 0.00, 0.04, 0.07, and 0.10. Driving performance was assessed by variables including time within target speed range, time spent speeding, braking reaction time, speed deviation, and lateral lane position deviation.*

Results: *In the BAC 0.07 and 0.10 alcohol conditions, participants spent less time in the target speed range and more time speeding and took longer to brake in the BAC 0.04, 0.07, and 0.10 than in the BAC 0.00 condition. In the mobile phone condition, participants took longer to brake in the natural hands-free conversation, cognitively demanding hands-free conversation and texting conditions and spent less time in the target speed range and more time speeding in the cognitively demanding, hands-free conversation, and texting conditions. When comparing the 2 conditions, the naturalistic conversation was comparable to the legally permissible BAC level (0.04), and the cognitively demanding and texting conversations were similar to the BAC 0.07 to 0.10 results.*

Conclusion: *The findings of the current laboratory study suggest that very simple conversations on a mobile phone may not represent a significant driving risk (compared to legally permissible BAC levels), whereas cognitively demanding, hands-free conversation, and particularly texting represent significant risks to driving.*

Keywords Simulated driving performance; Alcohol; Mobile phone; Cognition; Distractability

INTRODUCTION

Many people use mobile phones to send text messages, to have a casual conversation, or even to have a work-related conference while they are driving (Brusque and Alauzet 2008). Such multitasking activities typically divert attention away from the primary task of driving, and it has been shown that some types of mobile telephony while driving affect driving-related performance. Some observational research suggests that using a mobile phone while driving increases the risk of a crash, with odds ratios ranging from 1.4 to 9 (Laberge-Nadau et al. 2003; Redelmeier and Tibshirani 1997; Violanti 1998). McCartt et al. (2006) suggested that although this type of epidemiological research is the best means to examine crash risk, experimental research is better suited to clarify the issues of severity and causation (Volanti 1998), even though both types of research (epidemiological and experimental) suggest that distracted driving increases accident risk.

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Experimental studies using driving simulators, closed-track driving courses, and driving on public roads while using a mobile phone have also reported a variety of driving impairments. While drivers are texting, their braking reaction times are slower (Drews et al. 2009; Kircher et al. 2004), their lane position varies more (Drews et al. 2009; Hosking et al. 2009), the time drivers spend not looking at the road is higher, they miss more lane changes, and the following distances to lead vehicles varies more than baseline (Hosking et al. 2009). Having a conversation on a handheld mobile phone while driving reduces driving speed (de Waard et al. 2001; Tornros and Bolling 2005), impairs peripheral detection (Tornros and Bolling 2005), reduces the adaptation to speed of the car in front (Ranney et al. 2004), increases braking reaction time (Consiglio et al. 2003; Strayer and Johnston 2001; Woo and Lin 2001), and increases reaction time to signal change, obstacle falling, pedestrian intrusion, and cut-in vehicles (Woo and Lin 2001). Consistent with this, according to a recent meta-analysis, during mobile phone use there is significant impact on drivers' reaction to external events (Horrey and Wickens 2006).

The type of conversation has also been examined, with some evidence showing that emotional conversations lead to greater driving impairments (Dula et al. 2011). The effects of hands-free naturalistic conversations and cognitively demanding conversations have also been shown to impair driving performance (e.g., Alm and Nilsson 1994, 1995; Amado and Ulupinar 2005; Beede and Kass 2006; Brookhuis et al. 1991; Collet et al. 2009; Consiglio et al. 2003; Horberry et al. 2006; Irwin et al. 2000; Laberge et al. 2004; Lamble et al. 1999; Patten et al. 2004; Rakauskas et al. 2004; Shinar et al. 2005; Strayer and Johnston 2001; also see review by Collet at al. 2010), with some evidence that cognitively demanding conversations (e.g., involving mathematical tasks) cause greater impairment (Shinar et al. 2005). However, it should be noted that some of these mobile phone—related effects do not necessarily represent driving impairments. For example, included in the above effects are reduced speed (e.g., Alm and Nilsson 1994; Liu and Lee 2005, 2006), increased following distance (Strayer and Drews 2004; Strayer et al. 2003), and greater time to recover to normal speed (Strayer and Drews 2004), which may actually reduce crash risk. In fact, it has been suggested that these changes to driving behavior may represent drivers' compensatory mechanisms, because the driver may have appreciated the increased attention load associated with using the mobile phone (Cooper et al. 2003; Hancock et al. 2003; Liu and Lee 2005; Tornros and Bolling 2005). Therefore, it is difficult to determine from these studies whether such mobile phone conversation–related effects would relate to increased crash risk. Of those behaviors that have greater face validity (as driving risks) the only consistent finding is prolonged braking reaction time. This would suggest that, though taking longer to brake does reduce driving ability, the question remains as to whether this reduced ability represents a trivial or important driving risk and whether the abovementioned precautionary measures compensate to a degree that negates any increased risk of an accident.

To help quantify the impact of mobile phone–related driving effects, 3 studies have thus used the effect of alcohol (0.08% blood alcohol concentration [BAC], the legal limit for driving in the United States) on driving-related skills as a benchmark (Burns et al. 2002; Rakauskas et al. 2008; Strayer et al. 2006), because the impairments on driving skills due to alcohol, even from low doses, are well documented and widely accepted (e.g., Iudice et al. 2005; Leung and Starmer 2005; Liguori et al. 1999; Moskowitz et al. 2000; Rimm et al. 1982). The rationale is that if similar driving-related impairments are seen in alcohol and mobile phone use conditions, then we would have good reason to view such mobile phone use as a risk for driving (Dawson and Reid 1997).

Burns et al. (2002) reported that drivers under the influence of alcohol had slower reaction times to road signs and had more trouble keeping within designated traffic lanes than baseline, with the former but not the latter also observed while using a handheld or hands-free mobile phone. In contrast to alcohol-related effects, drivers using handheld phones exhibited other behaviors (driving slower on curves and dual-carriageway sections; more variable speed), which suggests that alcohol and phone use while driving may not be commensurate driving risks. Supporting this, Rakauskas et al. (2008) reported that in comparison to the group of intoxicated participants (BAC 0.08) who did not get distracted, the group of sober participants drove with less lane position variability when conversing on hands-free mobile phone but with more lane position and steering variability while performing an in-vehicle visual task. Strayer et al. (2006) reported that there were more accidents when drivers were using handheld or hands-free mobile phones than baseline or under the influence of alcohol (BAC 0.08) and argued that this suggests that using a mobile phone while driving causes similar or greater impairment than driving while under the influence of alcohol. However, the 3 above-mentioned studies only compared the mobile phone effect with one BAC level, which did not allow the examination of dose–response relationships. It is thus important to determine whether the impact of different types of mobile phone use is as severe as a range of BAC levels.

The current study thus aimed to determine whether different methods of talking on a mobile phone (naturalistic hands-free conversation, cognitively demanding hands-free conversation, texting conversation) increases accident risk, by comparing any such effects to that of a well-characterized accident risk, driving while under the influence of alcohol at a range of BAC levels (0.00, 0.04, 0.07, and 0.10). To this end, performance on driving simulation and cognitive tasks that have been shown to be sensitive to alcohol intoxication were assessed.

METHODS AND MATERIALS

Participants

Twelve healthy university students (10 female) aged 23.5 to 30.8 (mean 26.20, standard deviation [SD] 2.58) participated in the study. They were recruited via advertisements on university notice boards and by word of mouth. Participants held a current full Australian driving license (not a probationary license). Participants were excluded if they had not drunk alcohol before or if they were excessive drinkers (more than 4 standard drinks a day on average or more than 6 standard drinks on any one occasion for men; more than 2 standard drinks a day on average or more than 4 standard drinks on any one occasion for women; National Health and Medical Research Council [NHMRC] 2001). Participants were also excluded if they reported taking psychotropic medication, used illicit drugs more than 5 times a week, or smoked more than 10 cigarettes a day. They also underwent a medical examination by a registered physician to satisfy inclusion/exclusion criteria for the study. The study was approved by the Human Research Ethics Committee, Swinburne University of Technology, and written informed consent was obtained from all participants. Participants received financial reimbursement of AUD 120 for their time.

Procedure

Participants came to the laboratory on 3 separate days. On day 1 participants had a medical examination by a registered physician to check for contraindications to the study, had their weight and height recorded, and practiced the driving simulation task for 20 min and a psychomotor vigilance task (PVT) for 1 min. They also completed questionnaires concerning the type of conversation that they found interesting and boring (interesting topics were subsequently used as the basis for the naturalistic hands-free and texting conversations). Participants were requested to abstain from caffeine and alcohol for 24 h prior to each of days 2 and 3 and to have a light breakfast before each of days 2 and 3. Day 2 was between 7 and 14 days after day 1 and involved either the alcohol or mobile phone session. Day 3 involved whichever session did not occur on day 2 (with the order of the 2 sessions counterbalanced and randomized across participants). Day 3 was between 7 and 14 days after day 2. Days 2 and 3 commenced between 9:00 and 9:30 a.m.

Alcohol session. Participants first practiced the driving simulation task for 5 min, followed by the task battery at BAC = 0.00 (a 20-min driving simulation task and a 10-min PVT). To manipulate alcohol intoxication, participants then consumed measured amounts of alcohol, designed to reach a BAC level of approximately 0.04. The amount of alcohol was calculated based on participants' total body water (TBW; Watson et al. 1981), using the formulae below:

$$\text{Female : TBW} = -2.097 + 0.1069 \quad \text{Height (cm)} + 0.2466 \quad \text{Weight (kg)}$$

$$\text{Male : TBW} = 2.477 - 0.09546 \quad \text{Age (years)} + 0.1074 \quad \text{Height (cm)} + 0.3362 \quad \text{Weight (kg)}$$

$$\text{Alcohol Dose (g)} = \frac{\text{TBW}}{\text{Target BAC (g/L)} \times 0.8}$$

Fifteen minutes after participants finished consuming the alcohol, oral water rinses were used to rinse out alcohol content in the mouth. Participants' BAC levels were then tested (using a calibrated breathalyzer; Lion Alcometer SD 400 (Lion Laboratories, Glamorgan, UK), which has an accuracy of $\pm 10\%$), and once their BAC levels were within the range of 0.03 to 0.05, they performed the task battery again (BAC = 0.04 condition), followed by another BAC test. The intoxication procedure was repeated for each of the BAC 0.07 (range 0.06 to 0.08) and 0.10 (range 0.09 to 0.11) levels. Participants were then debriefed, asked to remain at the laboratory until their BAC levels dropped below 0.05, and taxi vouchers were provided for the participant to go home.

Mobile phone session. Participants first practiced the driving simulation task for 5 min. They then performed the task battery under each of 4 conditions (no phone usage [NP]; natural hands-free conversation [NC-P]; cognitively demanding hands-free conversation [CC-P]; and texting [TC-P]), as follows. Firstly, participants performed the tasks without any mobile phone usage. They were then given the experimental mobile phone and asked to familiarize themselves with it. Subsequently, they performed the tasks 3 more times, in a randomized order:

1. While having a natural conversation with a researcher using a hands-free mobile phone on topics that the participant reported being interested in.
2. While answering cognitively demanding questions (verbal and spatial—visual questions, such as "Can you describe the driving route from your work to home?" and "How many of your friends have names beginning with a vowel?") asked by the researcher, using the same hands-free mobile phone.
3. While exchanging SMS messages (naturalistic) with the researcher, using the same mobile phone (this had a T9 predictive texting interface, which was the most popular interface used by university students at the time of testing).

Tasks

Driving simulation task. Driving performance was assessed on a divided-attention driving task, the AusEd driving simulator. The AusEd driving simulation task is a PC-based representative task, designed to assess reaction time to road changes, lane tracking, and divided attention and to test for driver fatigue and sleepiness. The driving simulator is installed on a Windows NT workstation with steering wheel and pedals and dual stereo computer speakers (Desai et al. 2007).

During the 20-min task, participants viewed a full-screen projection of the view from the driver's seat of a car, and the driving scene displayed a dual-carriage rural road at night with common lane divisions and road edges marked with reflective posts. A small speedometer was displayed in the top left-hand corner of the screen, out of the line-of-sight of the road. The drive involved a series of straight and curved roads and required the use of a steering wheel and brake and accelerator pedals. Participants were instructed to maintain their position in the middle of the left-hand lane on the road (in accordance with

Australian driving code) and to keep their speed between 60 and 80 kph. During the drive, 11 slowly moving trucks appeared intermittently in a random fashion, driving in the same direction as the subject. Participants were instructed to brake as quickly as possible when they saw a truck appear in front of them (the truck appears dangerously close to the driver's car). They were also instructed to drive continuously and resume driving as quickly as possible after any crash. Continuous, low-frequency (approximately 60 dB) simulated engine sounds were played through the computer speakers for the duration of the drive, and the room lights were switched off to simulate a monotonous nighttime drive. Participants undertook a 5-min practice drive prior to testing to refamiliarize themselves with the road layout and driving instrumentation (steering wheel and pedals). This 5-min practice task had the same proportion of straight and curved roads as the 20-min task and required participants to brake for 3 trucks that appeared randomly.

The AusEd driving simulator measures several cognitive skills important for driving, including tracking ability, vigilance, divided attention, and reaction time (RT):

1. Velocity deviation: Deviation from the defined safe speed zone of 60 to 80 kph. Higher scores represent larger deviation from the prescribed speed and decreased vigilance.
2. Lateral lane position deviation: Deviation from the median lane position during the drive (averaged every 40 ms). Higher scores indicate larger deviations from the mean lane position and decreased vigilance.
3. Mean RT for braking episodes: Computer-scored and manually checked RTs.
4. Number of crashes: Crashes were registered where the following occurred: off-road events, collisions with a truck, or remaining stationary for more than 10 s.
5. Time spent speeding (over 80 km/h): This was computed to help clarify the relevance of any changes seen in velocity deviation.

Psychomotor vigilance task. The reasons for using the PVT as an additional task include the following: (1) PVT is highly correlated with driving performance, specifically lane deviation (Jackson et al. 2012); (2) it requires sustained attention, which is a large component of driving, and it is paced, nonstimulating, measurable, repetitive; free of aptitude and learning effects; and sensitive to sleepiness (Ardmore et al. 2000; Dinges and Powell 1985; Doran et al. 2001) and alcohol (Howard et al. 2007). Thus, PVT can provide an indication of driving-related performance in the absence of potential learning effects that may be found on the driving simulator, and it is a useful control task that is well validated and sensitive to the effects of alcohol and allows for a less contaminated assessment of driving-related skills.

The PVT is a 10-min computerized task that assesses sustained attention and reaction time and requires continuous attention to detect randomly occurring stimuli (Dinges and Powell 1985; Jewett et al. 1999). The PVT is run on a small handheld palm device, which is about the same size as a smart phone, with 2 response buttons (right and left) below a display window. Participants were required to observe the display screen and press the right (if left-handed) or left (if right-handed) button as quickly as possible in response to the appearance of a circular target. The interstimulus interval on the task varied randomly between 2 and 10 s. The following outcome measures were used in the current study:

1. Median RT: RT is the elapsed time between presentation of a stimulus and the subsequent button press, and the median value across the 10-min task was calculated.
2. Lapses: Number of RTs greater than 500 ms or errors of omission.

Statistical Analysis

Due to the presence of a number of outliers and skewed variables (which was not remedied through transformation), the variables were analyzed with nonparametric tests.

Alcohol effects. To determine whether different BAC levels affected participants' performance, for each of time within target speed, time spent speeding, braking reaction time, speed deviation, lateral lane position deviation, PVT RT, and PVT lapses, 3 separate Wilcoxon tests were conducted: (1) BAC 0.04 versus BAC 0.00, (2) BAC 0.07 versus BAC 0.00, and (3) BAC 0.10 versus BAC 0.00.

Mobile phone effects. For any of the above measures that were affected by alcohol, 3 separate Wilcoxon tests were conducted: (1) NC-P versus NP, (2) CC-P versus NP, and (3) TC-P versus NP. To explore the rest of the measures (i.e., those unaffected by alcohol), 3 separate Wilcoxon tests were conducted for each measure: (1) NC-P versus NP, (2) CC-P versus NP, and (3) TC-P versus NP.

Comparison between alcohol and mobile phone effects. For any of the above measures that were affected by both alcohol and mobile phone use, a third set of analyses was employed to compare the different mobile phone conditions to the different BAC conditions. For each such variable, we created 6 difference scores by subtracting the result of (1) BAC 0.04 from BAC 0.00 ($Effect_{0.04}$); (2) BAC 0.07 from BAC 0.00 ($Effect_{0.07}$); (3) BAC 0.10 from BAC 0.00 ($Effect_{0.10}$); (4) NC-P from N-P ($Effect_{NC\text{-}P}$); (5) CC-P from NP ($Effect_{CC\text{-}P}$); and (6) TC-P from NP($Effect_{TC\text{-}P}$). Then for each of $Effect_{0.04}$, $Effect_{0.07}$, $Effect_{0.10}$, this was compared to each of $Effect_{NC\text{-}P}$, $Effect_{CC\text{-}P}$, and $Effect_{TC\text{-}P}$ Wilcoxon signed-rank tests.

The critical *P*-value for all analyses, with Bonferroni adjustment, was .017.

RESULTS

Results of the statistical analyses for mobile phone effects and alcohol effects are shown in Figure 1 and summarized in Tables I and II.

Alcohol Effects

See Table I for full statistics on the effects of alcohol.

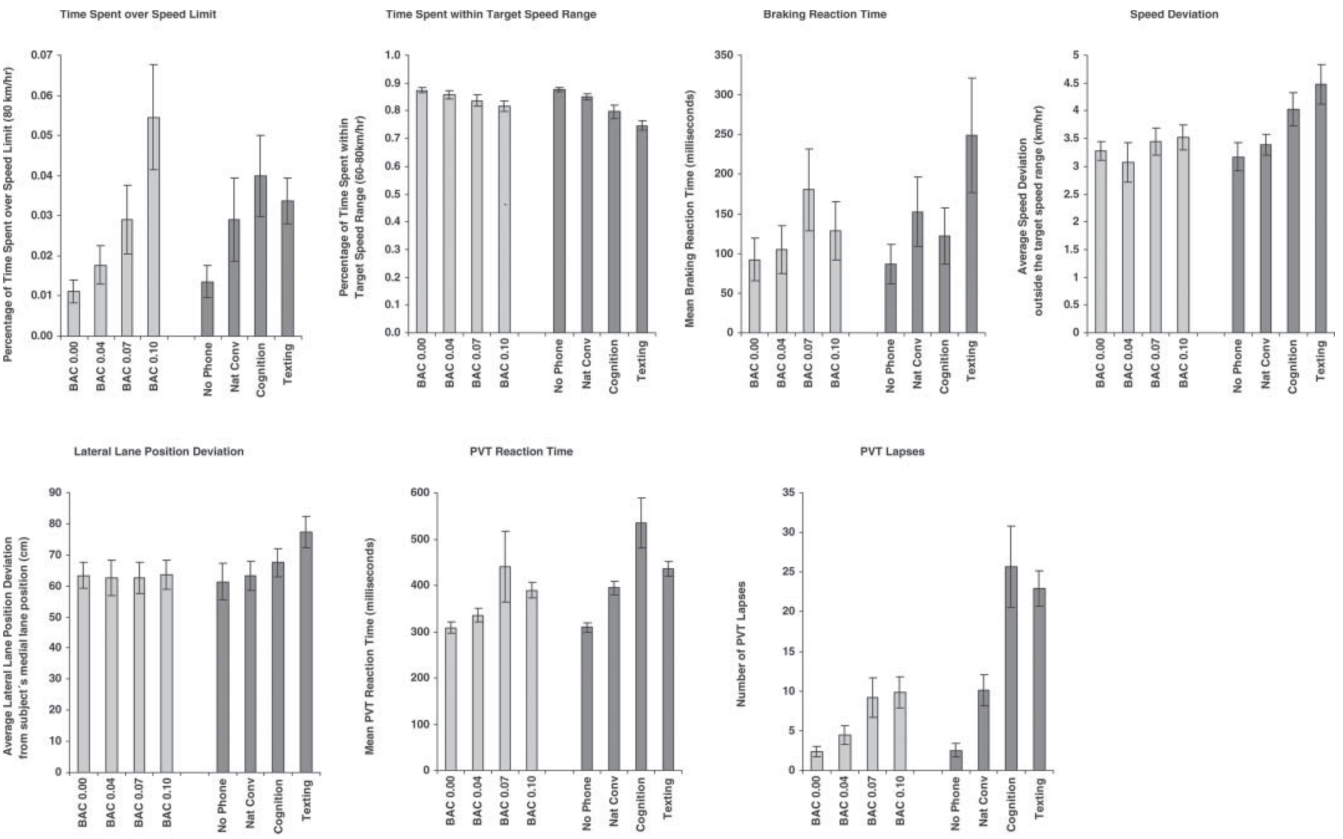

Figure 1 Mean and standard error (as represented by standard error bars) for alcohol and mobile phone effects on driving and PVT variables.

- Driving simulator. Compared to BAC 0.00, participants spent less time in the target speed range, and more time speeding, in the BAC 0.07 and 0.10 conditions, whereas no difference was found in the BAC 0.04 condition. Participants took longer to brake in the BAC 0.04, 0.07, and 0.10 conditions compared to BAC 0.00. Neither lateral lane position deviation nor speed deviation differed between BAC 0.00 and either the BAC 0.04, 0.07, or 0.10 conditions.
- Psychomotor vigilance. Compared to BAC 0.00, participants had slower reaction times and more lapses on the PVT in the BAC 0.07 and 0.10 conditions, whereas no difference was found in the BAC 0.04 condition.

Table I Full statistics for alcohol effects and mobile phone effects (the shaded cells for variables unaffected by alcohol)

	BAC 0.04 vs. baseline		BAC 0.07 vs. baseline		BAC 0.10 vs. baseline		Naturalistic vs. baseline		Cognitive demand vs. baseline		Texting vs. baseline	
	Z-score	*P*-value	*Z*-score	*P*-value	*Z*-score	*P*-value	*Z*-score	*P*-value	*Z*-score	*P*-value	*Z*-score	*P*-value
						Driving						
Time within target speed	1.96	.050	2.67	.008[a]	2.82	.005[a]	2.20	.028	3.06	.002[a]	2.98	.003[a]
Time spent speeding	1.96	.050	2.43	.015[a]	3.06	.002[a]	0.63	.530	2.67	.008[a]	2.67	.008[a]
Speed deviation	0.24	.814	1.18	.239	1.33	.182	1.41	.158	2.75	.006[a]	2.98	.003[a]
Braking reaction time	2.98	.003[a]	2.90	.004[a]	3.06	.002[a]	3.06	.005[a]	2.43	.015[a]	2.98	.003[a]
Lateral lane position	0.00	1.000	0.63	.530	0.00	1.000	1.02	.308	1.80	.071	2.67	.008[a]
						PVT						
Reaction time	2.35	.019	3.06	.002[a]	3.06	.002[a]	3.06	.002[a]	3.06	.002[a]	3.06	.002[a]
Lapses	2.32	.021	2.67	.008[a]	2.94	.003[a]	2.84	.004[a]	3.06	.002[a]	3.06	.002[a]

[a]Test reached significance level (less than the critical *P*-value of .017).

Table II The full statistics for comparison between alcohol and mobile phone effects

	Naturalistic vs. BAC 0.04		Naturalistic vs. BAC 0.07		Naturalistic vs. BAC 0.10		Cognitive demand vs. BAC 0.04		Cognitive demand vs. BAC 0.07		Cognitive demand vs. BAC 0.10		Texting vs. BAC 0.04		Texting vs. BAC 0.07		Texting vs. BAC 0.10	
	Z-score	*P*-value	*Z*-score	*P*-value	*Z*-score	*P*-value	*Z*-score	*P*-value	*Z*-score	*P*-value	*Z*-score	*P*-value	*Z*-score	*P*-value	*Z*-score	*P*-value	*Z*-score	*P*-value
Driving																		
Time within target speed	0.47	.638	0.71	.480	1.80	.071	2.59	.010[a]	1.88	.060	0.94	.347	2.90	.004[a]	2.74	.006[a]	2.35	.019
Time spent speeding	0.16	.875	0.39	.695	1.80	.071	1.88	.060	0.78	.433	0.78	.433	1.73	.084	0.47	.638	2.12	.034
Braking reaction time	0.47	.638	1.41	.158	2.28	.023	0.24	.814	0.55	.583	1.41	.158	2.51	.012[a]	2.28	.023	2.12	.034
PVT																		
Reaction time	3.06	.002[a]	1.18	.239	0.86	.388	3.06	.002[a]	1.73	.084	2.51	.012[a]	2.98	.003[a]	1.33	.182	1.88	.060
Lapses	2.55	.011[a]	0.87	.367	0.18	.859	3.06	.002[a]	2.59	.010[a]	2.35	.019	3.06	.002[a]	2.51	.012[a]	2.63	.009[a]

[a]Test reached significance level (less than the critical *P*-value of .017).

Mobile Phone Effects

See Table I for full statistics on the effects of mobile phones.

For variables affected by alcohol:

- Driving simulator. Compared to NP, participants took longer to brake in the NC-P, CC-P, and TC-P conditions and spent less time in the target speed range and more time speeding in the CC-P and TC-P conditions (whereas no difference was found for the NC-P condition).
- Psychomotor vigilance. Compared to NP, participants had slower reaction times and more lapses in the NC-P, CC-P, and TC-P conditions.

For variables unaffected by alcohol:

- Driving simulator. Compared to NP, participants drove with more varied speed in the CC-P and TC-P (but not NC-P) conditions, and their lane position deviated more in the TC-P (but not NC-P or CC-P) condition.

Comparison Between Alcohol and Mobile Phone Effects

See Table II for full statistics on the comparison between the effects of alcohol and mobile phones.

- Driving simulator. (1) Time within target speed—The $Effect_{CC\text{-}P}$ was larger than $Effect_{0.04}$ (but not $Effect_{0.07}$ or $Effect_{0.10}$), and the $Effect_{TC\text{-}P}$ was larger than the $Effect_{0.04}$ and $Effect_{0.07}$ (but not $Effect_{0.10}$). (2) Time spent speeding—No significant difference was detected between any of the mobile phone condition effects and any of the alcohol effects. (3) Braking reaction time—The $Effect_{TC\text{-}P}$ was larger than the $Effect_{0.04}$ (but not the $Effect_{0.07}$ or $Effect_{0.10}$).
- Psychomotor vigilance. (1) PVT reaction time—The $Effect_{NC\text{-}P}$ and $Effect_{TC\text{-}P}$ were both larger than the $Effect_{0.04}$ (but not the $Effect_{0.07\ or}$ $Effect_{0.10}$). The $Effect_{CC\text{-}P}$ was larger than the $Effect_{0.04}$ and $Effect_{0.10}$ (but not the $Effect_{0.07}$). (2) PVT lapses—The $Effect_{NC\text{-}P}$ was larger than the $Effect_{0.04}$ (but not the $Effect_{0.07}$ or $Effect_{0.10}$), the $Effect_{CC\text{-}P}$ was larger than the $Effect_{0.04}$ and $Effect_{0.07}$ (but not the $Effect_{0.10}$), and the $Effect_{TC\text{-}P}$ was larger than all BAC effects.

DISCUSSION

The current study has demonstrated that cognitively demanding conversation and texting had more detrimental effects on driving and psychomotor performance than a naturalistic conversation, with effects similar to or worse than the effects of alcohol at a BAC of 0.07 to 0.10 on most test outcomes. Specifically, our study has successfully achieved dose-dependent alcohol-related impairments on both the driving simulator task (more time outside and more time over the target speed range; longer time to brake) and the psychomotor vigilance task (slower reaction times and more lapses) and thus provides an opportunity to compare these alcohol effects to those of mobile phone use. The effects of the phone conditions on these identified dose-dependent variables were similar to those of alcohol, with time spent speeding the only measure not affected for the naturalistic conversation. Further, there was no evidence that the speed reduction due to mobile phone use reported previously (e.g., Burns et al. 2002) was replicated in any of the mobile phone conditions.

It is important to compare the magnitude of impairment found in the mobile phone conditions to the different BAC levels, in order to provide a comparison with impairment magnitudes that society treats as legally permissible or impermissible. For example, BAC 0.04 is treated as legally permissible in most countries (e.g., Australia), BAC 0.07 is legally permissible in some (e.g., the UK, the United States) but illegal in other countries (e.g., Australia), and BAC 0.10 is treated as legally impermissible in most countries (e.g., Australia, the UK and the United States). Using these levels as comparisons we may conclude the following:

Texting was clearly the worst driving condition, with performance on time outside the target speed range, braking reaction time (trend level), and PVT lapses worse than the BAC 0.07 condition (and speeding worse than BAC 0.00 and not differing from the BAC 0.04 and 0.07 conditions). The effect of texting on time outside the target speed range (trend level) and PVT lapses were also worse than the BAC 0.10 condition. Such a dramatic impairment may be predicted due not only to the cognitive resources that must be allocated to the task but also because one hand and a portion of visual scanning are occupied by the texting task. The results thus support Kircher et al. (2004) and Hosking et al. (2009) in demonstrating performance decrement but go further to suggest that the decrement is worse than even a BAC level of 0.07. This supports current legislation in Australia, Japan, and the United States that bans the use of texting while driving.

The effect of the cognitively demanding conversation was not as severe as texting but worse than the naturalistic conversation condition: it was worse than BAC 0.04 (and did not differ significantly from either BAC 0.07 or 0.10) for time in target speed range; worse than no phone for time spent speeding and braking reaction time (and did not differ significantly from BAC 0.04, 0.07, or 0.10); worse for PVT reaction time than BAC 0.04 and 0.10 (and did not differ significantly from BAC 0.07); and worse than BAC 0.04 and 0.07 for PVT lapses. However, it is important to note that the particular variables with more direct relevance to accidents (speeding and break reaction time) did not differ significantly from what is viewed in some countries as a legally permissible level (BAC 0.07). That is, although the more basic cognitive functions (as indexed by the PVT) were performed more poorly than the highest BAC levels, the effect of this on dangerous driving was not as severe. These results would thus suggest that a mobile phone conversation with a high cognitive load would impair aspects of driving performance more so than legal alcohol levels in some but not other countries.

The naturalistic conversation, although producing greater impairment than the no phone condition, was less important to driving performance than the texting and cognitively demanding tasks. It resulted in less time outside the target range, less time speeding, and faster braking reaction time than the BAC 0.10 condition (but these variables did not differ significantly from the BAC 0.04 or 0.07 conditions). It was worse than BAC 0.04 in terms of PVT lapses and reaction time, which did not differ from BAC 0.07 or 0.10. Thus, although performance decrements on the PVT were worse than the lowest BAC condition, there was no clear evidence that this affected the driving performance more than even the lowest BAC level. However, given the small sample size ($N = 12$) and the lack of statistical difference between the naturalistic conversation and BAC 0.07 conditions, there remains the possibility that even the naturalistic conversation may be as significant to driving as BAC levels considered legally impermissible in some countries (e.g., Australia) and the upper legal levels in other countries (e.g., the United States). Further research is required to clarify this issue.

The differential results from the naturalistic and cognitively demanding tasks indicate the importance of cognitive load on mobile phone driving performance. This is in contrast to a recent meta-analysis that failed to detect a difference between the effect from cognitive tasks and naturalistic conversation on reaction time performance (Caird et al. 2008). Rather, our results support the findings of Shinar et al. (2005) and Patten et al. (2004); the former found that both a difficult task (mathematics operation) and an emotionally involved task resulted in greater driving impairment than baseline and the latter found that driver distraction was related to the difficulty and complexity of the conversation. Related to this, Burns et al. (2002) reported slower reaction times to road signs when drivers were engaged in a hands-free conversation (which combined separate conditions of high and low cognitive demand) than a BAC 0.08 condition. The present data suggest that Burns et al.'s (2002) finding may be more influenced by the cognitively demanding task and thus it cannot be taken as evidence that a naturalistic conversation is equivalent to BAC 0.08. However, because it would be difficult to legislate against hands-free mobile phone use based on the difficulty of a conversation, it is not clear that this distinction is important for road safety.

Although not related to alcohol impairments, participants in the present study spent less time in the correct speed range during all 3 phone conditions, which was primarily due to more time spent speeding (i.e., over 80 km/h). This is not consistent with the reduced driving speed reported in previous studies (Burns et al. 2002; Haigney et al. 2000; Rakauskas et al. 2004; Tornros and Bolling 2005). Burns et al. (2002) suggested that driving slower might represent a compensatory behavior in recognition of the extra task demands associated with the use of the phone while driving. However, no evidence was found of this in the present study, which suggests that whether or not drivers engage in compensatory behavior is idiosyncratic and/or related to the task demands of the particular driving scenario and that this factor should not be used to infer that compensatory driving behavior is likely to mitigate against accident risk.

Alternatively, that the drivers in our study were less cautious (in terms of driving speed) than those in Burns et al. (2002) raises the possibility that the driving simulator task may not have been sufficiently realistic to encourage extra caution in the phone conditions. This cannot be determined from the present study, but if this is true it would follow that drivers may incorporate more compensatory behaviors on the road than we observed and, correspondingly, that in situ phone use may not be as detrimental as in the present study. This possibility relates to an important difference between the effects of alcohol and mobile phone use on driving that was highlighted by Dragutinovic and Twisk (2005). That is, although the effects of alcohol on driving performance and judgement are present for the duration of intoxication, drivers who use a mobile phone may be able to alter their behavior based on the perceived risk of the current driving environment. On the other hand, given that the present study used a PC-based simulator and not a high-fidelity simulator, the effects observed in the present study might be underestimated, because participants might not have had the same sense of immersion that they are likely to get from a high-fidelity simulator. In situ driving would thus appear necessary in order to confirm the conclusions reached in the present study.

When considering these results, it should be noted that there was a gender imbalance (10 females, 2 males) in the current study. Previous alcohol-driving research has demonstrated that female drivers are more affected by alcohol than male drivers in terms of lane position variation and speed of steering to maintain lane position (Miller et al. 2009). Although these particular variables were not of primary importance in the present study, should this gender pattern exist for other variables (such as time spent speeding and braking reaction time), this would have reduced the apparent effect of the mobile phone conditions in our study. That is, it may have emphasized the alcohol-related impairments and reduced the apparent effect of mobile telephony in relation to those alcohol-related impairments. Future studies could further explore potential gender differences in driving performance during mobile phone use. Another limitation of the present study may be the effect of the alcohol conditions being presented such that the dose was always increased as a function of time (as opposed to being counterbalanced across time), which may have influenced fatigue and/or learning and thus the BAC 0.10 condition (ie, as it was thus always later in the battery). Due to the experimental design, it is difficult to determine whether there is a strong learning effect on the driving simulation performance in the alcohol condition. However, we note that the testing was conducted during a period where people are typically very awake, outside of the circadian nadir (between 9 a.m. and 2 p.m.), and at least the PVT task has been shown to be independent of learning effects (Dinges and Powell 1985). Further research would be required to clarify the relative effects of these factors on the current results, including data on participants' accident records and their mobile phone usage during driving, psycholinguistic measures for the conversation tasks, and their text messaging proficiency.

CONCLUSION

In conclusion, the current study has demonstrated alcohol-related impairments on both driving simulator performance and a more sensitive (but less directly relevant) psychomotor vigilance task. Using these as a comparison, a hands-free naturalistic conversation resulted in more PVT impairment than the legally permissible BAC level (0.04) but did not differ from this on the more directly applicable driving task. However, a cognitively demanding hands-free conversation resulted in greater driving impairment than this legally permissible level, with performance intermediate between BAC 0.04 and 0.07 (and PVT reaction time worse then even the BAC 0.10 condition). Texting was clearly legally impermissible, resulting in driving simulator performance that was worse than the BAC 0.07 (and sometimes the 0.10) level, and represents a significant driving risk. Due to the possibility that compensatory behaviors that may be engaged when using a mobile phone on the road were not employed here (which may have exaggerated the risk of driving while using a mobile phone), it is important to replicate this research in situ.

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