Low Levels of Alcohol Impair Driving Simulator Performance and Reduce Perception of Crash Risk in Partially Sleep Deprived Subjects

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Study Objectives: Partial sleep deprivation and alcohol consumption are a common combination, particularly among young drivers. We hypothesized that while low blood alcohol concentration (<0.05 g/dL) may not significantly increase crash risk, the combination of partial sleep deprivation and low blood alcohol concentration would cause significant performance impairment.
Design: Experimental
Setting: Sleep Disorders Unit Laboratory
Patients or Participants: 20 healthy volunteers (mean age 22.8 years; 9 men).
Interventions: Subjects underwent driving simulator testing at 1 am on 2 nights a week apart. On the night preceding simulator testing, subjects were partially sleep deprived (5 hours in bed). Alcohol consumption (2-3 standard alcohol drinks over 2 hours) was randomized to 1 of the 2 test nights, and blood alcohol concentrations were estimated using a calibrated Breathalyzer. During the driving task subjects were monitored continuously with electroencephalography for sleep episodes and were prompted every 4.5 minutes for answers to 2 perception scales—performance and crash risk.

Measurements and Results: Mean blood alcohol concentration on the alcohol night was 0.035 ± 0.015g/dL. Compared with conditions during partial sleep deprivation alone, subjects had more microsleeps, impaired driving simulator performance, and poorer ability to predict crash risk in the combined partial sleep deprivation and alcohol condition. Women predicted crash risk more accurately than did men in the partial sleep deprivation condition, but neither men nor women predicted the risk accurately in the sleep deprivation plus alcohol condition.
Conclusions: Alcohol at legal blood alcohol concentrations appears to increase sleepiness and impair performance and the detection of crash risk following partial sleep deprivation. When partially sleep deprived, women appear to be either more perceptive of increased crash risk or more willing to admit to their driving limitations than are men. Alcohol eliminated this behavioral difference.
Key Words: Sleepiness, crash risk, driving, alcohol
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INTRODUCTION

IT IS WIDELY KNOWN THAT ALCOHOL CONSUMPTION SIGNIFICANTLY IMPAIRS DRIVING PERFORMANCE,[1-6] and driving with a blood alcohol concentration (BAC) in excess of 0.05 to 0.08 g/dL is considered in many countries to be dangerous and is punishable by law (except for several US states where a BAC of 0.1 while driving is acceptable). There is increasing awareness that sleepiness resulting from inadequate sleep or sleep disorders (eg, sleep apnea) also impairs driving performance and increases crash risk.[7] This awareness has led to an increased punitive approach to sleepiness while driving, as demonstrated following the train disaster in Selby, United Kingdom,[8] caused by a sleep-deprived driver and the introduction of new laws in New Jersey, USA, where driving while sleep deprived constitutes reckless driving (Maggie's Law[9]).

Additionally, studies have shown that sleep deprivation and alcohol interact, with sleepiness exacerbating the sedating effects of alcohol.[3,5,6,10]

Given the interactive effects of sleepiness and alcohol, it is possible that even low (legal) levels of BAC may adversely affect driving performance. Some research suggests that low levels of alcohol consumption, not considered to constitute a serious risk (eg, 0.02 g/dL BAC), in combination with factors such as sleep deprivation and circadian timing, can affect performance tasks (eg, visual tracking and divided attention).[11-13] A recent study by Horne et al[12] examined the combined effects of low alcohol consumption and mild sleep deprivation on driving simulator performance and perception of sleepiness in the afternoon. They found that performance was significantly impaired compared to baseline. This study however did not examine subject's perception of crash risk nor did they investigate sex differences.

While driving with a high (illegal) BAC or after total sleep deprivation does occur in our communities and is recognized to constitute a serious risk for an accident, driving after 1 or 2 drinks while partially sleep deprived is much more common, particularly among young drivers. A typical scenario would be an individual who, perhaps having gone to bed late the previous night, consumes 2 to 3 standard alcohol drinks at a function and drives home in the early hours of the morning. The individual may be technically legal to drive but is their safety compromised?

The primary aim of this study, therefore, was to test the effects of low BAC (< 0.05 g/dL) on driving performance in subjects who were partially sleep deprived and driving close to the circadian nadir (early hours of the morning).

A second aim was to examine subjects' perception of impairment. Previous studies have shown that alcohol affects perception of crash and traffic hazard risk.[14,15] If perception of impairment is affected, the individuals' ability to know when they are at risk is reduced. This is of critical importance in determining whether the driver is likely to take countermeasures to avoid an accident (for example a "power" nap or caffeine drink). We hypothesized that consumption of alcohol to a low BAC in the presence of partial sleep deprivation would limit subjects' ability to recognize their level of impairment.

METHODS

The ethics committee at the Repatriation General Hospital, Adelaide, approved this study. All subjects gave written informed consent.

Participants

Advertisements were posted at Flinders University of South Australia campus. Young people were recruited for this study due to the high number of 18- to 30-year-olds who have sleep-related car accidents in the early hours of the morning. Subjects were excluded if they had a sleep disorder (eg, self-reported snoring or difficulty sleeping), if they were taking any forms of medication, and if they suffered motion sickness. All subjects received an honorarium of $100.

Procedure

Familiarization Session

At the first visit to the laboratory, the subjects were introduced to the testing equipment and driving simulator. They underwent three, 10-minute practice sessions on the driving simulator and perception exercise and were randomly assigned to condition order. They then completed the Epworth Sleepiness Scale.[16] The subjects took home an activity monitor and a sleep diary to be completed in the week prior to testing. Subjects were not required to obtain a specific amount of sleep during the testing period (except on the partial sleep-deprivation night). They were instructed to keep to their normal sleep-wake pattern.

AusEd Driving Simulator

The AusEd driving simulation task used in this study was a computer program devised to monitor a number of performance variables. These included position on the road and speed deviation over time, reaction time to a braking task (appearance of trucks), and crashes (driving off the road, stoppage events, and crashing into the back of a truck). Early work suggests that this test is sensitive to varying degrees of sleep deprivation and sleepiness.[17-19] Subjects were required to "drive" the AusEd simulator using a steering wheel and pedals. The view, seen from a front-seat perspective, was of a dual-carriage rural road at night, with the usual lane divisions and the road edges marked by reflective posts. A speedometer was displayed in the top left corner of the computer screen. Subjects were asked to maintain their position in the left-hand lane on the road (in accordance with Australian driving code), to keep their speed within 60 to 80 kilometers per hour, and to react by braking firmly and as quickly as possible to any trucks that appeared ahead in the driving lane.

The simulator was programmed to present 4 trucks at approximately 10-minute intervals during the 70-minute task.

Perception Probes

The perception exercise required subjects to respond to an audio tone, played every 4.5 minutes, by rating their perceived level of driving simulator performance and indicating whether they felt they should stop driving to avoid an accident. The 4.5-minute time gap between each probe was chosen because this length of time made it less possible for subjects to predict the next tone. However, it was also frequent enough to provide multiple data points for analysis (15 over the 70-minute driving task). All responses were spoken and recorded for later analysis. A cue card of the perception scales was attached to the bottom of the computer screen. The perception scales and their anchors were: "Rate your driving performance since the last tone" (*1 = Excellent* to *9 = Terrible*) and "If you were driving a real car would you now stop to avoid an accident?" (*Yes* or *No*). Preliminary trials were conducted to ensure the tones played were not physiologically arousing (eg, significantly increasing heart rate above baseline). The tones were 60 dB at 1 meter from source, including background noise.

Each subject's ability to identify crash risk was determined from the proportion of all 4.5-minute periods containing a crash in which the subjects reported they would have stopped driving prior to the commencement of that period.

Experimental Conditions

The subjects were required to keep a detailed diary of their sleep habits and to wear an activity monitor (Gaehwiler Electronic, Hombrechtikon, Switzerland), which measured their sleep-wake activity for 1 week prior to the experimental conditions. This was done to verify the subjects had regular sleep habits in the week prior to testing, that they followed the sleep deprivation protocols, and that they did not nap during the day of testing. Subjects participated in the 2 experimental conditions in a repeated-measures design, attending the laboratory twice, with a week separating each visit.

In the partial sleep-deprivation condition, subjects were restricted to 5 hours time in bed on the night prior to testing (1 AM-6 AM). They were required to telephone a time- and date-stamped answering machine before going to bed and after rising in the morning to ensure compliance.

In the combined partial sleep-deprivation and alcohol condition, subjects were also required to restrict sleep according to the protocol above. As the legal BAC limit for driving in Australia is 0.05 g/dL, BAC below this level were targeted. At 10:30 PM, subjects consumed 1 mL of 50% alcohol per kg of body weight, in a carbonated noncaffeinated beverage, to produce a BAC of approximately 0.04 g/kg. At 12:15 AM, they consumed another drink with 0.5 mL of 50% alcohol per kg of body weight. Blood alcohol levels were estimated using a calibrated Breathalyzer (Dräger, Lübeck, Germany, Alcotest 7410[Plus]) accurate to 0.005 g/dL. Subjects were not blinded to alcohol presentation, as our aim in this study was to test the subjects in a common real-world situation where the subjects would be aware of alcohol consumption.

Experimental Procedure

Subjects arrived at the laboratory at 9:00 PM. They immediately analysis with the Breathalyzer, a urine sample was taken to test for habitual drugs of abuse (eg, opioids, cannabiniods, amphetamine), and activity monitors were downloaded to ensure that subjects had complied with the study protocol requirements. Timepieces were removed so there were no external time cues.

Standard surface electrodes were applied for monitoring: electroencephalogram (EEG)(C_3/A_2, C_4/A_1), submental electromyogram, left and right eye movements, and electrocardiogram. All parameters were recorded using the Sleepwatch (Compumedics, Melbourne, Australia) data-acquisition system. Subjects then completed the Stanford Sleepiness Scale.[20] Subjects were allowed a short practice run on the driving simulator and given a standardized snack (150 calories; dry biscuits and cheese) and alcohol or an equivalent volume of the carbonated noncaffeinated beverage at 10:30 PM and at 12:15 AM.

Subjects started the 70-minute driving simulation at 1:00 AM, and they were prompted every 4.5 minutes during the driving task to answer the perception probes. Subjects were told the probes would sound at random intervals. The driving task took place in a private semidark (10 lux) and sound-attenuated room. The experiment protocol concluded at approximately 3 AM, and subjects were taken home by taxicab.

Data Analysis

In order to assess the relationship between the perception scores and actual performance, the driving simulator and EEG were analyzed in fifteen 4.5-minute bins. The first tone was played 30 seconds after the driving simulator task started. As the perception questions were phrased with "*since the last tone,*" this initial tone did not provide useful information for analysis but was a starting point for the following perception probes. Therefore, 16 tones were played, but only 15 were used in the analysis. The last tone was played approximately 2 minutes before the end of the driving task, and data from these 2 minutes was not used in the analysis.

AusEd Driving Simulator

This study examined mean steering deviation (deviation from the subject's median position on the road averaged every 40 mil-

Table 1—Driving-Simulator Parameters and Microsleeps by Condition

Parameter	Condition	
	Partial Sleep Deprivation Mean ± SD	Partial Sleep Deprivation + Alcohol Mean ± SD
Microsleep, sec*	4.8 ± 6.6	8.9 ± 12.1
Braking reaction time, msec†	1512.1 ± 355.7	2041.5 ± 778.5
Steering deviation, cm*	82.0 ± 36.2	92.9 ± 33.1
Speed variability, km/h‡	8.9 ± 9.3	10.5 ± 7.3
Crashes, no.†	1.0 ± 1.2	4.3 ± 4.9

Data are presented as mean ± SD in 20 subjects.
*$P < .05$
†$P < .01$
‡Deviation from safe 60- to 80-km/h zone.

liseconds, excluding crashes), mean speed deviation (deviation from the safe speed zone 60-80 km), braking reaction time (in response to trucks on the road ahead), and mean number of driving-simulator crashes (off-road, truck collision, or stoppage events). The mean number of crashes was determined for each 4.5-minute bin.

EEG Microsleep Analysis

The EEG (C_3-A_2) during the driving simulation task was assessed for the appearance of microsleeps. A microsleep was defined as a burst of EEG theta activity greater than 3-seconds in length.[21,22] The cumulative theta time and number of discrete microsleeps were determined for each 4.5-minute bin.

Statistics

Analysis of variance for repeated measures was conducted to investigate the effects of condition (alcohol vs no alcohol), sex, and time on performance and perception variables. Group data are expressed as means ± SD of the mean, and $P < .05$ was considered significant.

RESULTS

Twenty healthy subjects (11 women, mean age 21.9 ± 2.2; 9 men, mean age 23.8 ± 4.8) participated. The mean Epworth Sleepiness Scale and Stanford Sleepiness Scale scores at familiarization for the whole group were 6.4 ± 3.9 and 1.7 ± 0.57, respectively. All subjects had a regular sleep-wake cycle in the week prior to testing, with activity-monitor data showing subjects were inactive for an average of 411 ± 37 minutes per night. They subjectively reported (sleep diary kept for 7 days) that they obtained an average of 423.59 ± 45.8 minutes of sleep per night. No subjects were excluded on the basis of the amount of sleep obtained in the week before testing. All subjects had 0 BAC and a negative urine drug test on arrival at the laboratory on experimental nights. Data from the activity monitors showed subjects complied with the sleep-restriction protocol. They were inactive for 270 ± 20 minutes on the night before testing. Subjects rated themselves as moderately sleepy according to the Stanford Sleepiness Scale on both experimental nights (partial sleep deprivation condition mean 4.0 ± 1.2, and partial sleep deprivation plus alcohol condition mean 4.0 ± 1.3).

The subjects' mean BAC on the alcohol night at the start and end of the 70-minute driving simulation were 0.037 ± 0.011 g/dL and 0.021 ± 0.009 g/dL. These values are well below the Australian legal limit for driving of 0.05 g/dL. Two subjects, 1 man and 1 woman, had a BAC of > 0.05 g/dL just before the driving simulation task. Their BAC were 0.054 g/dL and 0.056 g/dL, respectively.

Table 1 shows the driving-simulator and microsleep results for both conditions. The consumption of alcohol significantly increased mean steering deviation ($P = .05$) and the number of driving-simulator crashes ($P = .02$; see Figure 1). Both variables showed a significant increase with time on task ($P < .001$ and $P = .02$, respectively). Speed variability was not affected by alcohol ($P = .07$) but increased with time on task ($P < .001$). Braking reaction time to trucks increased after alcohol ($P = .01$) but not with time on task ($P = .09$). Figure 2 shows that the duration of microsleeps subjects experienced during the driving simulation
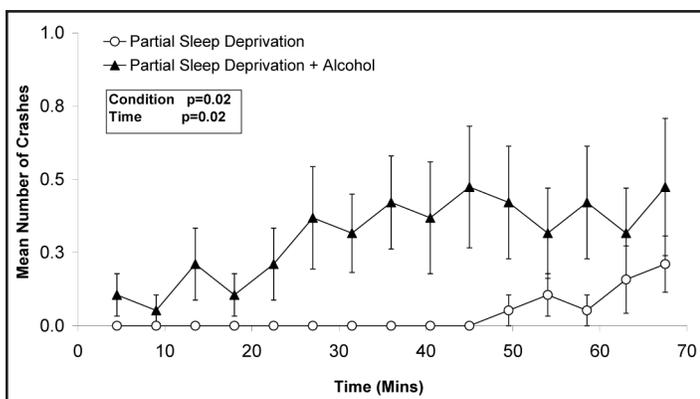
task increased with alcohol ($P = .04$) but not with time on task ($P = .13$). There were no significant sex differences in any driving performance variable.

Overall, subjects showed less insight about crash risk in the combined partial sleep deprivation and alcohol condition (38% compared to 64% in the partial sleep deprivation alone condition, $P = .04$; see Table 2). Women more accurately anticipated crashes than did men in the partial sleep-deprivation condition (85% to 37%, $P = .03$) but not after consuming alcohol (38% to 33%, $P = .12$). Women's ability to accurately anticipate crashes dropped from 85% to 38% following the consumption of alcohol ($P = .03$).
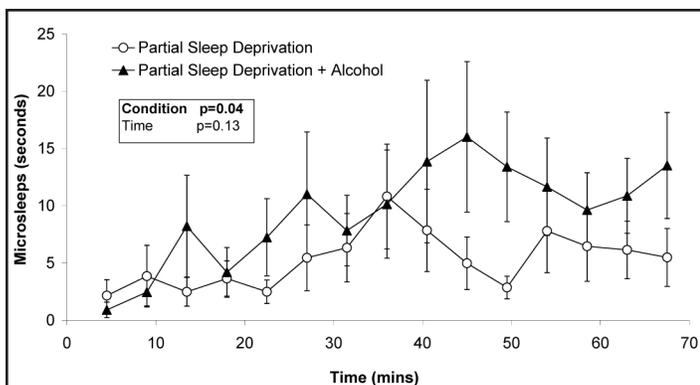
DISCUSSION

The principal finding of this study was that the addition of a low BAC to the presence of partial sleep deprivation caused increased sleepiness (microsleeps) while driving and impaired driving performance, without subjects appreciating the extent of their impairment. Even a small amount of alcohol combined with sleep loss appears to be sufficient to dramatically impair subjects' ability to 'drive' safely. These findings may have important road-safety implications.

This study aimed to simulate the 'real-life' combination of

Figure 1—Mean number of driving-simulator crashes in 11 women and 9 men for each 4.5-minute bin during the 70-minute task under the conditions of partial sleep deprivation alone and partial sleep deprivation combined with alcohol consumption (blood alcohol concentration < 0.05 g/dL).

Figure 2—Mean cumulative microsleeps (sum of all 3-second or longer episodes of theta activity on the electroencephalogram) in 11 women and 9 men for each 4.5-minute bin during the 70-minute task under the conditions of partial sleep deprivation alone and partial sleep deprivation combined with alcohol consumption (blood alcohol concentration < 0.05 g/dL).

alcohol and partial sleep deprivation on driving performance and perception. The amount of sleep deprivation and alcohol consumed are not only within the legal driving limits for most countries, but also at a level that many individuals would consider safe to drive. This is the first study to assess such a combination. A previous study by Horne et al,[12] examined performance in the afternoon during the 'post lunch dip' in circadian rhythm but focused primarily on only 1 aspect of driving-simulator performance and subjects' assessment of sleepiness. Additionally, they recruited only men and thus no sex comparisons were made. The current study extends this previous work by examining sex differences and driving performance in the early hours of the morning and by investigating subjects' perceptions of driving-performance impairment and assessment of crash risk. The driving-simulation task commenced at 1 AM to coincide with the time that many individuals drive home from social events and a time that also approaches the subjects' circadian nadir and greatest sleep pressure. We believed that it was also important to investigate subjects' perceptions of their driving performance and crash risk, since perception of ability likely influences the decision-making process to stop driving or engage in sleepiness counter-measures (eg, caffeine or nap).

Overall subjects did not realize the full extent of their performance impairment and were poorer at assessing crash risk in the partial sleep deprivation and alcohol condition. This is consistent with previous studies showing that alcohol impairs comprehension of cognitive impairment. A study by Deery et al[15] found that subjects with a BAC of 0.05 who watched a video of typical road traffic took longer to detect traffic hazards and accident risk and tended to respond to these hazards abruptly. Subjects' ability to accurately assess potentially dangerous situations was affected by alcohol, and this may in part explain the increased accident risk associated with drunk driving.

It has been found previously that young men are much more likely to have an accident in the early hours of the morning than are women.[23] Men's ability to assess crash risk was substantially less than that of the women in the sleep-deprivation condition. Women appeared to be perhaps more perceptive of increased crash risk or more willing to admit their limitations. This ability however was markedly reduced following the consumption of alcohol when women's crash-risk assessment was the same as men's. It was found in a previous study that men tend to be more optimistic, particularly regarding their driving skill and ability.[24] Subjects in this earlier study held similar perceptions concerning the frequency and accident likelihood of risky behaviors, but men perceived the behaviors generally less serious and less likely to result in accidents.[24] Men's attitudes could be potentially affect-

Table 2—Percentage of 4.5-minute time periods containing crashes in which subjects had reported they would have stopped driving prior to crash

Sex	Condition	
	Partial Sleep Deprivation	Partial Sleep Deprivation + Alcohol
All subjects, n = 20	64 ± 37	38 ± 36
Men, n = 9	37 ± 41	33 ± 42
Women, n =11	85 ± 23	38 ± 24

Data are presented as mean ± SD.

ed by the nature of the test situation and the tools used. When a 'computer game-like' simulator is used, the inevitable knowledge that that this is not a real-life situation might encourage false confidence or even arrogance in their abilities.

An inherent limitation of simulator studies is of course the fact that it is a simulation. While subjects may be less motivated and cautious in the laboratory, studies have found a strong association between laboratory simulator studies and on-road driving behavior.[25] Furthermore, simulator studies allow for control of relevant variables that is otherwise difficult or impossible in on-road research, particularly for the assessment of crash risk. Laboratory driving-simulator research shows trends in behavioral response, which can aid the development of more complex and costly on-road real-car research.

In conclusion, in this study, alcohol consumption to a BAC considered in most jurisdictions to be safe, when combined with sleep loss, increased EEG-defined sleepiness, impaired driving-simulator performance, and reduced subjects' ability to detect impairment in driving performance and assess crash risk. Women appeared to be more perceptive of increased crash risk or more willing to admit to their driving limitations under partial sleep-deprivation conditions. These results have may have implications for policy, including reduction in permissible BAC for drivers under 25 years of age and restricting young drivers to daytime driving (which has been successfully implemented in some areas[26,27]).

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