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Effects of Alcohol and Sleep Restriction on Simulated Driving Performance in Untreated Patients With Obstructive Sleep Apnea

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Background: Because of previous sleep disturbance and sleep hypoxia, patients with obstructive sleep apnea (OSA) might be more vulnerable to the effects of alcohol and sleep restriction than healthy persons.

Objective: To compare the effects of sleep restriction and alcohol on driving simulator performance in patients with OSA and age-matched control participants.

Design: Driving simulator assessments in 2 groups under 3 different conditions presented in random order.

Setting: Adelaide Institute for Sleep Health, Sleep Laboratory, Adelaide, Australia.

Participants: 38 untreated patients with OSA and 20 control participants.

Measurements: Steering deviation, crashes, and braking reaction time.

Intervention: Unrestricted sleep, sleep restricted to a maximum of 4 hours, and ingestion of an amount of 40% vodka calculated to achieve a blood alcohol level of 0.05 g/dL.

Results: Patients with OSA demonstrated increased steering deviation compared with control participants (mean, 50.5 cm [95% CI, 46.1 to 54.9 cm] in the OSA group and 38.4 cm [CI, 32.4 to 44.4 cm] in the control group; $P < 0.01$) and significantly greater steering deterioration over time (group by time interaction, $P = 0.02$). The increase in steering deviation after sleep restriction and alcohol was approximately 40% greater in patients with OSA than in control participants (group by condition interaction, $P = 0.04$). Patients with OSA crashed more frequently than control participants (1 vs. 24 participants; odds ratio [OR], 25.4; $P = 0.03$) and crashed more frequently after sleep restriction (OR, 4.0; $P < 0.01$) and alcohol consumption (OR, 2.3; $P = 0.02$) than after normal sleep. In patients with OSA, prolonged eye closure (>2 seconds) and microsleeps (> 2 seconds of theta activity on electroencephalography) were significant crash predictors (OR, 19.2 and 7.2, respectively; $P < 0.01$). Braking reaction time was slower after sleep restriction than after normal sleep (mean, 1.39 [SD, 0.06] seconds vs. 1.22 [SD, 0.04] seconds; $P < 0.01$) but not after alcohol consumption. No group differences were found.

Limitation: Simulated driving was assessed rather than on-road driving.

Conclusion: Patients with OSA are more vulnerable than healthy persons to the effects of alcohol consumption and sleep restriction on various driving performance variables.

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Obstructive sleep apnea (OSA) causes excessive daytime somnolence and reduced vigilance, concentration, and neurocognitive function (1, 2). Patients with OSA, particularly those with moderate to severe disease, have a 2- to 7-fold increased risk for motor vehicle accidents (3–10). Community surveys have shown that approximately 7% of the middle-aged population has at least mild OSA (>10 obstructive events per hour of sleep) (11–13), and up to 80% of these cases are undiagnosed (14–16). For patients whose condition is diagnosed, delays in instituting treatment are common (17). Between 46% and 83% of patients do not adhere to treatment over the long term (18).

The many patients with undiagnosed or untreated OSA represent a serious public health concern with respect to road safety. Accidents related to OSA result in an estimated 1400 road fatalities and cost $15.9 billion annually in the United States alone (19). Improving access to diagnosis and treatment may help reduce this public health burden. However, even with improved sleep medicine services, many unidentified or untreated patients with OSA will probably remain at increased risk for motor vehicle accidents. A better understanding of the factors contributing to motor vehicle accidents among patients with OSA is therefore needed to develop cost-effective prevention strategies.

This study was designed to compare the effects of 2 common "lifestyle" factors, low-dose alcohol and acute partial sleep deprivation, on driving simulator performance between untreated patients with OSA and healthy matched control participants. We postulated that because of previous chronic sleep disruption and possible hypoxia-induced brain damage (2, 20–26), patients with OSA would be more vulnerable to the effects of these common, mild central nervous system stressors and would experience significantly greater decrements in driving performance.

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Context

Obstructive sleep apnea (OSA) is associated with sleepiness and poor concentration, symptoms that could impair driving performance.

Contribution

This study evaluated simulated driving performance in 38 patients with untreated OSA and 20 control participants under 3 conditions: unrestricted sleep, sleep restriction, and consumption of alcohol. Compared with control participants, patients with untreated OSA had worse simulated driving performance. Patients with OSA also had greater decrements in driving performance after sleep restriction and after alcohol consumption.

Implication

Consider alerting patients about the potential negative influence of untreated OSA on driving performance and their heightened vulnerability after sleep deprivation and alcohol consumption.

—The Editors

METHODS

The study was approved by the Human Research Ethics Committees of the Repatriation General Hospital, University of South Australia, and University of Adelaide. Participants were introduced to the study objectives and protocol during an introductory session, gave written informed consent, and were remunerated for their participation.

Study Design

Patients with OSA and control participants underwent driving simulator assessments under 3 conditions that were presented in random and counterbalanced order: after a normal nighttime sleep, after a single night of sleep restriction (4 hours in bed from 2:00 a.m. to 6:00 a.m.), and after acute administration of low-dose alcohol (target blood alcohol concentration, 0.05 g/dL). All driving simulator sessions began at 2:00 p.m. and were conducted at least 5 days apart to avoid carryover effects from the previous interventions.

Participant Selection

Thirty-eight untreated patients with OSA of varying severity were recruited after diagnostic polysomnography. Neither they nor their referring physician had specific concerns about their driving. To minimize selection bias, patients were told that the study objective was to investigate general neurocognitive performance; they were unaware that the trial measured driving performance until after they agreed to attend an introductory session. Twenty healthy control participants matched for age and sex were recruited from the general population through newspaper advertisements, which only generally described the study and did not mention driving performance measures.

Exclusion criteria were employment as a professional driver or shift worker; history of driving less than 2 years or less than 2 hours per week; notable medical comorbid conditions (such as cardiac or respiratory failure), periodic limb movement disorder (periodic limb movement arousal index >5 per hour), or past head injury or depression; use of alertness-altering prescription medications that may change neurocognitive function (such as antihistamines, opiates, or antidepressants); and history of alcohol abuse or current use of recreational drugs. Control participants were also excluded if they had higher-than-normal scores on sleep quality and daytime drowsiness questionnaires.

Baseline Measures

Before the driving simulator assessment, all participants completed questionnaires that evaluated general health (medical conditions, medication, alcohol intake, caffeine and drug use), sleep quality and habits, and daytime drowsiness using the Pittsburgh Sleep Quality Index (27) and the Epworth Sleepiness Scale (28). All participants underwent overnight standard diagnostic polysomnography with the following recordings: electroencephalography (C3/A2, C4/A1 lead placements), left and right electrooculography, submental electromyography, nasal cannulization to measure nasal pressure, limb movement sensors, inductive plethysmography for thoracoabdominal motion, lead II electrocardiography, and finger pulse oximetry (to measure arterial oxygen saturation). All signals were digitized and stored by using a Compumedics-E Series sleep system (Melbourne, Australia). Sleep and sleep arousals were scored by using standardized methods (29, 30). Apneas and hypopneas were scored according to internationally agreed-on criteria (30). All studies were scored by 1 staff member certified by the Board of Registered Polysomnographic Technicians. **Table 1** shows participant characteristics, sleep study results, caffeine and alcohol consumption, and medication use.

Main Outcome Measures

The main outcome measures were performance on the driving simulator, including lateral steering deviation, braking reaction time, crash frequency, and precrash electroencephalography and electrooculography results. Driving performance was assessed by using the AusEd driving simulator (Woolcock Institute for Medical Research, Sydney, Australia), which ran on a purpose-built Windows 2000 workstation (Microsoft, Redmond, Washington) with a 19-inch FP937s monitor (BenQ, Taipei, Taiwan); the MOMO steering wheel and pedals (Logitech, Fremont, California) were used to assess the driving variables.

Steering deviation was measured as the average deviation in centimeters from the driver's median lane position sampled at 30 Hz. Participants were instructed to maintain speed within 60 to 80 km/h but to apply the brakes as quickly as possible whenever a slow-moving truck appeared ahead in the driving lane. The latter occurred 7 times dur-

ing the drive, and the mean braking reaction time was computed for the 7 truck-ahead incidents. Crashes occurring throughout the driving task were defined as follows: car deviating from the road (all 4 wheels completely off the road), collision with a truck, or stationary position of the car for more than 3 seconds.

The main outcome measure for crashes was the number of control participants and patients with OSA who experienced at least 1 crash incident. A secondary crash analysis was undertaken to determine whether crashes were associated with brief falling-asleep episodes and prolonged eye closures. Fifteen-second epochs of electroencephalography, electrooculography, and synchronized video (head and shoulders) before each crash (crash epoch) were scored for the presence of prolonged eye closure (>2 seconds) and microsleeps (>2 seconds of continuous electroencephalographic theta activity) within each crash epoch. A random sample of an equal number of 15-second noncrash epochs was selected and matched within participants and condition so that they could be compared with the crash epochs.

The simulated driving task used in the study consisted of a 90-minute country nighttime drive on a predominantly straight dual-lane road with bends occurring at 10-minute intervals, each taking approximately 30 seconds to negotiate. There was no oncoming traffic or traffic lights. Driving simulator studies have been shown to correlate reasonably well with on-road driving (31, 32), and the AusEd simulator has been validated and shown to be sensitive to fatigue in a range of experimental settings (33–37).

Detailed Experimental Procedures

For all 3 conditions, participants' sleep patterns and duration were monitored throughout the study by using actigraphy monitors (Actiwatch Model-AW64, Mini-Mitter Co., Bend, Oregon) worn from at least 5 days before the experiments began until study completion to estimate sleep/wake timing, to ensure adherence to the sleep restriction protocol, and to ensure that patients did not nap in the 24 hours before the experiments (38). In addition, during the night of sleep restriction, participants left a message on a time- and date-stamped answering machine at bedtime (2:00 a.m.) and wake time (6:00 a.m.), again to ensure adherence to the protocol. Participants were instructed to abstain from alcohol and caffeinated beverages, not to nap for 24 hours before each experimental session, and to consume breakfast before 9:00 a.m. on the day of each experiment. They were transported by taxi to and from the laboratory.

Upon arrival at the laboratory at 12:00 p.m., each participant's blood alcohol concentration was estimated by using a calibrated breathalyzer (Alcotest7410^{Plus}, Dräger, Mississauga, Ontario, Canada), sleep diaries were collected, activity monitor data were downloaded, and the answering machine was checked for adherence to the sleeping regimen.

Participants consumed a standardized lunch with a glass of water at 12:15 p.m. before electrode application for electroencephalographic monitoring (C3/A2, C4/A1, O1/A2, O2/A1, and electrooculography) of drowsiness throughout the driving test. At 1:30 p.m., all participants consumed either 375 mL of a sugar-free, noncaffeinated control soft drink (in the normal and restricted sleep conditions) or a volume of vodka (40% alcohol) calculated to achieve a target blood alcohol concentration of 0.05 g/dL mixed with the same soft drink (in the alcohol condition). Target blood alcohol concentrations were achieved by using doses of alcohol derived from the mathematical formulas below (36, 39), where total body water is first calculated by using age, height, and weight, before alcohol dose estimation from total body water and the target blood alcohol concentration:

Total body water = 2.447 − (0.09516 × age [years]) + (0.1074 × height [cm]) + (0.3362 × weight [kg])

Alcohol dose [g] = (target blood alcohol concentration [g] × 0.8)/total body water

Statistical Analysis

Data on steering deviation, excluding the first minute of acceleration and initial lane positioning, were divided and averaged into 18 intervals for the remaining 89 minutes of the drive. Mixed-model analysis was used to exam-

Table 1. **Patient Characteristics, Polysomnography Results, and Medication Use***

Variable	Control Group (n = 20)	Obstructive Sleep Apnea Group (n = 38)
Men/women, *n/n*	15/5	28/10
Age, *y*	50.6 (10.1)	52.0 (10.4)
Body mass index, kg/m^2	24.5 (2.5)	33.9 (8.1)†
Apnea–hypopnea index score, *events/h*	8.3 (4.0)	46.4 (21.7)†
Sleep time with SaO_2 <90%, %	0.07 (0.3)	6.7 (14.7)†
Average SaO_2 desaturation, %	2.4 (0.8)	4.1 (1.8)†
Pittsburgh Sleep Quality Index score	2.9 (1.0)	9.4 (4.9)†
Epworth Sleepiness Scale score	5.0 (3.0)	9.3 (5.3)†
Driving history, *km/y*	11 450 (5762)	13 983 (7906)
Education, *y*	12.9 (2.8)	11.7 (2.7)
Caffeine consumption, *cup or equivalent/d*	2.7 (1.3)	3.6 (1.9)†
Smoking, *cigarettes/d*	0.2 (0.9)	1.5 (4.0)
Habitual alcohol intake, *standard drinks/wk*	8.8 (5.8)	7.4 (10.2)
Medication use, *n*		
Hypertension	0	11
Hyperlipidemia	0	6
Diabetes	0	2
Gastroesophageal reflux disease	0	5
Arthritis	0	4
Thyroid disease	0	4
Asthma	0	2
Gout	0	2
Hay fever	0	1

* Unless otherwise noted, values are means (SDs).
† $P < 0.05$.

ine fixed effects of condition (normal sleep, sleep restriction, and alcohol), group (patients vs. control participants), and time on task (18 intervals), with the participant as a random intercept that was assumed to be constant across conditions, and using an autoregressive covariance structure (AR1) to adjust for serial correlation across time (SPSS software, version 16.0; SPSS, Chicago, Illinois). The fully saturated model was run first, followed by removal of the nonsignificant 3-way (group by condition by time) interaction term. The final mixed model included the main effects of group, condition, time, and all 2-way interaction terms. Significant interaction effects were explored by using custom contrasts within the mixed model. Mixed-model analysis was also used to examine braking reaction time with fixed effects of condition (normal sleep, sleep restriction, and alcohol) and group (patients vs. control participants), with the participant as a random intercept that was assumed to be constant across conditions and using a diagonal covariance structure.

We performed binary logistic regression (generalized estimating equation for longitudinal/repeated-measures data, clustering on participant) (40, 41) to investigate group and condition effects on the presence of at least 1 crash (no/yes) (Stata software, version 9.0; Stata, College Station, Texas). Because only 1 crash occurred in the control group, group-by-condition effects could not meaningfully be examined in this analysis. Condition effects were therefore examined only in patients who had OSA, with condition specified as a predictor variable (normal sleep/sleep restriction/alcohol) and each patient appearing in the model 3 times (1 observation per condition).

A second model was used to investigate whether the presence of microsleeps (>2 seconds of theta activity) or eye closures (lasting >2 seconds) in the preceding 10 seconds was predictive of a crash. This model included all crashes in patients with OSA; crash epochs were matched with randomly selected noncrash epochs from the same driver in the same condition (1 observation per epoch). Because of this matching of crash and noncrash epochs, it was not appropriate to assess the effect of condition in this model—different participants contributed differently to the 3 conditions.

Values are expressed as means (SDs) unless otherwise indicated, and adjusted odds ratios (ORs) with *P* values less than 0.05 were considered significant.

Role of the Funding Source

This study was designed and conducted by the investigators and was funded by the Australian National Health and Medical Research Council. The funding source had no role in the design, conduct, and reporting of the study or in the decision to publish the manuscript.

RESULTS

Thirty-eight patients with OSA and 20 control participants were recruited. **Table 2** shows the estimated sleep time (measured by actigraphy) during normal and restricted sleep, average amount of alcohol ingested, and blood alcohol concentrations before and after the driving task. All participants adhered to the sleep restriction protocol and had a blood alcohol concentration of 0.0 g/dL upon arrival to the laboratory on each experimental day.

Steering Deviation

The **Figure** shows steering deviation in the OSA and control groups over the course of the drive in each condition. The group by condition by time interaction term was not statistically significant in the fully saturated model and was removed for the remaining analyses. In the final model, statistically significant effects were observed for group ($F_{[156]} = 10.6$; $P < 0.01$), condition ($F_{[2325]} = 16.1$; $P < 0.001$), and time ($F_{[171\ 937]} = 6.8$; $P < 0.001$) and for group by time ($F_{[171\ 967]} = 1.8$; $P = 0.02$) and group by condition ($F_{[2533]} = 3.4$; $P = 0.04$), but not for condition by time. When data were averaged across all time points, patients with OSA showed statistically significantly greater steering deviation than control participants under all conditions (mean over all conditions: OSA group, 50.5 cm [95% CI, 46.1 to 54.9 cm] and control group, 38.4 cm [CI, 32.4 to 44.4 cm]; mean differences between OSA and control groups: normal sleep condition, 9.5 cm [CI, 1.8 to 17.4 cm], $t_{68} = 2.5$, $P = 0.02$; sleep restriction condition, 14.4 cm [CI, 6.7 to 22.1 cm], $t_{65} = 3.7$, $P < 0.001$; alcohol condition, 12.2 cm [CI, 4.5 to 20 cm], $t_{68} = 3.1$, $P < 0.01$).

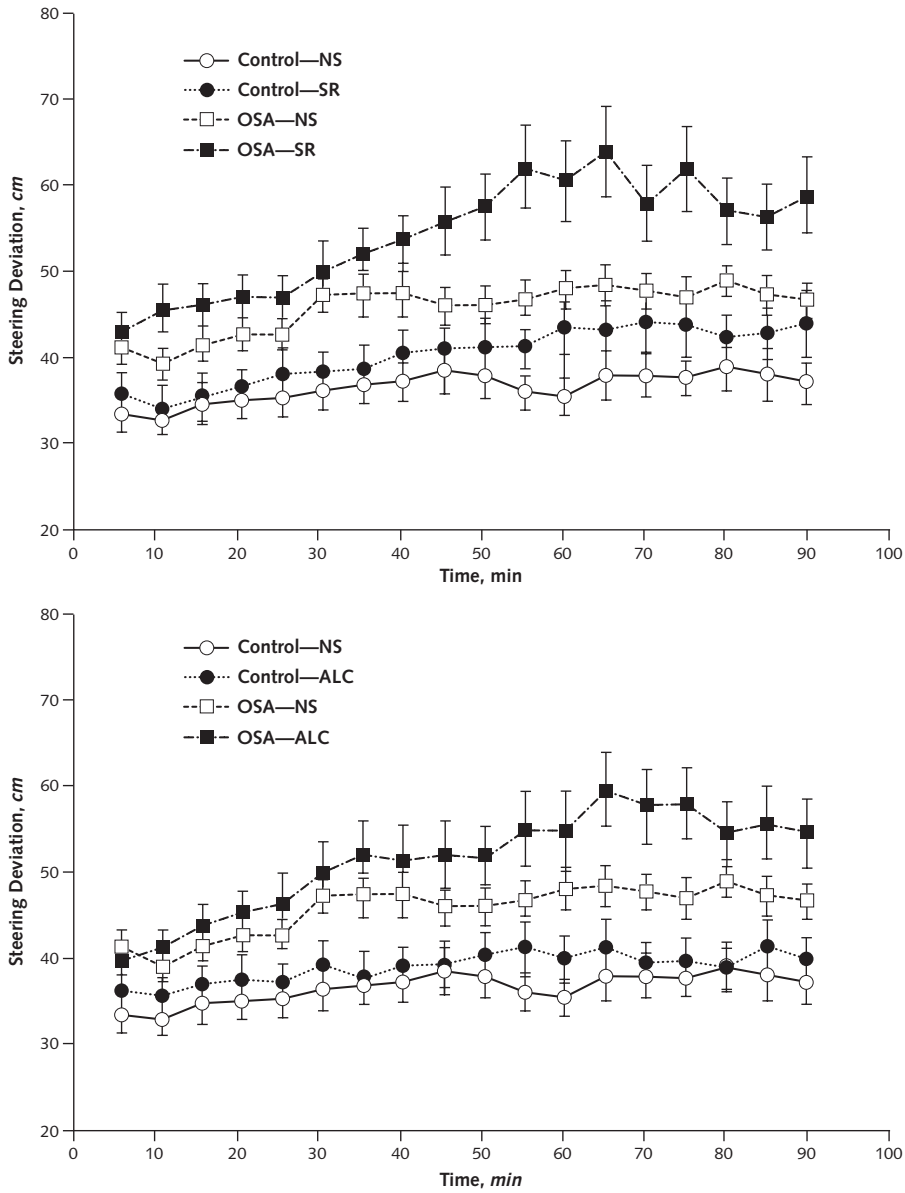
Changes in steering deviation over time were also greater in patients with OSA than in control participants (group by time interaction). An increase in steering deviation averaged across the whole drive in the sleep restriction compared with the normal sleep condition was statistically significantly greater in the OSA group than the in control group (difference from normal sleep: OSA group, 8.5 cm [CI, 6.1 to 10.9 cm], $t_{390} = 6.9$, $P < 0.001$; control group, 3.7 cm [CI, 0.5 to 6.9 cm], $t_{484} = 6.9$, $P = 0.02$; differ-

Table 2. **Actigraphy-Estimated Sleep Time, Average Amount of Alcohol Consumed, and Blood Alcohol Concentration Before and After the Driving Task**

Variable	Control Group	Obstructive Sleep Apnea Group
Mean estimated sleep time (SD), *min*		
Normal sleep	468 (42)	456 (48)
Restricted sleep	222 (24)	228 (60)
Mean alcohol consumed during study (SD), *g*	41.6 (8.5)	48.6 (8.7)*
Mean blood alcohol concentration (SD), *g/dL*		
2:00 p.m. (start of driving task)	0.045 (0.01)	0.048 (0.02)
3:30 p.m. (end of driving task)	0.023 (0.01)	0.023 (0.01)

* $P < 0.05$.

Figure. **Mean steering deviation at 4.9-minute intervals throughout 90-minute simulator driving in patients with OSA (n = 38) and control participants (n = 20).**



Error bars represent SEs. ALC = low-dose alcohol; NS = normal sleep; OSA = obstructive sleep apnea; SR = sleep restriction. **Top.** NS versus SR conditions. **Bottom.** Normal sleep versus ALC conditions.

ence between groups, 4.8 cm [CI, 1.1 to 8.5 cm], t_{674} = 2.6, P = 0.01).

The change in steering deviation averaged over time in the alcohol condition versus normal sleep condition did not differ between groups. However, there was a statistically significant increase in steering deviation averaged over time in the alcohol compared with the normal sleep condition only in patients with OSA (difference from normal sleep: OSA group, 5.4 cm [CI, 2.8 to 8.1 cm], t_{306} = 4.1, P < 0.001; control group, 2.8 cm [CI, −0.7 to 6.3 cm], t_{322} = 1.6, P = 0.12; difference between groups, 2.6 cm [CI, −1.6 to 6.9 cm], t_{343} = 1.2, P = 0.23).

Braking Reaction Time

Condition had a significant main effect on braking reaction time ($F_{(2\ 77)}$ = 4.0; P = 0.02). Braking reaction time was statistically significantly slower after the sleep restriction condition (1.39 seconds [CI, 1.28 to 1.59 seconds]) than after normal sleep (1.22 seconds [CI, 1.14 to 1.30 seconds], t_{67} = 3.2, P < 0.01) but not after the al-

Table 3. **Participants Experiencing Crashes**

Condition	Control Group ($n = 20$), *n* (%)	Obstructive Sleep Apnea Group ($n = 38$), *n* (%)
Baseline	1 (5)	4 (10.5)
Sleep restriction	0 (0)	12 (32)
Alcohol consumption	0 (0)	8 (21)

cohol condition (1.34 seconds [CI, 1.21 to 1.46 seconds], $t_{79} = 1.3$, $P = 0.175$). There were no significant group differences in braking reaction time or interaction effects between groups.

Crashes

Table 3 shows the number and proportion of participants in both groups who experienced at least 1 crash during the simulator drives. Patients with OSA were approximately 25 times more likely to have at least 1 crash (OR, 25.4 [CI, 1.3 to 500.1]; $P = 0.03$). The high OR and CI in this model probably reflect the fact that only 1 crash occurred in the control group. Patients with OSA were significantly more likely to have at least 1 crash in the sleep restriction condition (OR, 4.0 [CI, 1.8 to 8.8]; $P < 0.01$) and the alcohol condition (OR, 2.3 [CI, 1.0 to 5.1]; $P < 0.05$) than in the normal sleep condition ($P < 0.01$).

Precrash Analysis

Only 1 person in the control group had 1 crash under the normal sleep condition and was excluded from this analysis. Among patients with OSA, 125 individual crashes occurred. Most (96%) crashes were off-road events; the remainder were collisions that occurred when a slow-moving truck appeared ahead in the driving lane or a stopping event happened. Microsleeps (OR, 19.2 [CI, 9.1 to 40.7]; $P < 0.01$) and prolonged eye closures (OR, 7.2 [CI, 3.3 to 15.7]; $P < 0.01$) were significant predictors of having at least 1 crash ($P < 0.01$).

DISCUSSION

This study shows that performance on a driving simulator is impaired in patients with OSA compared with healthy, age-matched control participants. The findings support previous studies showing reduced driving simulator performance (3, 6, 7) and increased risk for motor vehicle accidents (4, 5, 8–10) among patients with OSA. The important new findings are that 1) a single night of partial sleep restriction caused more steering impairment and a higher crash rate during a monotonous driving task in patients with OSA than in healthy control participants and 2) a low dose of alcohol similarly increased the crash rate in patients with OSA. The deterioration of steering in patients with OSA was also more influenced by time on task compared with healthy persons. The degree of experimental acute sleep restriction that was used is commonly experienced by shift workers (42) and others in the community (43). Similarly, the level of blood alcohol concentration achieved just before the drive (≤0.05 g/dL), which we found to impair driving simulator performance, equates to "responsible" social drinking and is currently legal with respect to driving in almost all legislatures. Thus, the finding that patients with OSA had more marked driving impairment than healthy persons as a result of both partial sleep deprivation and low-dose alcohol consumption has broad and direct clinical relevance.

This study did not address specific mechanisms for the increased vulnerability to sleep restriction and alcohol observed in patients with OSA. However, recent evidence suggests that changes in the prefrontal cortex may play an important role. The prefrontal cortex seems to be particularly vulnerable to the effects of sleep deprivation and alcohol (44–48) and is the brain region primarily responsible for executive function and vigilance (1). Driving simulation can be considered a global test of executive function because it comprises many different aspects of neurocognition, including vigilance, attention, visuospatial coordination, tracking, and non–target-related stimulus inhibition. Recent brain imaging studies suggest that functional changes in the prefrontal cortex may be responsible for many of the neurobehavioral deficits observed in patients with untreated OSA (1, 49–51) and in healthy persons after sleep deprivation (44–46).

A literature search using the PubMed database and the key words *sleep apnea*, *driving performance*, *driving simulation*, *traffic accidents*, *sleep restriction*, and *alcohol* revealed only 2 previous reports directly relevant to the present study. Using the same driving simulator, but with a 30-minute driving task, Desai and colleagues (34) found that after 1 night of total sleep deprivation, steering performance did not significantly differ between patients with mild OSA and control participants. Similarly, Wong and colleagues (37) found no significant difference between patients with moderate to severe OSA and control participants during a 30-minute driving simulator task after 40 hours of constant wakefulness. These results contrast with our findings after partial sleep restriction and could be due to a time dependence of performance decrements—the driving task was 1 hour longer in our study. We found that after the sleep restriction and alcohol conditions, deviations in driving simulator performance under the control condition seemed to emerge after only approximately 30 minutes on task. To explore this further, we repeated the statistical analysis of steering deviation, using the same mixed-model approach but on data only from the first 30 minutes of the driving task. In keeping with the findings of previous studies, no significant condition or group-by-condition differences were found. Thus, the shorter driving task used by Desai and Wong and their colleagues may have been insensitive for detecting condition-dependent performance decrements between patients with OSA and healthy control participants.

In driving simulation studies, steering deviation is generally found to be highly sensitive to sleepiness in monotonous driving environments (52). It is not surprising, therefore, that this variable was adversely affected in patients with OSA, more so after both sleep restriction and alcohol consumption. A surprising finding was that alcohol consumption, unlike sleep restriction, did not result in a greater steering decrement in patients with OSA than control participants. This may reflect the fact that blood alcohol concentrations decreased during driving simulation under the alcohol condition, in contrast to increasing homeostatic sleep pressure during the sleep restriction drive. Of note, although there were no group differences in steering after alcohol consumption, steering deviation progressively increased over time as blood alcohol concentrations decreased. Others have observed persistent depression of driving performance after alcohol administration and when blood alcohol concentrations have returned toward zero (53). As a result, it may be prudent to advise patients with OSA about the potential additional risks of alcohol. The increased crash rate in patients with OSA after alcohol consumption and sleep restriction appeared to be due principally to inattention and steering failure. "Off road" episodes accounted for 96% of crashes, and prolonged eye closures and microsleeps were more frequent in crash versus noncrash epochs. This finding supports the notion that sleepiness and falling asleep during driving substantially contribute to the more frequent simulator crashes (performance failures) observed in patients with OSA.

In contrast to steering performance and crash incidence, which were differentially impaired by sleep restriction and alcohol consumption in patients with OSA, braking reaction time did not differ between patients with OSA and control participants under any condition. Thus, it would seem that patients with OSA may not be able to sustain concentration as well as healthy persons during monotonous tasks, particularly under the additional stress of alcohol or sleep restriction. However, they can equally and relatively rapidly activate critical areas of the prefrontal cortex and engage alerting responses when novel stimuli suddenly appear (for example, a truck ahead).

Some caution needs to be exercised in extrapolating the findings of this driving simulation study to on-road driving. Nevertheless, driving simulators do measure the main aspects of real driving, including visual tracking and coordination, attention, reaction, and vigilance (32, 52). In direct comparison studies, simulator results tend to overestimate some driving abnormalities but correlate well with on-road driving performance (32). Simulators offer the advantage of assessing driving performance in a safe and controlled environment, particularly in such studies as ours, in which the effects of experimental interventions are unpredictable and potentially severe (that is, a crash occurring when the participant falls asleep).

A potential limitation in interpreting the results of this study is that the patients with OSA were on average heavier than the control participants, reflecting the fact that obesity is a major cause of OSA. It is very difficult to find body mass index (BMI)–matched control participants who do not have sleep-disordered breathing. The different BMIs of the 2 groups nevertheless suggest that overweight or obesity rather that sleep apnea could be responsible for the driving impairments observed in the OSA group. Although obese persons without sleep apnea have been reported to have disturbed sleep at night and to be sleepier in the day compared with persons of normal weight (54), we think it is highly unlikely that obesity was responsible for the driving impairments observed among the patients with OSA in our study. First, obesity itself is not known to be a risk factor for motor vehicle accidents. Second, a secondary analysis comparing the 10 lightest patients with OSA in our study (BMI, 26.1 kg/m^2 [SD, 2.0]) with the control participants (BMI, 24.5 kg/m^2 [SD, 2.5]) showed, as did the main results, significant group, condition, time, and group-by-condition interaction effects on steering deviation (mixed-model analysis; $P < 0.05$ for all comparisons).

Finally, this study did not address whether OSA treatment mitigates the increased vulnerability to alcohol and sleep restriction. These effects might be reversed with treatment (such as continuous positive airway pressure), but this hypothesis requires confirmation, particularly in light of previous observations that neurobehavioral deficits may persist in some patients with OSA despite treatment (20, 21).

With a prevalence of OSA of 7% or more among the middle-aged population, these findings have potentially important implications for patient and public safety (11–13). Patients with OSA are at increased risk for motor vehicle accidents (3–10). Many patients, however, even those with severe OSA, do not report symptoms of daytime sleepiness or falling asleep during routine driving. Our results suggest that some of the increased risk for motor vehicle accidents observed in patients with OSA may be attributable to common behaviors, such as alcohol consumption and sleep restriction (42, 55–57), that seem to amplify driving impairment and induce microsleeps. Thus, in sleep clinics with substantial waiting lists or delays between diagnosis and treatment, it seems prudent to warn patients of both the increased risk for driving accidents and the potential additional risks associated with consuming even small quantities of alcohol and with restricting their sleep.

The prevalence and severity of OSA are linked to aging and obesity, both of which are increasing globally (12, 58). In most patients with OSA, the condition remains undiagnosed and untreated (14, 15, 17). Reducing the accident risk due to OSA in the general population will therefore be challenging. However, this effort may be assisted by public health and self-help campaigns that warn of the likely additional risks of alcohol and sleep loss in people at high risk for OSA, such as obese, middle-aged, or elderly snorers. Future epidemiologic or case–control stud-

ies of accidents and OSA should pay specific attention to the possible interactive effects of alcohol and previous sleep time.

In conclusion, we have shown that compared with healthy individuals, patients with OSA are more vulnerable to the deleterious effects of low-dose alcohol and 1 night of moderate sleep restriction on driving performance variables. Thus, it may be advisable for untreated patients with diagnosed OSA or persons showing symptoms of OSA to avoid even legal doses of alcohol or sleep restriction before driving or performing other tasks in which safety is a factor.

From Repatriation General Hospital, University of Adelaide; Adelaide Institute for Sleep Health; University of South Australia, Center for Sleep Research; and Flinders University, Park, Australia.

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