Sleepiness Combined with Low Alcohol Intake in Women Drivers: Greater Impairment but Better Perception than Men?

Pauline R Barrett, BSc; James A Horne, PhD; Louise A Reyner, PhD

Sleep Research Centre, Loughborough University, Loughborough, Leicestershire, UK

Objectives: We have previously shown that low blood alcohol concentrations (BAC) (at approximately half the legal driving limit in both the United Kingdom and in most states in the United States) exacerbate moderate sleepiness (sleep during the night restricted to 5 hours) and markedly impair driving ability in young men. There are distinct physiologic sex differences in the absorption, metabolism, and central nervous system effects of alcohol; therefore, we replicated this earlier study, this time using women and using similar BAC to provide a comparison.

Design: 2 × 2 repeated-measures counterbalanced.

Setting: 2-hour drive from 2:00 pm in an instrumented car on a simulated highway.

Interventions: Alcohol versus control and normal sleep versus sleep restricted to 5 hours.

Measurements and Results: Driving impairment (lane drifting), subjective sleepiness, and electroencephalographic measures of sleepiness. Sleep restriction significantly worsened driving performance and subjective sleepiness as it had in men. Surprisingly, unlike men, women showed no apparent adverse effects of alcohol alone on these indexes; they seemingly compensated for the effects of alcohol. However, alcohol’s effects were profound when alcohol was combined with sleep restriction; nevertheless, women, unlike men, were aware of this enhanced sleepiness. After alcohol ingestion, the electroencephalogram showed increased beta activity, an effect not seen in men, indicating a differential pharmacokinetic effect of alcohol on the central nervous system, compensatory effort, or both. Debriefing questionnaires indicated that women were aware of the varying risks of driving under these different conditions.

Conclusions: Legally “safe” BAC markedly worsen sleepiness-impaired driving in women. However, they seem to be aware of their impaired driving and are able to judge the degree of risk entailed. Such an attitude may contribute to the lower incidence of sleep- or alcohol-related crashes in women compared with men.

Key Words: Sleepiness, alcohol, women, driving

Citation: Barrett PR; Horne JA; Reyner LA. Sleepiness combined with low alcohol intake in women drivers: greater impairment but better perception than men? SLEEP 2004;27(6):1057-62.

INTRODUCTION

A RECENT EPIDEMIOLOGIC STUDY1 FOUND THAT SLEEPINESS COMBINED WITH BLOOD ALCOHOL CONCENTRATIONS (BAC) AS LOW AS 0.010 G OF ALCOHOL PER 100 ML OF BLOOD (0.01%) WAS A SIGNIFICANT CAUSE OF FATAL ROAD CRASHES. We2 have also shown, using a real-car simulator, that low BAC (about 0.03% in the Breathalyzer “pass” region and less than half the legal limit to drive in the United Kingdom and most states in the United States) combined with sleepiness markedly worsen afternoon driving in young men. Moreover, subjectively these young men seemed unable to perceive that the alcohol had significantly increased their sleepiness, as reflected by both the electroencephalogram and a deterioration of their driving performance.

There are sex differences in the physiologic processing and bioavailability of alcohol, to the extent that women achieve higher BAC than men after drinking equivalent amounts of alcohol, even when doses are adjusted for body weight.3 Women also have lower levels of gastric alcohol dehydrogenase, resulting in less alcohol being metabolized before it reaches the bloodstream (higher BAC).4 Once absorbed, alcohol distributes into body water, but because women have a lower percentage of body water (higher body fat), a dose of alcohol based on body weight has less water in which to distribute (higher BAC).5 On the other hand, women have a larger liver mass per kilogram of body weight, which allows them to metabolize alcohol faster once it enters the liver, leading to quicker alcohol elimination from the body.6,7 Therefore, we would expect women (in comparison with men and given the same dose of alcohol) to show an initial higher BAC and consequently greater impairment, followed by an earlier reduction both in BAC and its consequences. There are no consistent findings with regard to the menstrual cycle affecting alcohol pharmacokinetics.8

Even when these sex differences have been accounted for, and target BAC are the same for both sexes, sex differences still occur. In the few studies comparing moderate BAC (eg, 60 mg %), women showed greater impairment with divided attention tasks8 although, subjectively, they were less likely to notice the effect of alcohol.

In the United Kingdom, only about 10% of sleep-related crashes are caused by female drivers9 for reasons that are not clear, although, women are probably less exposed to sleepy driving. The extent to which low BAC (ie, Breathalyzer “pass” levels) may have contributed to these crashes is unknown. The effect of modest alcohol consumption combined with sleepiness on driving performance has not been investigated in women, and only 1 study has specifically looked at the effects of alcohol on (simulated) monotonous driving in non–sleep-deprived women (there was no comparable male group).10 During the afternoon, their driving was severely impaired by BAC well below legal limits. The present study provides a direct sex comparison to the earlier study with men,2 by assessing the effects of both low BAC

Disclosure Statement
This is not an industry-sponsored study. Drs. Barrett, Horne, and Reyner have indicated no financial conflicts of interest.

Submitted for publication February 2004
Accepted for publication June 2004

Address correspondence to: James A Horne, PhD, Sleep Research Centre, Loughborough University, Loughborough, Leicestershire, LE11 3TU, UK; Tel: 44 1509 223004; Fax: 44 1509 228480; E-mail: j.a.horne@lboro.ac.uk
and sleepiness alone, and in combination, on afternoon simulated driving performance in women. The experimental protocol up to the end of the drive was identical to that used in the previous study except that, the women in this study, compared to the men in the previous study, consumed slightly lower amounts of alcohol to allow for sex differences in alcohol pharmacokinetics and to provide equivalent target BAC. After the drive, both groups were debriefed, although with the men this had not been formalized into a questionnaire until half way through that study.

METHOD

Participants

Twelve women (mean age, 20.7 years; SEM, 0.1 years) were recruited via advertisements and screened at an initial interview. They were healthy (medication free, with the exception of the oral contraceptives [n = 4]) nonsmokers with a mean weight of 62.8 kg (SEM, 2.6 kg) and a mean body mass index of 23.1 (SEM, 0.7); they were experienced drivers (having held a full United Kingdom driving license for more than 2 years and driving on average more than 3 hours per week), good sleepers (no sleeping complaints, slept regular hours, scored less than 10 on the Epworth Sleepiness Scale,11 took fewer than 1 daytime nap per month), were low to moderate caffeine consumers (0-4 cups daily), and were regular but not excessive alcohol drinkers (mean, 20.2 units per week; SEM, 1.5). The procedures were fully explained, and the participants signed consent forms and were paid to participate. On an initial day, separate from the main study, they underwent a 30-minute practice drive in the simulator to check for any potential adverse effects. The study was approved by the university ethics committee.

Design and Procedure

The following protocol was identical to that adopted for men,2 using a repeated-measures, four-condition, 2×2, blind (for alcohol) balanced design, comprising (1) a normal night’s sleep without alcohol (BASELINE), (2) reduced sleep to 5 hours without alcohol (SLEEPY), (3) a normal night’s sleep plus alcohol (ALCOHOL), and (4) reduced sleep to 5 hours plus alcohol (COMBINED). Conditions were given at least a week apart. To ensure compliance with sleep instructions, participants wore wrist actimeters (Cambridge Neurotechnology, Cambridge, UK) the night prior to each condition. These were able to confirm either normal sleep time (approximately 8 hours) or that sleep was restricted to 5 hours. The latter was accomplished by a bedtime of 2:00 AM and waking at 7:00 AM.

No alcohol was consumed 36 hours prior to arrival at the laboratory, and no caffeine was consumed after 6:00 PM the evening before. Participants were asked to refrain from eating after 10:00 AM on the morning of the drive and to have consumed only a light breakfast. The simulated drive took place from 2:00 PM to 4:00 PM, a time of day when sleep-related vehicle crashes are more evident and that is linked to the natural circadian dip in alertness.9 Participants arrived at the laboratory at 1:00 PM and provided a urine sample that was screened (6 drug MultiTest 1; Suresscreen Diagnostics, Derby, UK) for recreational drug use. This was followed by a Breathalyzer test with a calibrated Alcometer (model SD 400 – Lion Laboratories, Glamorgan, UK) to confirm prior abstinence from alcohol. Two cheese rolls were consumed at about 1:15 PM followed by a 375-mL drink of orange juice. In both ALCOHOL and COMBINED conditions, the drink contained 65 mL of 37.5% proof vodka, compared to the 75 mL that we had previously used in men,2 consumed by 1:30 PM. To disguise the lack of alcohol in the other conditions, the rim of the glass was dipped in vodka. Breathalyzer tests were conducted on all participants at 1:45 PM, at 1:55 PM just before the drive, and again at 4:00 PM upon completion of the drive.

Simulator

The driving simulator consisted of an immobile car with a full-size, interactive, computer-generated road projection of a dull monotonous dual carriageway. The image was projected onto a 2.0-m × 1.5-m screen, located 2.3 m from the windscreen of the car. The road had a hard shoulder and simulated auditory “rumble strips,” with long straight sections followed by gradual curves. Participants sat in the driver’s seat and were asked to drive in the left-hand lane at all times (unless overtaking) and at their normal cruising speed (identical instructions to those given to the men).2 Lane drifting is the most common manifestation of sleepy driving, and during the drive, a car wheel that touched (or crossed) the left rumble strip or central white line was identified as a driving “incident.” Split-screen video footage of the roadway and driver’s face (filmed with an unobtrusive infrared camera) enabled the cause of the incident to be determined. Those caused by sleepiness (eg, eye closure or vacant staring ahead) were logged as a “sleep-related incident.” As a further check for sleep-related incidents, the electroencephalogram (EEG) and electrooculogram (EOG) were examined respectively for alpha or theta intrusions and possible “eye rolling.”

Subjective Sleepiness

Throughout the drive, and every 200 seconds, participants were verbally prompted to report their subjective sleepiness and responded using a 10-point scale adapted from the Karolinska Sleepiness Scale12: 1 = extremely alert; 2 = very alert; 3 = alert; 4 = rather alert; 5 = neither alert nor sleepy; 6 = some signs of sleepiness; 7 = sleepy, no effort to stay awake; 8 = sleepy, some effort to stay awake; 9 = very sleepy, great effort to keep awake, fighting sleep; 10 = extremely sleepy, can’t keep awake. The scale was present at all times in front of the driver on the car’s dashboard. Other than this subjective response request, the experimenter did not engage in any conversation with the driver and remained out of their sight.

EEG and EOG

Electrodes were attached for 2 channels of EEG (main channel C3-A1, backup channel C4-A2). To identify “eye rolling”, there were EEG channels (electrodes 1 cm lateral to and below left outer canthus and 1 cm lateral to and above right outer canthus; both referred to the center of the forehead). Interelectrode distance was carefully maintained between conditions by using the 10-20 system for electrode placement. The EEG and EOG were collected using Embla (Flaga Medical Devices, Reykjavik, Iceland) and spectrally analyzed using Somnologica (Flaga) in 4-second epochs. Low and high band-pass filtering of the EEG at >
30 Hz and < 0.3 Hz removed slow eye movements and muscle artifact. An increase of EEG power in the alpha (8-11 Hz) and theta (4-7 Hz) ranges indicated an increase in sleepiness.\textsuperscript{12,13} EEG power in the 4- to 11 Hz (alpha and theta combined) range was averaged in 1-minute epochs. Because there are individual differences in EEG power, and to allow comparisons between conditions, we\textsuperscript{2} standardized each individual’s power in these ranges, for all conditions, by taking the difference between each 1-minute epoch and the individual’s mean value over the first 30 minutes of BASELINE EEG data and divided this by the standard deviation around the mean of that 30 minutes of data. Because of unexpected findings with the EEG (see below), we undertook a further analysis, concentrating on beta (14-26 Hz) EEG activity, which can be increased by the use of alcohol and which can mask alpha and theta activity, but is usually not so evident at low BAC.\textsuperscript{14} Increases in beta activity can also reflect heightened arousal, anxiety, and apprehension. Analysis and standardization of beta activity (ie, beta power) was exactly the same as that for the 4- to 11 Hz activity.

Debriefing Questionnaire

On completion of each drive, participants were asked, via a short structured questionnaire, the following questions:

A. How would you class your driving performance, here, compared with your normal driving? To which they could respond: 1 = much better than normal, 2 = moderately better than normal, 3 = normal, 4 = moderately worse than normal, and 5 = much worse than normal.

B. How willing would you be to drive for an unimportant but gratifying reason? To which they could respond: 1 = extremely willing, 2 = moderately willing, 3 = neither willing or unwilling, 4 = moderately unwilling, and 5 = not willing at all.

C. How willing would you be to drive for an important but avoidable reason? Same responses as for B.

D. How willing would you be to drive for an urgent reason? Same responses as for B.

E. Do you think you had consumed alcohol just before the drive? (Yes/No).

Statistical Analyses

Sleep-related incidents, EEG, and subjective sleepiness were averaged into 30-minute epochs per participant and condition. Sleep-related incidents were square root to further normalize the data. Two-way (condition \times time) repeated-measures analyses of variance were applied (using the Huynh-Feldt [\(\epsilon\)] adjustment). All degrees of freedom shown are adjusted for \(\epsilon\) when appropriate. Tukey tests were employed as posthoc tests, and findings with a significance level of \(P < .05\) are reported. For sex-difference comparisons, univariate analyses of variance were utilized instead. Friedman tests (including posthoc analyses) were used to analyze the results of the questionnaire.

RESULTS

Mean sleep times were 486.5 minutes (SEM 12.5) and 289.2 minutes (SEM 3.5) for “normal” sleep and sleep-restricted conditions, respectively. For ALCOHOL and COMBINED, BAC taken 5 minutes prior to the start of the drive were, respectively, 0.043 g/100 mL blood (SEM 0.003 g/100 mL) and 0.046 g/100 mL blood (SEM 0.002 g/100 mL). Following the drive, and with both alcohol conditions, all BAC had fallen to < 0.004 g/100 mL.

Driving Performance

Figure 1 shows the mean number of sleep-related incidents per condition, in 30-minute epochs. There was a significant effect of condition (\(F_{2,6,28,2} = 15.12, P < .001, \epsilon = 0.85\)) on the number of sleep-related incidents. Posthoc tests revealed that COMBINED produced more sleep-related incidents than any other condition. There was no difference in the number of sleep-related incidents between BASELINE and ALCOHOL, but for both, there were significantly fewer sleep-related incidents than for the SLEEPY condition. For the whole 2-hour drive, the percentage increase in sleep-related incidents for SLEEPY over BASELINE was 784%, for ALCOHOL this was 99%, and for COMBINED, it was 1926%. There was a significant effect of time (\(F_{2,6,29,1} = 9.86, P < .001, \epsilon = 0.88\)) with posthoc tests showing that, in the first 30-minute epoch, fewer sleep-related incidents occurred than at any other time, and fewer sleep-related incidents occurred in the fourth 30-minute epoch compared with the second and third 30-minute epochs. There was no significant interaction between condition and time.

Subjective Sleepiness

The mean subjective-sleepiness responses for each condition given every 200 seconds throughout the drive can be seen in Figure 2, where there was a significant effect of condition (\(F_{2,8,12,2} = 4.45, P < .001, \epsilon = 0.94\)). Posthoc tests were significant for COMBINED compared with all other conditions, which mirrored the situation with sleep-related incidents. There was no difference in this sleepiness between BASELINE and ALCOHOL, nor between ALCOHOL and SLEEPY. However, under BASELINE conditions, participants were significantly more alert than during SLEEPY conditions. There was a significant effect of time (\(F_{2,5,27,9} = 28.94; P < .001, \epsilon = 0.85\)). Posthoc tests showed significantly more alertness during the first 30 minutes than at any other time and more alertness during the fourth 30-minute epoch compared with the third epoch. Again, there was no significant

![Figure 1](image-url)
interaction between condition and time.

**Electroencephalogram**

Unlike our earlier findings in men, there was no significant difference between conditions for 4- to 11-Hz power, neither was there any significant effect of time nor interaction by time. However, we noticed that, compared with the men, these women generally showed much more beta (14-26 Hz) power during both alcohol conditions. The outcome from this (see Method) is seen in Figure 3. There was some partial loss of data from 2 participants during SLEEPY conditions (first two 30-minute epochs for 1 participant and first 30 minutes for another). It can be seen that whereas beta power was similar for both BASELINE and SLEEPY conditions across the 4 epochs, the 2 alcohol conditions showed a marked rise after the first 30 minutes. Collapsing the data across time for a 2 × 2 (with and without alcohol vs normal or reduced sleep) analysis of variance was significant for alcohol ($F_{1,11} = 5.21; P < .043$, $\varepsilon = 1$).

**Debriefing Questionnaire**

After the drive, all participants correctly identified the alcoholic drinks, with the exception of 2 “not sure” responses in the ALCOHOL condition, despite the trial being “blind” to its presence. Table 1 shows the mean responses to the other post-drive questions. Friedman tests showed that there was a significant effect of condition on subjective ratings of driving performance ($\chi^2 = 14.138$, df = 3, $P < .003$). A posthoc Friedman test confirmed that participants rated their driving better during BASELINE when compared to COMBINED conditions. There were also significant effects of condition for all willingness-to-drive questions (Question B: $\chi^2 = 13.933$, df = 3, $P < .003$; Question C: $\chi^2 = 16.013$, df = 3, $P < .001$; Question D: $\chi^2 = 13.344$, df = 3, $P < .004$). Posthoc tests again confirmed that participants were more willing to drive during BASELINE conditions for each of the 3 scenarios than during COMBINED conditions. Interestingly, despite a trend to rate their driving better during the ALCOHOL condition compared with the SLEEPY condition, the women also showed a trend to be less willing to drive during the former condition.

**Additional Effects of Alcohol on Sleepiness: Women versus Men**

Despite similarly low BAC (an independent $t$ test showed no difference) for these women compared with the 12 men from the previous study (men: mean age 22.7 years, SEM 0.6 years; weight 74.8 kg, SEM 2.1; body mass index 23, SEM 0.6), it was clear that for the women, the additional effect of alcohol on driving and subjective sleepiness seemed worse. This can be seen in Figure 4 showing the difference between SLEEPY and COMBINED conditions for incidents and subjective sleepiness, per 30-minute epoch. However, despite a clear trend for sleep-related incidents to be worse for women following COMBINED conditions, an analysis of variance (sex × time) showed no significant sex differences, although this was significant for subjective sleepiness ($F_{3,88} = 6.748, P < .011$, $\varepsilon = 1$). There was a significant

![Figure 2](image1)

**Table 1—Responses to Postdrive Questionnaire**

<table>
<thead>
<tr>
<th>Condition</th>
<th>Driving performance compared to normal</th>
<th>Willingness to drive in an unimportant yet gratifying situation</th>
<th>Willingness to drive in an important but avoidable situation</th>
<th>Willingness to drive in an urgent situation</th>
</tr>
</thead>
<tbody>
<tr>
<td>BASELINE</td>
<td>3.92 (0.19)</td>
<td>3.33 (0.36)</td>
<td>2.92 (0.40)</td>
<td>1.92 (0.29)</td>
</tr>
<tr>
<td>SLEEPY</td>
<td>4.33 (0.14)</td>
<td>3.58 (0.38)</td>
<td>3.33 (0.38)</td>
<td>2.33 (0.43)</td>
</tr>
<tr>
<td>ALCOHOL</td>
<td>4.00 (0.21)</td>
<td>4.08 (0.34)</td>
<td>3.92 (0.42)</td>
<td>3.00 (0.46)</td>
</tr>
<tr>
<td>COMBINED</td>
<td>4.75 (0.25)</td>
<td>4.67 (0.26)</td>
<td>4.58 (0.26)</td>
<td>4.00 (0.35)</td>
</tr>
</tbody>
</table>

Data are presented as mean (SEM). Driving performance: 1 = much better than normal, 3 = normal, 5 = much worse than normal. Willingness to drive: 1 = extremely willing, 5 = not willing at all.
effect of time on Sleep-related incidents ($F_{3.88} = 3.982, P < .010, \epsilon = 1$), with less of an increase in the first 30-minute epoch compared with the second epoch. Previously, men had shown a non-significant increase in subjective sleepiness with the addition of alcohol, despite significantly increased incidents, whereas, here, women showed a significant increase in both sleepiness and sleep-related incidents (see above).

**DISCUSSION**

While the SLEEPY condition caused significant increases in driving impairment and subjective sleepiness compared with the BASELINE condition, the BAC equal to approximately half of the legal driving limits in the United Kingdom and United States had no such effect, unlike the previous findings in men, where the ALCOHOL condition did impair sleepiness and driving ability. We appreciate that, in making comparisons between the present study in women and the previous one on men, there is the possibility of intervening variables other than sex that might have differentially affected the outcomes. However, we emphasise that the protocols for these 2 studies were identical apart from the 2 caveats mentioned at the end of the introduction section of this paper. Comparisons of this nature between results from the sexes, in relation to alcohol and sleepiness, have never been presented before and, despite this possible shortcoming, do present potentially very interesting findings.

The lack of any significant effect with alpha and theta power in the EEG in these women also contrasted with the men. But unlike the findings in men, in the women, alcohol produced a marked increase in beta power during both the non–sleep-restricted ALCOHOL and sleep restricted COMBINED conditions. One obvious explanation is that alcohol was having a direct pharmacologic effect on the EEG that was not evident in men, despite both groups having almost identical BAC levels. There is little information in the scientific literature to guide us further on this matter. The main EEG study on the effects of relatively low BAC on normal (nonalcoholic) people, confined itself to men.

Another possibility, given that beta activity also reflects arousal, anxiety, and apprehension, is that the women drivers were applying more compensatory effort under both alcohol conditions, which was sufficient to maintain normal driving performance when on its own (without sleep restriction). It should be remembered that, after the drive, almost all the women knew they had consumed alcohol (because of the sensation it produced). However, when combined with sleepiness, alcohol impaired driving beyond any compensatory effort and was accompanied by a significant increase in subjective sleepiness and a reduction in self-assessed driving ability. Of course, both these explanations may be applicable.

The significant rise in subjective sleepiness in women, when alcohol was combined with sleep restriction, contrasts with the findings in men who, as a group, hardly noticed this subjective change despite a significant worsening of their driving; this is illustrated in Figure 4 (mainly in the second 30-minute epoch). It seems that women are more aware of more profound sleepiness and consequent driving impairment. Moreover, from Table 1, it seems that women will abstain from driving when impaired. Unfortunately, we only have comparable debriefing data for 6 of the 12 men (insufficient men for statistical comparison).

In the United Kingdom, men are responsible for the majority (90%) of sleep-related crashes and comprise 85% of those drivers over the legal limit when they are tested with the Breathalyzer. However, men have a higher exposure to driving than women, especially during the early morning hours when sleep restricting crashes are prevalent. Nevertheless, young men see themselves as relatively immune to driving hazards, underestimate personal risk, and overestimate their driving competence in comparison with women. Men also have a more optimistic view of their driving skills, and although they do perceive driving to be a dangerous activity, they do not perceive this to apply personally. They also rate driving with a BAC slightly over the legal limit as less serious than do women. All these factors support the hypothesis that sex differences in sleepiness- or alcohol-related, or sleepiness- and alcohol-related accident involvement are, at least partially, due to women’s better or more conscientious perception of sleepiness or alcohol effects in relation to driving impairment.

**ACKNOWLEDGEMENTS**

This research was funded by the United Kingdom Department for Transport. We would like to thank Mr. Martin Boddy for technical assistance.

**REFERENCES**