



# How do prolonged wakefulness and alcohol compare in the decrements they produce on a simulated driving task?

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Received 14 June 1999; received in revised form 31 March 2000; accepted 28 April 2000

## Abstract

The effects of alcohol ingestion were compared with those of prolonged wakefulness on a simulated driving task. Eighteen healthy, male subjects aged between 19 and 35 years drove for 30 min on a simulated driving task at blood alcohol concentrations of 0.00, 0.05 and 0.08%. Subjective sleepiness was assessed before and after the driving task. Driving performance was measured in terms of the mean and standard deviation (S.D.) of lane position (tracking); the mean and S.D. of speed deviation (the difference between the actual speed and the posted speed limit); and the number of off-road occurrences. Ratings of sleepiness increased with increasing blood alcohol concentration, and were higher following the driving task. With increasing blood alcohol concentration, tracking variability, speed variability, and off-road events increased, while speed deviation decreased, the result of subjects driving faster. The results were compared with a previous study examining simulated driving performance during one night of prolonged wakefulness [Arnedt, J.T., MacLean A.W., 1996. Effects of sleep loss on urban and motorway driving stimulation performance. Presented at the Drive Alert... Arrive Alive International Forum, Washington DC], using an approach adopted by Dawson and Reid [Dawson, D., Reid, K., 1997. Fatigue, alcohol and performance impairment. *Nature* 388, 23]. For mean tracking, tracking variability, and speed variability 18.5 and 21 h of wakefulness produced changes of the same magnitude as 0.05 and 0.08% blood alcohol concentration, respectively. Alcohol consumption produced changes in speed deviation and off-road occurrences of greater magnitude than the corresponding levels of prolonged wakefulness. While limited to situations in which there is no other traffic present, the findings suggest that impairments in simulated driving are evident even at relatively modest blood alcohol levels, and that wakefulness prolonged by as little as 3 h can produce decrements in the ability to maintain speed and road position as serious as those found at the legal limits of alcohol consumption. © 2001 Elsevier Science Ltd. All rights reserved.

**Keywords:** Alcohol; Prolonged wakefulness; Driving; Simulated driving

## 1. Introduction

This study addresses the comparative effects of alcohol and prolonged wakefulness on driving performance. According to the US Department of Transportation National Highway Traffic Safety Administration, in 7% of accidents and 39% of fatalities in 1997 either a driver or a non-occupant had a blood alcohol concentration

(BAC) of at least 0.01%. Where fatalities occurred, 30% of drivers or non-occupants were found to have a BAC of 0.10% or higher, the legal limit in most states (US Department of Transportation, 1998). The values in Canada for 1996, where the legal limit in most provinces is 0.08%, are similar with 35% of fatalities involving alcohol (Transport Canada, 1998).

Sleepiness, like alcohol, is a factor that impairs functioning at the level of the central nervous system (CNS) and which can similarly jeopardize the safety of both the sleepy driver as well as others on the road. Although recognized for several decades as a major contributing factor to accidents (Kearney, 1966; Sussman et al., 1985), there has been a recent resurgence of

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interest in the systematic study of sleepiness (e.g. Dinges, 1995; Horne and Reyner, 1995a,b; Lyznicki et al., 1998). Sleepiness has been directly implicated in from as low as 1–3% (Knippling and Wang, 1995; US Department of Transportation, 1998) to as high as 35–42% (Dingus et al., 1987; Leger, 1994) of automobile fatalities. Despite this discrepancy, what seems apparent is that sleepiness-related accidents are insufficiently recognized (Brown, 1994; Åkerstedt et al., 1994) and a major financial burden (Leger, 1994; Webb, 1995).

Apart from being risk factors for motor vehicle accidents, sleepiness and alcohol share other elements that make them of interest from both a theoretical and practical perspective. It is well recognized that the group at highest risk for both types of accidents comprises of young adult males between the ages of 18–34 years (Pack et al., 1995; US Department of Transportation, 1998). In addition, crashes attributable to the driver falling asleep follow the natural circadian variations in sleepiness, with the majority occurring at night between 23:00 and 07:00 h, and a smaller secondary peak, particularly evident in older drivers, in the mid afternoon (Mitler et al., 1988; Summala and Mikkola, 1994). Alcohol-related accidents increase monotonically throughout the day, reaching a peak occurrence, similar to sleepiness-related accidents, between the hours of midnight and 03:00 h (Schwing, 1990; US Department of Transportation, 1998). During these hours sleepiness and alcohol frequently occur in combination, and may interact synergistically to produce an even greater risk for automobile accidents (Roehrs et al., 1994; Corfitsen, 1996).

While the deleterious effects of alcohol on performance are reasonably well quantified (Koelega, 1995) and many countries have established a legal limit for alcohol consumption in relation to driving, similar standards do not exist for sleepiness. One approach towards the development of such a standard is to evaluate alcohol consumption and sleepiness in terms of a common measure, namely the performance decrements produced by each. Such an approach has been adopted by Dawson and Reid (1997). On a (non-driving) tracking task these authors compared performance decrements due to alcohol with those produced by sustained wakefulness. The results indicated that after 19 h of sustained wakefulness (at 03:00 h) performance deteriorated to a level equivalent to that observed at a BAC of 0.05%; after 24 h (at 08:00 h the following day), performance was similar to a BAC of 0.10% (Dawson and Reid, 1997). The authors concluded that moderate levels of fatigue can produce decrements in performance equivalent to those produced by BAC levels determined by law to prohibit safe automobile operation.

The present study extends the findings of Dawson and Reid (1997) by comparing the performance of two groups of subjects on a simulated driving task. Such a task offers advantages over a simple tracking task, in that it replicates at least some aspects of real driving (e.g. maintaining speed and lane position) and has been shown to be sensitive to the impairments produced by both sleepiness (Roehrs et al., 1994) and alcohol (Gawron and Ranney, 1988). The first group, described below, was tested at BACs of 0.00, 0.05 or 0.08%; the second group, reported on previously (Arnedt and MacLean, 1996), underwent one night of prolonged wakefulness and drove on the driving simulator at 24:00, 02:30, 05:00, and 07:30 h. The results from the latter study indicated that simulated driving performance deteriorated progressively with the increasing time awake.

The first aim of the present study was to examine the sensitivity of performance in a driving simulator to impairments produced by BACs of 0.00, 0.05 and 0.08%. The 0.05% level was selected to be consistent with the legal limit in most European countries, and it has been argued that it should also be adopted in countries where the limit is currently either 0.08 or 0.10% (Howat et al., 1991). It was predicted that performance would deteriorate with increasing blood alcohol concentrations. The second aim of the study was to compare the results of the present study with those obtained earlier (Arnedt and MacLean, 1996). It was expected that prolonged wakefulness would produce levels of performance decrement comparable with the equivalent BACs established by Dawson and Reid (1997).

## 2. Methods

### 2.1. Subjects

Subjects were recruited through advertisements and through the subject pool for students enrolled in the Introductory Psychology course at Queen's University. They were 18 males between the ages of 19 and 35 years (mean = 19.9, S.D. = 2.3) who met the inclusion criteria, agreed to comply with the requirements of the study, and gave their informed consent. Inclusion criteria were, good health; non-smoking; a valid driver's license; a regular sleep schedule; moderate to good sleeper (Monroe, 1967); neither extreme morning nor evening type (Circadian Rhythm Questionnaire; Horne and Östberg, 1976); no evidence of alcohol abuse, indicated by a score of less than nine on the Alcohol Dependence Scale (Skinner and Horn, 1984) or drug abuse, indicated by a score of less than five on the Drug Abuse Screening Test (Skinner, 1982); normal levels of daytime sleepiness, evidenced by a score below 14 on

the Epworth Sleepiness Scale (Johns, 1991, 1992); and no use of medications with sleep altering qualities. The study was approved by the Ethics Committee in the Department of Psychology at Queen's University.

Subjects were instructed to go to bed between 23:00 and 01:00 h and get up between 07:00 and 09:00 h on the nights before the experimental days. Napping was not permitted on these days. Drugs and alcohol were prohibited beginning 48 h prior to the first experimental day and then for the duration of the study. Subjects were requested to abstain from caffeine a minimum of 24 h prior to each experimental day, and otherwise to consume it only in moderation.

Compliance with these conditions was assessed by sleep and activity logs that subjects kept throughout the study.

Subjects were instructed to eat a light meal approximately 2 h prior to coming to the laboratory on the experimental days. On completion of the study, subjects received either \$30.00 or a 5% addition to their overall course mark.

## 2.2. Dependent measures

### 2.2.1. Subjective

The Stanford Sleepiness Scale (SSS) (Hoddes et al., 1973) and a modified version of the Stanford Scale (Modified Stanford Scale (MSS); MacLean et al., 1992) were used to assess subjective sleepiness. The former requires subjects to rate their current level of sleepiness on a 1–7 scale according to a series of descriptors, with higher ratings indicating greater subjective sleepiness. The latter requires subjects to respond 'Yes/No' to 24 statements about their current level of sleepiness. This questionnaire identified two distinct factors described as, respectively, 'an energetic or activating factor' (Factor 1; range 0–13) and a factor 'related to consciousness, sleepiness and a loss of control over remaining awake' (Factor 2; range 0–11), consistent with the multidimensional nature of sleepiness proposed by Broughton (1992). The dependent measures were the scores on the SSS and the two factors of the MSS.

### 2.2.2. Performance

The York Driving Simulator (York Computer Technologies) is equipped with an accelerator, brakes and a steering wheel that subjects use to control the simulated car. A digital speedometer is located on the dashboard. The simulator software runs on a personal computer system, and an electronic interface provides driver inputs to the software (steering, brakes, accelerator). Simple line graphics are used to portray objects and to induce a sense of apparent motion by using real-time perspective generation. The simulator presents a forward view from the driver's seat of a motorway road scene, with standard lane markings and signs and sig-

nals appropriate for the road environment. The subject navigates within the computer driving environment interactively just as one would navigate a car in the real world, obeying all road signs and traffic signals, and maintaining the car in the appropriate lane on the road.

The motorway route consisted of an S-shaped four lane road loop with long, straight stretches, few turns and speed limits between 70 and 100 km/h. Subjects drove for 30 min, and were instructed to stay in the right hand lane and to obey all lane markings and speed signs. There were no other cars on the simulated road.

The dependent measures included (1) tracking, measured as the deviation in feet of the center of the vehicle from the center of the right hand lane; (2) tracking variability, the S.D. of tracking; (3) speed deviation, calculated as the difference in speed of the vehicle from the speed limit; (4) speed variability, the standard deviation of speed deviation; and (5) off-road incidents, calculated as the number of times that the simulated vehicle left the road.

## 2.3. Procedure

Subjects attended a 1 h training session at the Sleep Laboratory 48 h prior to their first experimental day, where they were weighed; assigned to the order of conditions in the study; provided instructions for the sleep and activity logs; oriented to the Borkenstein Breathalyzer (Centre of Forensic Sciences, Toronto, Ont., Canada; Serial #1348); oriented to the driving simulator; and given four consecutive ten-minute training sessions on the driving simulator.

The three experimental conditions (0.00, 0.05, and 0.08% BAC) were administered according to two di-gram-balanced Latin Square designs. Subjects were informed of their condition allocation at the training session, and underwent all the three test conditions at the same time-of-day either 14:00, 17:00 or 20:00 h. A balanced placebo design (Marlatt and Rohsenow, 1980) was not used based on findings that subjects cannot be deceived with regard to beverage content at BACs greater than about 0.05% (Martin and Sayette, 1993; Sayette et al., 1994). In addition, unblinding subjects to the nature of the condition afforded the study greater ecological validity.

On the experimental days, subjects received two 10-min training sessions on the driving simulator to re-familiarize them with the instrument. Subjects then consumed two 250-ml drinks containing either only tonic water or tonic water mixed with 100% ethyl alcohol (USP). Alcohol doses were calculated per litre of body water computed from the height, weight and age of each subject (Watson et al., 1981), to attain peak BACs of 0.05 or 0.08%. Subjects were given one half hour to ingest the drinks, and at 30 min post-ingestion,

completed the SSS and the MSS, and then drove on the motorway route of the driving simulator for 30 min. These subjective scales were also completed at the conclusion of the 30-min driving task. Subjects were not permitted to consume food or caffeinated beverages during testing. In case of emergency, a physician was on call.

Breath samples were analyzed a minimum of four times on each experimental day. The first sample was provided by subjects on arrival at the Sleep Laboratory to ensure compliance with the study protocol. The second and third were provided before and after the 30-min driving sessions on the simulator and the final analysis was conducted just prior to subjects leaving the laboratory. Subjects whose BAC just prior to driving was more than 0.005% below the target BAC received an additional 250-ml drink containing the additional alcohol estimated to be necessary to reach the desired BAC. These drinks were consumed within 5 min, and another breath sample was taken 10 min later.

At the conclusion of each experimental day, subjects rated their certainty of having consumed alcohol on a 0–100 scale and completed a symptom checklist to determine whether they experienced any adverse effects from the alcohol. The ratings indicated that subjects did not believe that they were being deceived with regard to the content of their drinks in the three experimental conditions. No one experienced adverse reactions to the alcohol. Subjects in the alcohol conditions remained in the laboratory until their BAC was less than 0.05%, after which time they were either personally escorted to their place of residence or sent home in a taxi.

### 3. Results

In general, the data were analyzed using split plot analyses of variance in which Time (14:00, 17:00 and 20:00 h) was extracted as a between subjects source of variance and BAC (0.00, 0.05 and 0.08% BAC) was extracted as a within subjects source of variance. For the subjective measures, Time of Scale Administration (before and after the driving task) was extracted as an additional within subjects factor, and Block (six 5-min blocks of the driving task) was extracted as a within subjects effect for all of the simulated driving measures.

Univariate *F*-ratios were evaluated using the Huynh-Feldt correction factor for sphericity (Huynh and Feldt, 1976). Where appropriate further comparisons were carried out using Bonferroni corrected *t*-tests. The level of significance for all analyses was set at 0.05.

#### 3.1. BAC levels

Initial BAC levels for all subjects were zero. For the 0.05% alcohol condition, mean BAC was 0.055% (S.D. = 0.006) prior to the simulated driving task and 0.044% (S.D. = 0.007) following the 30-min task. For the 0.08% condition, mean BACs were 0.080% (S.D. = 0.007) and 0.077% (S.D. = 0.012), respectively.

#### 3.2. Effect of alcohol

The principal results are summarized in Table 1.

##### 3.2.1. Subjective

Ratings of sleepiness increased as alcohol dosage increased for the SSS ( $F[2,30] = 47.21$ ,  $P < 0.0005$ ) and

Table 1  
Mean and standard error of the mean (S.E.M.) for dependent measures

Target blood alcohol level	0.00%		0.05%		0.08%	
	Mean	S.E.M.	Mean	S.E.M.	Mean	S.E.M.
<i>Stanford Sleepiness Scale</i>						
Before driving	1.3	0.2	2.5	0.2	3.1	0.2
After driving	1.6	0.2	3.2	0.2	3.8	0.3
<i>Modified Stanford Scale: Factor 1</i>						
Before driving	1.6	0.4	5.8	0.9	7.4	0.9
After driving	2.9	0.6	7.2	0.9	9.1	1
<i>Modified Stanford Scale: Factor 2</i>						
Before driving	0.2	0.1	1	0.4	1.8	0.5
After driving	0	0	1.9	0.6	2.9	0.8
<i>Driving simulator</i>						
Mean tracking (m)	−0.1	0.03	−0.1	0.03	−0.14	0.04
Tracking variability (m)	0.5	0.02	0.5	0.02	0.7	0.06
Speed deviation (km/h)	−5.06	1.4	−2.32	1.2	−0.22	1.4
Speed variability (km/h)	10.1	0.9	11.31	1.1	13.31	1.4
Off-road events (number per 5 min)	0.1	0.03	0.5	0.09	1	0.2

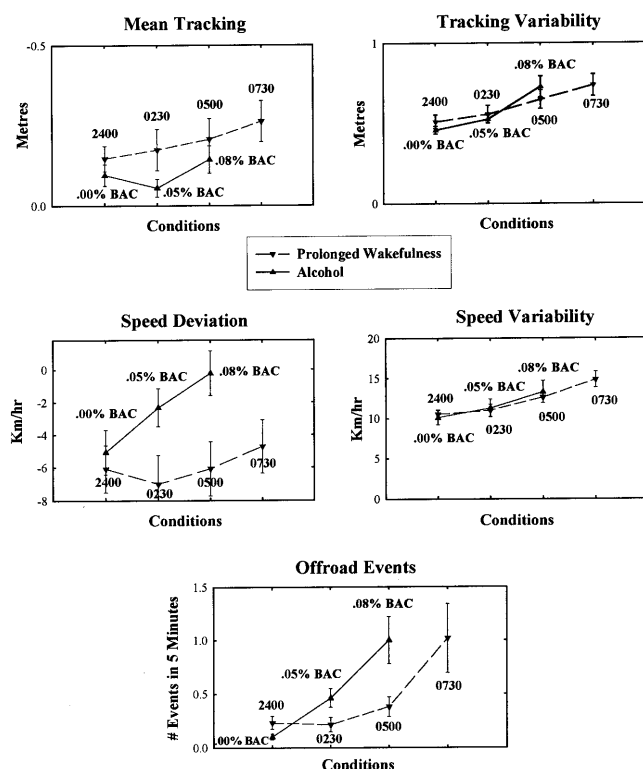


Fig. 1. Comparative effects of alcohol and prolonged wakefulness on five measures of simulated driving performance (mean  $\pm$  S.E.M.). Conditions were aligned according to Dawson and Reid (1997) (Fig. 2, p. 235).

for both Factor 1 ( $F[2,30] = 27.75$ ,  $P < 0.0005$ ) and Factor 2 ( $F[2,30] = 8.28$ ,  $P = 0.002$ ) of the MSS. Subjects rated themselves as more sleepy after the driving task than before on each of these scales ( $F[1,15] = 33.11$ ,  $P < 0.0005$ ;  $F[1,15] = 13.63$ ,  $P = 0.002$ ; and  $F[1,15] = 10.62$ ,  $P = 0.005$ , respectively). No significant time-of-day effects were evident on any of the subjective sleepiness measures.

### 3.2.2. Simulated driving task

With increasing alcohol dose: tracking variability increased ( $F[2,30] = 15.53$ ,  $P < 0.001$ ); speed deviation from the posted speed decreased as subjects drove faster ( $F[2,30] = 4.30$ ,  $P < 0.05$ ); speed variability increased ( $F[2,30] = 9.58$ ,  $P = 0.002$ ); and number of off-road incidents increased ( $F[2,30] = 13.14$ ,  $P = 0.001$ ). There were statistically significant differences between BAC 0.00 and BAC 0.05% conditions for tracking variability ( $t[17] = 2.95$ ,  $P = 0.027$ ) and off-road events ( $t[17] = 4.08$ ,  $P = 0.002$ ); between BAC 0.00 and BAC 0.08% for tracking variability ( $t[17] = 4.25$ ,  $P = 0.002$ ), speed variability ( $t[17] = 3.47$ ,  $P = 0.009$ ) and off-road events ( $t[17] = 4.16$ ,  $P = 0.002$ ); and between BAC 0.05 and BAC 0.08% for tracking variability ( $t[17] = 4.04$ ,  $P = 0.003$ ) and off-road events ( $t[17] = 3.11$ ,  $P = 0.019$ ).

While, in general, performance declined within the 30-min driving period, this only reached statistical signifi-

cance in the case of tracking variability ( $F[5,75] = 9.38$ ,  $P < 0.0005$ ). Time-of-day effects were largely absent, the only exception being that speed deviation was lowest at 17:00 h relative to the other two test times ( $F[2,15] = 4.05$ ,  $P < 0.05$ ).

### 3.3. Alcohol and prolonged wakefulness

The results from this study were compared to those obtained previously in a study by Arnedt and MacLean (1996), described earlier. The two studies were compared using analysis of variance (ANOVA) in which Study (prolonged wakefulness or alcohol) was extracted as a between groups factor and Condition was extracted as a within groups effect. The test conditions from both the studies were aligned using the results from Dawson and Reid (1997) (Fig. 2, p. 235). In this figure, it is shown that performance following 19 and 22 h of wakefulness was equivalent to 0.05 and 0.08% BAC, respectively.

The 0.00% BAC condition in the present study was aligned with the 24:00 h test time (16 h of wakefulness). For 0.05 and 0.08% BAC, the most comparable test times in the Arnedt and MacLean (1996) study were 02:30 h (18.5 h of wakefulness) and 05:00 h (21 h of wakefulness), respectively. The 07:30 h test time (23.5 h of wakefulness) was not included in the ANOVA because there was no alcohol condition in the present study that was comparable, based on the Dawson and Reid (1997) findings; independent *t*-tests were, therefore, conducted comparing the results from the 07:30 h test time with the alcohol condition in the present study that presumably induced the greatest impairment, i.e. the 0.08% BAC condition.

The subjects in the two studies were not significantly different on any of the following demographic characteristics, age, score on the Circadian Rhythm Questionnaire (Horne and Östberg, 1976), self-reported sleep quality, and score on the Epworth Sleepiness Scale (Johns, 1991, 1992). As can be seen in Fig. 1, driving performance was, in a number of respects, affected similarly by prolonged wakefulness and by alcohol. With increasing time awake and increasing blood alcohol level, subjects tracked increasingly to the left of the center of the lane ( $F[2,68] = 3.82$ ,  $P = 0.032$ ), and their tracking variability ( $F[2,68] = 24.23$ ,  $P < 0.0005$ ) and speed variability ( $F[2,68] = 17.91$ ,  $P < 0.0005$ ) increased.

In the case of speed deviation, however, there was an overall significant difference between the effect of prolonged wakefulness and alcohol ( $F[1,34] = 8.11$ ,  $P = 0.007$ ). Specifically, alcohol produced a more marked increase in speed than prolonged wakefulness, with a statistically significant difference between 0.08% BAC and the 05:00 h test time ( $t[34] = 2.74$ ,  $P = 0.029$ ) but not the 07:30 h test time. For the off-road events, there was both an overall difference between the effect of prolonged wakefulness and alcohol ( $F[1,34] = 5.32$ ,  $P = 0.027$ ) and an interaction between this effect and

condition ( $F[2,68] = 9.27$ ,  $P = 0.002$ ). Post-hoc analyses indicated that the frequency of off-road occurrences was significantly greater in the 0.08% BAC condition than in the 05:00 h test time ( $t[34] = 2.80$ ,  $P = 0.025$ ), but was not significantly different from the 07:30 h test time.

## 4. Discussion

### 4.1. Alcohol and subjective sleepiness

The increase in subjective sleepiness with increasing BAC is consistent with the CNS depressant properties of alcohol (Finnigan and Hammersley, 1992), as well as studies examining subjective ratings of sleepiness following alcohol ingestion using a subjective rating scale (Landauer and Howat, 1983; Jones and Neri, 1994) and the SSS (Horne and Gibbons, 1991; Walsh et al., 1991). These subjective evaluations of increased sleepiness following are further supported by studies using objective measures to observe changes in sleepiness following alcohol consumption. Ingestion of alcohol has been demonstrated to lead to dose-dependent reductions in sleep latencies, and therefore, presumably greater sleepiness, both at night time (MacLean and Cairns, 1982), and on a standardized measure of daytime sleepiness, the Multiple Sleep Latency Test (Carskadon et al., 1986; Zwyghuizen-Doorenbos et al., 1988). The sedative effects of alcohol, as measured by latency to sleep onset, can also be potentiated by restricting nocturnal time in bed (Lumley et al., 1987; Zwyghuizen-Doorenbos et al., 1988), and attenuated by lengthening nocturnal sleep time (Lumley et al., 1987), suggesting a synergistic relationship between alcohol and sleep duration with regard to physiological sleepiness. Somewhat surprisingly, time-of-day effects were absent for all the three subjective measures used in the present study. This was most likely due, however, to the limited power of this between groups analysis.

### 4.2. Alcohol and simulated driving performance

The driving simulator was sensitive to the acute impairments produced by alcohol, such that there was a dose-dependent relationship between alcohol consumption and performance degradation. These findings are consistent with several previous studies examining simulated driving performance following alcohol ingestion (Huntley and Centybear, 1974; Dott and McKelvey, 1977; Ranney and Gawron, 1986; Gawron and Ranney, 1988; Horne and Baumber, 1991; Roehrs et al., 1994). Alcohol has also been found to produce impairments on other psychomotor tasks, such as tracking and choice reaction time tasks (Moskowitz et

al., 1985; Hindmarch et al., 1992; Koelega, 1995), and it has been suggested that psychomotor tasks are more sensitive to the effects of alcohol than the tasks tapping cognitive skills (Buysse, 1991; Hindmarch et al., 1992). In addition, the progressive decline in performance within the 30-min driving task is consistent with findings from studies of the degradation in performance associated with both alcohol (Rohrbaugh et al., 1988) and sleep loss (Dinges and Kribbs, 1991). Decrements in performance have been found to occur more rapidly in simulator driving as compared with actual driving, most likely due to the greater monotony associated with a simulated driving task (Lenné et al., 1997). The lack of time-of-day effects on driving performance was unexpected, but again most likely due to the small number of subjects at each test time ( $n = 6$ ), thereby limiting the power of this between groups analysis.

Clear decrements in driving performance were evident in the BAC 0.05% condition relative to BAC 0.00%. This was true for both tracking variability and the number of off-road incidents. The modest number of studies that have examined the impact of lower BACs on simulated driving performance have found deteriorations in both steering ability (Dott and McKelvey, 1977; Landauer and Howat, 1983) and speed variability (Gawron and Ranney, 1988). Taken together, these findings suggest that degradation in driving-related performance is evident at lower BACs than the legal limits in the Canadian provinces and many states currently allow.

### 4.3. Comparison of the impairments induced by alcohol and by prolonged wakefulness

Consistent with Dawson and Reid (1997), alcohol produced changes in mean tracking and tracking variability that were similar to those produced by comparable periods of prolonged wakefulness. Speed variability in the present study was also found to be affected similarly by alcohol and by prolonged wakefulness. However, in the case of off-road events, it appears that alcohol ingestion produces more rapid deterioration in performance than the comparable periods of wakefulness suggested by Dawson and Reid (1997). In addition, subjects drove faster following alcohol consumption, while there was little change in mean deviations from the speed limit during the night of prolonged wakefulness. These findings may indicate greater disinhibition or feeling of increased self-confidence following alcohol consumption, or perhaps suggest better insight regarding the degree of impairment during prolonged wakefulness, resulting in compensatory driving behavior. Acquiring self-ratings of driving performance under both prolonged wakefulness and alcohol conditions might help to clarify this issue.

An important issue not considered in the comparison of prolonged wakefulness and alcohol is circadian influences on performance. Virtually all the performance tests demonstrate time-of-day variations, with the nadir in performance closely approximating the trough in core body temperature (Monk et al., 1997). Two recent driving simulator studies found clear circadian variations in performance regardless of whether subjects had slept normally or been kept awake the previous night (Lenné et al., 1997, 1998). Ideally, in our cross-study comparison, time of testing and length of wakefulness would not have been confounded.

Inferences from the comparison between prolonged wakefulness and alcohol must also be qualified by the fact that the measures considered were limited to speed and road position in circumstances in which drivers were not exposed to other traffic or the necessity to make complex decisions. As Koelega (1995) points out, “the ability to time-share in a divided-attention task is seriously impaired” following alcohol ingestion. Had drivers been exposed to the perceptual and judgement demands of dealing with the greater hazards created by the presence of other traffic, it is possible that driving performance would have differed under prolonged wakefulness and alcohol conditions.

The present study and the study by Dawson and Reid (1997) raise important issues regarding driving after consuming alcohol at times of increased physiological sleepiness, namely between the 23:00–07:00 and 14:00–17:00 h. It has been observed that fatigue-related accidents are more likely to occur during these peak times for sleepiness (Mitler et al., 1988), and undoubtedly a large proportion of accidents after midnight involve the combination of alcohol and sleepiness. It, therefore seems reasonable to suggest that the deteriorations in simulated driving performance evident at 0.05 and 0.08% BAC in the present study would have been magnified had subjects been required to drive during the night time hours. The co-occurrence of alcohol and prolonged wakefulness has been demonstrated to augment the impairments in performance induced by each factor independently (Horne and Gibbons, 1991; Roehrs et al., 1994; Corfitsen, 1996), theoretically producing an even greater risk for automobile accidents, although this issue has, surprisingly, received little direct attention in the literature. The question is of both theoretical and practical importance for groups at increased risk for both types of accidents, such as young drivers (Corfitsen, 1996). In addition to the problem of fatigue, there has been some suggestion that the legal BAC limit should be reduced during the zones of vulnerability for fatigue-related accidents, and that the statutory limit should be lowered for young drivers at all times. It seems appropriate that the results of the present study should be taken in to account in any discussion of legislative changes to reduce legal limits to

0.05% or lower, as is the case in many countries in the European Community (Koelega, 1995).

## Acknowledgements

The support of the Ontario Ministry of Transport and Queen's University is gratefully acknowledged as is the technical assistance of J. Brown, S. Ferguson and R. Dupras. M. York's assistance with the simulator was invaluable. We also are indebted to the Centre for Forensic Sciences for supplying the Borkenstein Breathalyser and to G. Daugherty of the Kingston Police Department for technical support.

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