The Effects of Alcohol on Driving-Related Sensorimotor Performance across Four Times of Day*

JOHN C. DALRYMPLE-ALFORD, PH.D.,† P. ANNE KERR, M.A. (HONS), AND RICHARD D. JONES, PH.D.†

Christchurch Movement Disorders and Brain Research Group, Department of Psychology, University of Canterbury, Private Bag 4800, Christchurch 8004, New Zealand

ABSTRACT. *Objective*: The effect of alcohol on driving-related tracking tasks at four times of day was examined to address concerns that the legal driving alcohol threshold in New Zealand (80 mg/dl blood) may have greater effects during the early afternoon and early morning than during the evening and midmorning. *Method*: A volunteer group of 16 male army personnel provided a homogenous sample with respect to time-of-day characteristics. After a formal practice session, members of the sample performed lateral (one-dimensional) tracking tasks in eight counterbalanced sessions, either with or without alcohol (0.836 g/kg), at 0900, 1300, 1800 and 0100 hours. The tasks varied in terms of smooth and ballistic motor pursuit, unpredictability and availability of target preview. *Results*: Alcohol markedly impaired tracking accuracy (error from target), especially in nonpreview conditions. The only evidence for an overall time-of-day effect was on a ballistic pursuit nonpreview task, but there was no indication of any alcohol by time-of-day interactions. *Conclusions*: When tested 30 minutes after consumption of alcohol, sensorimotor tracking skills are markedly impaired at alcohol levels approaching the New Zealand threshold for legal driving, but these effects are not subject to circadian variations. (*J. Stud. Alcohol* **64:** 93-97, 2003)

MANY FACTORS, including age, sex, personality, driving experience, alcohol tolerance and general metabolism, influence the relationship between alcohol and driving-related performance (Adan, 1994; Jaccard and Turrisi, 1987; Jonah, 1997; Moskowitz et al., 1985; Stacy et al., 1991). Time of day is another potentially important but frequently neglected variable that may also affect this relationship. Evidence for circadian variations in the physiological correlates of alcohol is now well established (Danel et al., 2001; Liu et al., 2000; Reinberg, 1992; Yap et al., 1993). It is therefore reasonable to suspect that alcohol effects on behavior may also vary across times of day.

There is, however, much uncertainty whether the behavioral effects of moderate alcohol levels (e.g., at current thresholds for legal driving) differ across times of day. An early report suggested that complex cognitive skills, as measured by the Advanced Raven's Progressive Matrices, was markedly impaired after alcohol in the afternoon, whereas alcohol in the evening had no effect (Jones, 1974). Similarly, two influential studies reported a greater impairment on an auditory vigilance task (Horne and Baumber, 1991) and a driving simulator (Horne and Gibbons, 1991) after alcohol in the early afternoon than after alcohol in the early evening. Mental arithmetic and fine motor skill have also been found to be impaired after alcohol at only some points in the day (at 0700h and 2300h, but not at 1100h and 1900h; Reinberg, 1992). In contrast, Yap et al. (1993) found no alcohol by time-of-day interaction on response time for digit symbol coding, critical flicker fusion threshold or tracking and peripheral reaction time in a divided attention task. Roehrs et al. (1992) also reported that ethanol's effects on divided attention did not vary after day versus after evening drinking but suggested that alcohol may enhance general sleepiness during the day, when alertness is relatively low, but not in the evening, when alertness is increasing. Unfortunately, many previous studies suffer from one or more methodological weaknesses, such as small sample size, only a couple of test points across the day, between-group designs and the absence of controls for personality and other factors.

Clearly, additional evidence is needed for the potentially important issue of circadian variations in the behavioral effects of alcohol. The most immediate concern is the influence of alcohol on driving-related behavior because there are suggestions that the standard regulatory limits for alcohol may be less effective at certain times of day (Chan, 1987; Koelega, 1995). The present study investigated the effects of alcohol at four times of day on upper-limb sensorimotor skills using highly sensitive tracking tasks that were developed, in part, for off-road driving assessment of

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†Correspondence may be addressed to John C. Dalrymple-Alford at the above address, or via email at: psyc338@psyc.canterbury.ac.nz. Richard D. Jones is also with the Department of Medical Physics and Bioengineering, Christchurch Hospital, Christchurch, and the Department of Medicine, Christchurch School of Medicine and Health Sciences, University of Otago, Christchurch, NZ.

neurologically impaired subjects (Croft and Jones, 1987; Jones, 2000; Jones and Donaldson, 1986; Jones et al., 1983, 1989). The 0100h session represented an overnight body temperature nadir and the peak time for alcohol-related driving accidents (Schwing, 1989-90). The afternoon (1300h) and evening (1800h) times were those used by Horne and colleagues. As an early afternoon susceptibility to alcohol might be exaggerated by inexperience with drinking at that time rather than a true reflection of underlying circadian variations, this potentially confounding factor was addressed by including a fourth, midmorning time (0900h) that offered an ascending body temperature phase not typically associated with social alcohol consumption. Following Koelega's (1995) recommendation, we used a relatively short alcohol-test interval and a brief test period to minimize intrasession variations in blood alcohol.

Method

Subjects

Sixteen male unpaid volunteers who were noncombatant soldiers at a local New Zealand Army camp (mean [SD] age was 29 [6] and weight 82.9 [7.9] kg) gave informed consent after a general briefing and were tested in a familiar work environment to reduce any sensitivity or tolerance that might otherwise ensue (Bierness and Vogel-Sprott, 1984). These participants were in good health and could be expected to have regular sleep/wake patterns and exercise regimes. They gave subjective reports that they were social drinkers, but no formal measures of alcohol tolerance were recorded. The group was homogenous in their lack of morning or evening preference, based on the Horne and Ostberg (1976) "morningness/eveningness" preference scale (mean [SD] = 55.1 [5.1]), bar one mild morning preference score of 69. Similarly, the Rotter Internal/External Locus of Control Inventory (Lefcourt, 1976), used to measure personality factors associated with decision-making and causal attributions, revealed homogenous middle-range scores only (mean = 11.3 [2.0]).

Procedure

Subjects fasted for 4 hours and abstained from alcohol for a minimum of 12 hours prior to each session (and avoided driving or other hazardous activity for 6 hours posttesting). One part vodka (37% alcohol by volume) was diluted with 1.5 parts of tonic water and a few drops of lime for a total of 5.65 ml/kg and was consumed over 20 minutes with a light meal (12 g bread roll, cold meat and salad), followed by a 10-minute wait prior to testing. The dose of 0.836 g of alcohol/kg was used to produce a blood alcohol concentration (BAC) approaching 80 mg/dl of blood (Farrimond, 1990), the legal limit for driving for New Zealand adults, which was confirmed by breath alcohol readings just prior to sensorimotor testing (350 [84] μg/l of breath $\simeq$ 70 mg/dl of blood; Alcometer, Lion Laboratories, U.K.). These procedures produced appropriate peak BACs that would remain relatively stable for the duration of our tests (Horne and Gibbons, 1991; Jones et al., 1991).

The same sequence of seven tracking tasks (30-60 second intervals; 12-15 minutes in total) was performed on nine sessions, with the last eight sessions used to obtain counterbalanced data for the four times of day, both with and without alcohol (using equivalent control procedures). The intersession interval was usually 7 days (range: 1-9), but was only 1-2 days on 9 of 128 occasions due to changes in work schedule. No explicit feedback on performance was provided. A color monitor (312 × 234 mm; eye-to-screen distance, 130 cm) displayed stimuli for tracking tasks (Jones, 2000; Jones and Donaldson, 1986) that required a lateral (one-dimensional) response via a standard steering wheel (395 mm diameter) to move a vertical white arrow (16 mm high, 11 mm wide) horizontally on a black background (top of arrow 58 mm from bottom of screen). The dependent measure was the mean absolute error (horizontal distance between arrow head and target sampled at the screen vertical interrupt rate of 60.34 Hz). The first two tracking tasks, sine tracking nonpreview and sine tracking preview, were taken as initial warmups for similar random tracking nonpreview and random tracking preview tasks. For the latter tasks (each 70 seconds duration), the subject made smooth movements over a 175-degree range of the steering wheel (counting left and right of center) to keep the arrow aligned with a randomly displacing target (same thickness yellow line down the full screen; maximum displacement of 96 mm). Movement of the target signal was generated by adding together 23 harmonically related sinusoids of randomly selected phase (fundamental frequency of 0.0147 Hz) to obtain a fixed pseudorandom signal with a band width of 0.34 Hz and a period of 70 seconds. For the nonpreview version, the target was a straight line that displaced in an unpredicted lateral fashion. For the preview version, the target signal descended as a wavy line from the top of screen giving a preview of up to 7.5 seconds before reaching the level of the arrowhead (and postview of 2.5 seconds). For the step tracking nonpreview task (120 seconds duration), the subject used fast ballistic movements to keep the arrow on a vertical-line target. In this instance, the target moved abruptly on 32 occasions, which presented one of four unpredictable displacements from ("step out") and return to ("step back") the center of the screen (a vertical line of nine dots) via large (90 degrees on wheel) and small (22 degrees) left or right steps. Temporal unpredictability was ensured by using four randomly distributed durations between steps (2.8, 3.4, 4.0, 4.6 seconds) and the absence of preview. For the step tracking preview version, preplanning and preparation of the ballistic response was possible because the step target signal descended at a constant rate from the top of the screen and had the appearance of a sequence of irregular-sized steps (vertical lines of varying lengths joined by horizontal lines), which "stepped" out and back to the center of the screen (preview of 7.5 seconds; postview of 2.5 seconds). For the last task, combination tracking (120 seconds duration), the target alternated between random tracking preview and step tracking nonpreview over 11-second cycles. Thus, while tracking the random wavy-line target, the preview signal was abruptly and unpredictably replaced by a stationary full-screen vertical line at some distance from the random signal, and vice versa. Random tracking preview measures performance that has face validity for the smooth but variable sensorimotor movements required for driving. Step tracking nonpreview is analogous to having to respond quickly and appropriately to an unexpected obstacle. Combination tracking includes the ability to change motor set between quite different modes of tracking. The inclusion of random tracking nonpreview and step tracking preview allows a more systematic evaluation of the effects of alcohol across the random and step tracking contexts because any differences may relate to preview/nonpreview rather than the specific sensorimotor nature of the tasks.

Results

Tracking performance at each of the four times of day and the relative influence of alcohol versus nil alcohol is shown in Table 1. Overall, alcohol impaired performance in each task, with a larger effect size for step tracking nonpreview (unpredicted ballistic movements) than for random tracking preview (predicted smooth movements). The alcohol effects sizes were, however, far greater for nonpreview than preview tasks in general. No time-of-day main effect was apparent (all F's < 1.53, all p's $> .22$), with the exception of the step tracking nonpreview task ($F = 2.69$, 3/45 df, $p < .06$). More important, there was no statistical evidence of any alcohol by time-of-day interaction (all F's < 1.0). Indeed, contrary to expectations, Table 1 shows that for 1300h and 0100h, the two time periods when alcohol might be thought to exert a greater influence, the average effects of alcohol were if anything generally weaker than at 0900h and 1800h.

Reaction time (RT) data for the step tracking nonpreview task also produced expected alcohol main effects for step out RT and step back RT ($F = 68.84$ and 54.30, respectively, 1/15 df, $p < .0001$). For step out, the mean (SD) differences at 0900h, 1300h, 1800h, 0100h were 38.0, 34.5, 47.8, 31.4 (18.3) milliseconds (ms). For step back, the corresponding mean differences were 30.7, 47.8, 30.9, 27.3 (18.5) ms. There was no alcohol by time-of-day interaction in either case ($F < 1.0$). These RT data did reveal, however, some evidence for time-of-day main effects (mean [SD] differences at 0900h, 1300h, 1800h, 0100h: step out, 441.7, 417.0, 411.5, 431.6 [28.55] ms; $F = 3.38$, 3/45 df, $p < .03$; step back, 388.3, 392.0, 383.1, 398.2 [23.92] ms; $F = 2.26$, 3/45 df, $p < .10$).

As the within-group design required repetition of the tasks, mean error scores were sorted by order instead of time of day, and the four repetitions of alcohol and nonalcohol conditions were reanalyzed to assess any practice or tolerance effects. There was no indication of any tolerance effects. Only the random tracking preview task revealed evidence that performance improved progressively with repeat testing ($p < .01$), irrespective of alcohol condition (interaction, $F < 1.0$).

Discussion

Alcohol levels just below the legal threshold for driving for New Zealand adults (80 mg/dl blood) produced marked impairments on several tracking tasks, with the exception of a modest effect when predictable ballistic movements were required (step tracking preview). The sensitivity to alcohol of tasks that require lateral movements is consistent with the observation that alcohol-related accidents are more likely when the driver has to negotiate a bend, although other factors such as speed and perception will also be relevant in real-life situations (Johnston, 1982). Nonpreview

Table 1. Mean (SD) tracking error (in mm) in terms of alcohol versus nil alcohol and four times of day

	Overall performance across time of day				Alcohol-nil alcohol difference across time of day				Overall alcohol effect	
Tracking task	0900h	1300h	1800h	0100h	0900h	1300h	1800h	01000h	% Diff.	Effect size[a]
Random nonpreview	3.69 (0.99)	3.70 (0.99)	3.80 (0.86)	3.88 (1.13)	0.57 (0.64)	0.39 (0.62)	0.51 (0.66)	0.70 (0.61)	15.8	1.48‡
Random preview	2.54 (0.42)	2.48 (0.58)	2.63 (0.45)	2.67 (0.39)	0.30 (0.60)	0.19 (0.38)	0.35 (0.61)	0.35 (0.74)	12.8	0.93†
Step nonpreview	7.40 (1.23)	7.50 (1.11)	7.44 (0.99)	7.69 (1.08)	0.63 (0.80)	0.54 (0.63)	0.60 (0.54)	0.24 (0.77)	7.0	1.71‡
Step preview	2.91 (0.91)	2.94 (1.02)	3.08 (0.97)	3.06 (1.03)	0.17 (0.50)	0.09 (0.34)	0.25 (0.46)	0.17 (0.63)	5.8	0.51*
Combination	8.61 (0.96)	8.79 (0.97)	9.01 (1.04)	8.93 (1.19)	0.56 (0.93)	0.51 (0.89)	0.94 (0.89)	0.54 (0.92)	7.4	1.22‡
Means	5.03	5.08	5.19	5.25	0.45	0.34	0.53	0.40	9.8	1.17

[a]Cohen's d (Cohen, 1988); *$p < .05$, †$p < .01$, ‡$p < .0001$.

conditions produced the largest effects of alcohol, irrespective of the requirement for smooth or ballistic movements. Despite these variations in alcohol effects and task difficulty, there was no indication that these effects were influenced by time of day. Contrary to the findings of previous reports (Horne and Baumber, 1991; Horne and Gibbons, 1991; Jones, 1974), alcohol did not produce greater effects in the early afternoon than in the early evening. Contrary also to other suggestions (Chan, 1987; Keolega, 1995), alcohol at 0100h did not produce greater effects compared to alcohol at other points in the day. Only the random tracking preview task revealed evidence for a task repetition effect, so it is unlikely that the failure to observe any time-of-day by alcohol interaction was confounded by possible tolerance or practice effects across sessions. The step nonpreview task showed evidence for a time-of-day main effect, which appeared to be due mainly to poorer performance at 0100h. Although this evidence suggests that the separate, additive effects of alcohol on some measures at certain times of day may be of particular concern, even that possibility received little support from this study because the effect of alcohol on step nonpreview at 0100h was if anything weaker than at other times of day.

The failure to observe any circadian effects of alcohol is consistent with two other reports that employed relatively brief tasks (Roehrs et al., 1992; Yap et al., 1993). Our dose, administration and timing procedures, as well as the avoidance of personality extremes that may otherwise introduce intrinsic circadian variability (Horne, et al., 1980), were similar to those used in the alcohol studies of Horne et al. Our within-subject design and sample size was an improvement on previous work, so variables that may account for these differences more likely include gender (we used males), regularity of circadian rhythms (military personnel are likely to have more regular day/night schedules) and the particular tasks used. Of interest, Horne's laboratory found no effect of alcohol on occasional steering movements in the simulated motorway driving task, measured at 40-80 minutes postconsumption when alcohol levels were down to about 40 to 60 mg/dl. Instead, it found that alcohol, particularly in the afternoon, impaired the maintenance of a "safe" distance behind the imaginary vehicle. Perhaps the type of task in combination with the duration since consumption, rather than current BACs, determines whether the effects of alcohol will show a time-of-day interaction. For example, Roehrs et al. (1992) found impaired performance on a 15-minute divided-attention task at 90 minutes postconsumption, regardless of whether day or evening drinking was tested, but alcohol slowed reaction time to a greater extent after day than after evening drinking for the first 20 minutes of a 40-minute auditory vigilance task when tested at 5 hours postconsumption. Breath ethanol concentration in the study by Roehrs et al. (1992) was maximal 30 minutes after consumption (40 mg/dl), but had returned to nil after 5 hours. Thus, it may be the "residual sedating effects" of alcohol (Roehrs et al., 1990) that pose a threat with respect to time-of-day and driving, not the commonly employed legal thresholds for BACs.

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