Fatigue, alcohol and performance impairment

Reduced opportunity for sleep and reduced sleep quality are frequently related to accidents involving shift-workers[1–3]. Poor-quality sleep and inadequate recovery leads to increased fatigue, decreased alertness and impaired performance in a variety of cognitive psychomotor tests[4]. However, the risks associated with fatigue are not well quantified. Here we equate the performance impairment caused by fatigue with that due to alcohol intoxication, and show that moderate levels of fatigue produce higher levels of impairment than the proscribed level of alcohol intoxication.

Forty subjects participated in two counterbalanced experiments. In one they were kept awake for 28 hours (from 8:00 until 12:00 the following day), and in the other they were asked to consume 10–15 g alcohol at 30-min intervals from 8:00 until their mean blood alcohol concentration reached 0.10%. We measured cognitive psychomotor performance at half-hourly intervals using a computer-administered test of hand–eye coordination (an unpredictable tracking task). Results are expressed as a percentage of performance at the start of the session.

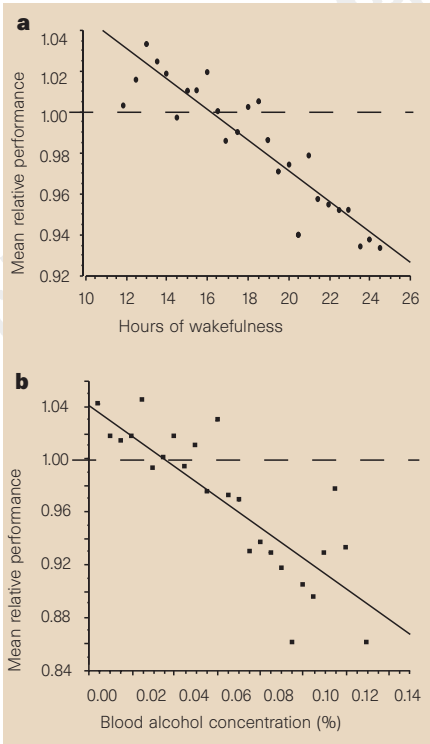

Figure 1 Scatter plot and linear regression of mean relative performance levels against: **a,** time, between the tenth and twenty-sixth hour of sustained wakefulness ($F_{1,24}$=132.9, P<0.05, R^2=0.92); and **b,** blood alcohol concentrations up to 0.13%, ($F_{1,24}$=54.4, P<0.05, R^2=0.69).

Performance decreased significantly in both conditions. Between the tenth and twenty-sixth hours of wakefulness, mean relative performance on the tracking task decreased by 0.74% per hour. Regression analysis in the sustained wakefulness condition revealed a linear correlation between mean relative performance and hours of wakefulness that accounted for roughly 90% of the variance (Fig. 1a).

Regression analysis in the alcohol condition indicated a significant linear correlation between subject's mean blood alcohol concentration and mean relative performance that accounted for roughly 70% of the variance (Fig. 1b). For each 0.01% increase in blood alcohol, performance decreased by 1.16%. Thus, at a mean blood alcohol concentration of 0.10%, mean relative performance on the tracking task decreased, on average, by 11.6%.

Equating the two rates at which performance declined (percentage decline per hour of wakefulness and percentage decline with change in blood alcohol concentration), we calculated that the performance decrement for each hour of wakefulness between 10 and 26 hours was equivalent to the performance decrement observed with a 0.004% rise in blood alcohol concentration. Therefore, after 17 hours of sustained wakefulness (3:00) cognitive psychomotor performance decreased to a level equivalent to the performance impairment observed at a blood alcohol concentration of 0.05%. This is the proscribed level of alcohol intoxication in many western industrialized countries. After 24 hours of sustained wakefulness (8:00) cognitive psychomotor performance decreased to a level equivalent to the performance deficit observed at a blood alcohol concentration of roughly 0.10%.

Plotting mean relative performance and blood alcohol concentration 'equivalent' against hours of wakefulness (Fig. 2), it is clear that the effects of moderate sleep loss on performance are similar to moderate alcohol intoxication. As about 50% of shift-workers do not sleep on the day before the first night-shift[5], and levels of fatigue on subsequent night-shifts can be even higher[6], our data indicate that the performance impairment associated with shift-work could be even greater than reported here.

Our results underscore the fact that relatively moderate levels of fatigue impair performance to an extent equivalent to or greater than is currently acceptable for alcohol intoxication. By expressing fatigue-related impairment as a 'blood-alcohol equivalent', we can provide policy-makers and the community with an easily grasped index of the relative impairment associated with fatigue.

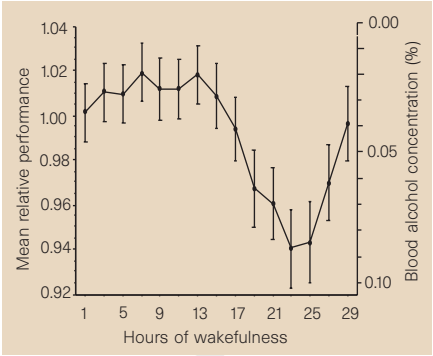

Figure 2 Performance in the sustained wakefulness condition expressed as mean relative performance and the percentage blood alcohol concentration equivalent. Error bars ± s.e.m.

Drew Dawson
The Centre for Sleep Research,
University of South Australia,
The Queen Elizabeth Hospital,
Woodville, 5011 South Australia
e-mail: ddawson@tqehsmtp.tqeh.sa.gov.au
Kathryn Reid
Department of Obstetrics and Gynaecology,
University of Adelaide,
The Queen Elizabeth Hospital, Woodville,
5011 South Australia

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Entropy difference between crystal phases

In a recent Letter[1], Woodcock reported the results of a molecular dynamics study in which he claims to have finally determined the free-energy difference between the hexagonal close-packed (h.c.p.) and face-centred cubic (f.c.c.) phases of a crystal of (classical) hard spheres. Woodcock reports a small positive difference in the reduced Gibbs free-energy, which is equivalent to a difference in the reduced Helmholtz free-energy of $\Delta F^* \equiv (F_{hcp} - F_{fcc})/RT = 0.005(1)$ at the melting density (R is the gas constant, T is the absolute temperature, and the num-