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REVIEW

H. S. Koelega

Alcohol and vigilance performance: a review

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Abstract In the literature on the effects of alcohol on driving-related skills, it is sometimes claimed that vigilance tasks are insensitive instruments whereas divided-attention tasks are extremely sensitive to the effects of alcohol. The results of the present review, based on the analysis of 38 comparisons of alcohol and placebo in vigilance tasks, require that these claims be restated. Both types of attentional task (concentrated and divided) are indispensable in test batteries, although not all types of vigilance and divided-attention task are equally sensitive, e.g. some types of vigilance task, using spatial stimuli, were sensitive to BAC levels of 0.03% whereas other types were insensitive to levels of 0.10%. In contrast, the usefulness of tasks of questionable validity and/or low sensitivity (such as the DSST, CFF, digit span, simple RT and choice RT) is questioned. Apart from issues of validity and sensitivity of tests, the ways in which alcohol may affect performance are also discussed. The main effect of moderate doses of alcohol is on attention and information processing. The capacity to divide and sustain attention is already impaired at BAC levels of 0.02–0.03%. Further, alcohol effects appear to some extent to be time-dependent, and are greatest during periods of sleepiness (the early afternoon and after midnight). Some current BAC levels concerning drinking and driving are far too generous. There is sufficient evidence from the literature on performance indicating that the BAC standard for driving should be lowered to 0.02% for driving after midnight and for special risk groups (young and less experienced drivers).

Key words Alcohol · Attention · Vigilance performance · Test batteries · Time of day · Legal limits for driving

H. S. Koelega (✉)
Departments of Psychopharmacology and Psychology Laboratory, Utrecht University, Heidelberglaan 2, NL-3584 CS Utrecht, The Netherlands

Introduction

Alcohol is one of the most widely self-administered drugs in the world. Wesnes and Warburton (1983) report that firm knowledge of its use stems back to more than 8000 years ago, but there are indications that it was already used in the Palaeolithic Age, about 10 000 years ago. Moderate drinking for recreational purposes is generally considered to be a socially acceptable practice and decreases the risk of cardiovascular disease.

Although moderate drinking may contribute to longevity and pleasure in life, use of alcohol cannot always be encouraged: drinking has a firmly established relationship to automobile accidents and even moderate drinking has effects on the unborn child: several longitudinal studies have shown that moderate drinking during early pregnancy impaired children's IQ and attention (performance on a vigilance task) when tested at ages 4 and 7. The effects of alcohol are especially important in the area of human attention and performance, the subject of this paper. In the Netherlands it has been estimated that almost 40% of all working employees, or about 2 000 000 people, take alcohol from time to time *during working hours*, and 6% (about 300 000) frequently drink on the job. Studies in the UK have shown that in about 40% of industrial accidents leading to death, alcohol was a factor. Streufert et al. (1994) report that alcohol consumption is especially extensive among senior level decision making personnel such as managers in the private sector and officers in the military. Access to alcohol at the workplace is easier at higher job levels and may even be considered justified. Working with samples of senior level managers, Streufert et al. showed that even moderate levels of alcohol consumption had a considerable impact on activities such as planning and strategy, even where task demands were not unusual; in particular, the capacity to deal with novel problems or emergency diminished considerably.

The relationship of alcohol to automobile accidents is well-documented: in the USA alcohol is involved in about 50–55% of fatal vehicle crashes, most occurring at night; alcohol related motor-vehicle accidents are the leading cause of mortality in men under 37 years (Leger 1994). Alcohol related accidents at home have rarely, if ever, been the subject of research. The use of alcohol also affects flying. Of the pilots passing time zones, 50% have sleeping problems, and pilots sometimes take alcohol in order to fall asleep. Some 20 years ago, Billings et al. (1973) showed that low concentrations (roughly equivalent to two pints of beer in an average male) caused significant performance decrements in flights, were associated with substantial and highly significant increases in procedural errors committed by both inexperienced and highly experienced pilots; the effects of alcohol were assessed in an actual flying situation, flights took place with a safety co-pilot and a physician was located behind the pilot. Data provided by the Federal Aviation Administration and the Air Line Pilots Association show that over the period 1968–1985, one in eight fatally crashed pilots had a BAC (blood alcohol concentration) of more than 0.04% (mg alcohol per 100 ml blood). Approximately 10–30% of general-aviation pilots involved in fatal aircraft accidents due to pilot error had measurable alcohol concentrations on postmortem examination (Modell and Mountz 1990), but this figure may underestimate the involvement of alcohol since pilot performance is also impaired when blood alcohol levels are near zero and postmortem toxicologic analysis subsequently is negative for alcohol. Yesavage and Leirer (1986) investigated pilot performance 14 h after drinking when alcohol levels in the body were no longer measurable, and found significantly impaired performance on most measures as well as a lack of awareness of these hangover effects by pilots.

Many researchers have been intrigued by the question of how and why alcohol affects such behavior.

Reviews of effects of alcohol on behavioral measures

The effects of alcohol on behavior have been the object of research from the very beginning of experimental psychology. Experiments were reported as early as 1851 (Lichtenfels, cited in Jellinek and McFarland 1940). The effect of alcohol on simple reaction time, for example, has been investigated in the earliest (1870) as well as in recent studies (in 1986 Gustafson published seven articles on the subject), so this may be a research topic as long as there are experimental psychologists or psychopharmacologists.

Seminal studies have been carried out by Kraepelin (1892), who published a book on the effects of drugs on sensory and motor functions. Kraepelin started his investigations in 1882 in Wilhelm Wundt's laboratory, where he performed a large number of experiments with alcohol, but also with caffeine (tea), morphine, chloral hydrate etc. Kraepelin noted that under some circumstances, with low doses of alcohol a facilitation of performance (lasting about 20 min) precedes the impairment (p. 175), that information processing could be impaired at the same time that motor functions were facilitated (p. 181), that under alcohol "false alarms" (premature reactions) often occurred (p. 182), and that the facilitating and debilitating effects of alcohol may cancel each other out (p. 187). He also noted that there are large individual differences and that the effects of alcohol are task-dependent (p. 176). These observations are reiterated because one still encounters them as "findings" in more recent literature.

A large number of reviews of the effects of alcohol have appeared, e.g. the extensive review of Jellinek and McFarland (1940). These authors discussed several pitfalls of experiments with alcohol and indicated main factors which may influence the evaluation of effects and the comparability of results: crossover vs parallel designs, the nature of subjects (abstinent, social drinkers, or alcoholics), the modus and time of alcohol administration etc. The authors state that the data are only meaningful when the BAC at the time of the test observations is also given. Among the findings reported by Jellinek and McFarland is a curious one, that subjects are unable to note objects approaching from the side when driving ("channel driving", p. 319). Sensory acuity is usually not affected, but the ability to discriminate between intensities is (p. 315). And "there is no question that the effect of alcohol is greater in tests which involve active attention" (p. 323). The authors state that the effect of alcohol is always one of reduced efficiency, such stimulating effects as have been reported, are pseudostimulations (p. 362). As the most urgent need in psychological experimentation they see the exploration of individual differences in *inherent* (or initial) tolerance to alcohol in contrast to *acquired* tolerance ("habituation").

Later reviews, e.g. by Carpenter (1962), Moskowitz (1973), and Perrine (1973), concurred in the view that the major impairing effects of alcohol are to be found on tasks requiring attention and information processing, whereas psychomotor performance appears to be more resistant to alcohol impairment. Levine et al. (1975) classified tasks according to ability requirements and concluded that psychomotor tasks are least impaired and that especially tasks involving selective attention are seriously impaired.

Many authors have expressed the view that vigilance tasks (tasks requiring detection of and responding to specified changes in the stimulus situation, occurring rarely and unpredictably) are insensitive instruments to monitor the effects of alcohol. Moskowitz (1973) stated that there is considerable evidence that there is no impairment of attention conceived as vigilance. Linnoila (1974) and Fagan et al. (1987) also reported that alcohol does not affect vigilance and Miles et al.

(1986) noted that sustained attention tasks "have consistently failed to reveal alcohol-induced impairments"; in contrast, tasks requiring selective attention do reveal such impairments. The authors probably mean divided rather than selective attention, because alcohol effects on selective attention, performing in the presence of distracting external stimulation (e.g. of the dichotic listening type of tasks), have as yet not been investigated (but see Ward and Lewis 1987). Davies and Parasuraman (1982 p. 157) concluded that "reliable effects of alcohol on vigilance have yet to be demonstrated". A recent review (Foltin and Evans 1993) even concluded that in some studies alcohol has improved auditory vigilance, but, unfortunately, this claim cannot be evaluated because the authors failed to indicate which particular studies were meant.

An impressive, large scale, review of the experimental literature on alcohol effects on skills related to driving, has been published by Moskowitz and Robinson (1987). The authors found 557 citations, of which 399 publications were obtained and of this number, 178 were used in their report. The evidence reviewed indicates that alcohol does not uniformly impair all aspects of performance. In some areas (divided attention and oculomotor function) impairment can occur at BACs as low as 0.02%. According to Moskowitz and Robinson (1987), divided attention performance is the most sensitive area to alcohol impairment, whereas vigilance performance, or concentrated attention, is the least sensitive measure, with all other categories (information processing, tracking, RT, driving, etc.) in between. Their conclusion is that "the existing evidence does not reliably indicate that BACs below 0.08% impair vigilance performance".

In contrast, the present author is aware of vigilance studies finding effects of low doses of alcohol, and the validity of some interpretations of earlier studies is also questioned. For example, the seminal study by Moskowitz and DePry (1968) showing that divided attention was impaired but vigilance not has always been cited by later investigators as a demonstration of this phenomenon. However, the "vigilance" task was not really a vigilance task but a mixture of a selective attention and signal detection task: noise bursts (half of which contained a tone at near-threshold level which had to be detected) were presented to the left ear, and digits (which had to be ignored) were simultaneously presented to the right ear, while the subject had to report both nonsignals and signals verbally. Further, the study was flawed in that there was no alternation of order of presentation, the divided attention task (responding to the input of both ears) always followed the "vigilance" task, always started 30 min later and thus was carried out in a different region of the BAC curve. Moskowitz and DePry (1968) have also interpreted the Talland (1966) study, employing only two subjects, as evidence that alcohol affects divided attention but not vigilance; however, the same effect also occurred in the "visual only" (vigilance) condition.

Generalizations about the effect of alcohol on vigilance or divided attention are often the result of consideration of a very limited portion of the available literature, the same situation as encountered in an earlier review of the effects of benzodiazepines (Koelega 1989). For example, in the review of Moskowitz and Robinson (1987) only three vigilance experiments were inclded in their Table 5, although the authors discuss three more studies which were not included for various reasons. Most reviews do not discuss more than half a dozen vigilance studies, especially those reviews attempting to cover "performance" in general, such as that by Finnigan and Hammersley (1992), an adequate review for that matter, emphasizing again the many methodological defects of most studies including recent ones. The review by Foltin and Evans (1993), has an even wider scope, viz. to review the effects of all kinds of drugs of abuse on performance. Such reviews often end with the conclusion that alcohol sometimes does, and sometimes does not, impair performance. Finnigan and Hammersley have also stated that "by now it should be obvious that it is naive to hypothesize about effects on performance as if it were a single, easily measured phenomenon". I have suggested before (Koelega 1989) that reviews of this kind may aim too high and that probably more insight can be obtained when specific tasks are exhaustively reviewed. Only an extensive, detailed analysis, covering as much data as possible, can produce an accurate picture of the sensitivity of vigilance (and other) tasks to alcohol. It is quite possible that vigilance tasks are rather insensitive, but then the question arises why effects of alcohol would be hard to detect with tests which have been shown to be sensitive to the effects of other drugs including those which are daily used such as caffeine and nicotine (Koelega 1989, 1993). It is also possible that divided attention tasks in general are more sensitive than vigilance tasks, but there may be some types of vigilance task finding alcohol effects at low doses and there certainly also are divided attention studies finding no effects at rather high doses (Miles et al. 1986; Marks and MacAvoy 1989; Kuitunen et al. 1990). There are studies where both types of task are affected (Erwin et al 1986; Putz-Anderson et al. 1981), there are studies showing that vigilance performance after alcohol was sensitive to time of day but divided attention was not (Roehrs et al. 1992), and there are also divided attention studies reporting *improvement* under alcohol (e.g. Pearson 1968).

This is not to say that vigilance tasks probably are more sensitive instruments to monitor alcohol effects than are divided attention tasks or that the latter should be replaced by the former in test batteries. Both types of task have their place in psychopharmacology: both sustained concentrated-attention (or vigilance) and divided-attention are components of the demands of skills situations such as driving, flying or operating machinery. Moskowitz (1984) has also emphasized that it is not merely the information overload requirement, manifest in divided attention, that is important; it is advantageous to have both conditions within the same experiment, if only because there are drugs (e.g. marihuana) which impair vigilance but not divided-attention behavior. From the above it is clear that not all divided-attention tasks are of equal sensitivity and that the generalization encountered in the literature (divided-attention tasks are sensitive and vigilance tasks are not) may not be well founded. Much depends probably on the components making up a divided-attention task (whether they tax common or separate resources etc.) and an exhausive review of experiments using this task after ingestion of alcohol could be useful in constructing test batteries, but it is beyond the scope of the present review to do this. The aim is to produce a detailed account of the effect of alcohol on vigilance performance.

Of course, alcohol affects a broader range of functioning than vigilance, and in order to obtain a profile of the effects of alcohol (or of any other drug), investigators usually employ a battery of tests encompassing a wide range of functions (motor, sensory, memory, attention etc.). Parrott (1991) has stated that most batteries comprise an ad hoc collection and that issues of sensitivity and validity have been ignored. Various authors (e.g. Baker et al. 1985; Tiplady 1991) have argued that a particular test should be sensitive to the effects of alcohol before it is included in a test battery for any kind of drug. The present review is an attempt to assess the sensitivity of vigilance tasks to the effects of alcohol. Is performance impaired and, if so, are some types of task more sensitive than other types, are the effects mainly on (overall) level of performance or also on the decrement with time, and is impairment possibly dependent on time of day? Further, can something be concluded with respect to the validity of vigilance tasks and some other widely employed tasks in the study of driving related skills? Finally, are there indications in the performance literature that the legal limits for driving should be adapted?

Effects of alcohol on vigilance performance

In essence, the way of searching the literature (a computer search and following up cross-references), the inclusion of test characteristics, the measures of performance considered etc. are the same as described in two earlier reviews of the effects of drugs on vigilance (Koelega 1989, 1993). For various reasons some studies have not been included in the review: Putz-Anderson et al. (1981) used an adaptive version of the Mackworth Clock, in which task load was maintained at 70% performance accuracy, McClelland and Raptopoulos (1985) provided insufficient data, and five studies had no placebo condition and/or employed alcoholics as subjects (Colquhoun 1962b; Talland et al. 1964; Docter et al. 1966; Ludwig and Stark 1975; Cohen et al. 1983). One could argue about the exclusion of studies lacking placebo-treatment. Firstly, there does not seem to be a compelling reason to exclude placebo-lacking studies when there is no effect of alcohol compared to a control condition (e.g. Colquhoun 1962b), unless the lack of an effect is attributed to the lack of a placebo. Secondly, to give placebos an alcohol taste, some drops of alcohol are usually sprinkled on the top of the beverage, e.g. orange juice. However, in a number of studies where experimenters assessed the subjective state of intoxication, it appeared that subjects often can clearly differentiate between alcohol and placebo or between different doses of alcohol (e.g. Hamilton et al. 1984; Miller 1984). Mattila et al. (1982) mention that every subject in their experiment recognized alcohol from its effects, so it is rather unlikely that a "real" effect of alcohol may in fact have been a placebo effect. O'Boyle et al. (1994) have recently shown that there is an asymmetrical transfer of placebo efficacy.

Effects on measures of performance

Table 1 presents 28 sources of alcohol and vigilance, providing 38 overall-level comparisons for the measure of hits or "errors". Most studies employed males only as subjects, a universal phenomenon in psychopharmacology. Details of procedures and results are presented in the footnotes. Of the 38 comparisons, 20 found no effect of alcohol (but two of these measured after 6 and 12 h when BAC had reached zero, leaving 18 "no-effect" comparisons), whereas 18 reported an effect, a 50% effect-score, comparable with the effect found for benzodiazepines (Koelega 1989).

Finnigan and Hammersley (1992) have concluded that the effects of small doses of alcohol are difficult to detect with less than 15 subjects. Studies with a small sample size may have low power due to the large variance caused by the ingestion of alcohol. In more than half of the comparisons of the present review, small-sized (< 15) samples were used. In the small-sized samples, more studies reported "no effect" than "effect" (62% versus 38%), whereas in the larger-sized samples the opposite occurred (41% versus 59%), a 60% effect-score which increases to 67% when two studies measuring at zero BAC levels are removed. Note, however, that the picture is more complex than just "effect" or "no effect"; sometimes an effect is noted only in one session and not in another session, or with one dose and not with other doses, etc. (information to be found in the footnotes to Table 1). With respect to the question of whether alcohol aggravates the normally occurring decrement, only nine comparisons are available: seven reported no effect of alcohol on hits,

Table 1 Alcohol effects on vigilance performance

Study	Dose (excl. placebo)	Time after ingestion(min)	Subjects (sex; age)	Cross-over design	Task				Measure of performance	Effect on overall level	Effect on time course	Remarks (see Footnotes)
		BAC (mg/100 ml blood)			Duration (min)	Modality	Event rate (min)	Signal probability				
1) Colquhoun (1962a)	32 g	60 0.045%	33(M; 18–25)	No	90	A/V	60	0.01	Hits	Yes	NR[a]	1
2) Talland (1966)	0.5 g/kg	I: abt. 5 0.07%	24(M; NR)	Yes	120	A	60	0.07	Errors	No	No	2
	0.25 g/kg	II: abt. 5 0.035%	12(M; NR)	Yes	120	A	60	0.07	Errors	Yes	No	
3) Moskowitz and DePry (1968)	0.5 g/kg	20 0.07%	10(M; 21–40)	Yes	16	A	4	0.50	Hits	No	NR	3
									d′	No	NR	
									β	No	NR	
4) Pearson and Neal (1970)	0.3 g/kg	abt. 50, 100, 150, and 200 0.05, 0.047, 0.03 and 0.02%	9(M; 21–30)	Yes	14	A	30	0.03	Hits	No	NR	4
									F.a.s[b]	No	NR	
5) Wesnes et al. (1976)	0.33, 0.67 and 1.0 g/kg	20 0.04, 0.085 and 0.135%	8(M; 19–22)	Yes	60	V	60	0.02	Hits	Yes	Yes	5
6) Erwin et al. (1978)	0.5, 0.8, and 1.2 g/kg	60 0.04, 0.07 and 0.10%	15(7F,8M; 21–26)	Yes	30	V	60	0.017	Hits	Yes	No	6
									RT	Yes	No	
7) Horváth et al. (1978)	BACs 0.04, 0.06 and 0.08%	20 0.035, 0.055 and 0.075%	80(M; 20)	Yes?	70	A	3.6	0.50	Hits	Yes	NR	7
									F.a.s	No	NR	
									RT	No	NR	
8) Linnoila et al. (1978)	0.5, 0.8, and 1.2 g/kg	35 and 125 F: 0.035, 0.065 and 0.10% M: 0.04, 0.07 and 0.105% second session: F: 0.026, 0.06 and 0.095% M: 0.03, 0.06 and 0.09%,	20(10F 10M; 21–26)	Yes	4	V	30	0.47	Hits	Yes	NR	8
									RT	No	NR	
					30	V	60	0.017	Hits	Yes	NR	
									RT	Yes	NR	
9) Linnoila et al. (1980a)	0.5, 0.8, and 1.2 g/kg	abt. 60 0.035, 0.065 and 0.095%	20(M; 20–45)	Yes	4	V	30	0.47	Hits	No	NR	9
									RT	No	NR	
					30	V	60	0.017	Hits	Yes	NR	
									RT	Yes	NR	
10) Linnoila et al. (1980b)	0.5, 0.8, and 1.2 g/kg	abt. 60 0.03, 0.06 and 0.10%	10(F; 20–25)	Yes	4	V	30	0.47	Hits	No	NR	10
									RT	Yes	NR	
					30	V	60	0.017	Hits	Yes	NR	
									RT	Yes	NR	
11) Tong et al. (1980)	0.5 g/kg	abt. 30 0.055%	32(M; 18–30)	Yes	72	A	60	0.017	Hits	Yes	No	11
									F.a.s	No	No	
12) Linnoila et al. (1981)	0.8 g/kg	abt. 120 and 630 0.04 and 0.00%	12(M; 21–25)	Yes	5	V	30	0.39	Hits	No	NR	12
									F.a.s	No	NR	
									RT	No	NR	
		abt. 630 0.00%	12(M: 21–25)	Yes	30	V	60	0.016	Hits	No	NR	
									F.a.s	No	NR	
									RT	No	NR	

Table 1 Continued

Study	Dose (excl. placebo)	Time after ingestion(min) BAC (mg/100 ml blood)	Subjects (sex; age)	Cross-over design	Task Duration (min)	Modality	Event rate (min)	Signal probability	Measure of performance	Effect on overall level	Effect on time course	Remarks (see Footnotes)
13) Linnoila et al. (1983)	0.8 g/kg	60 0.07%	12(M; 21–26)	Yes	20	V	75	0.03	Hits RT	No	NR	13
14) Hamilton et al. (1984)	12.8 and 25.6 g	30 and abt. 220 F: 0.035 and 0.075% M: 0.02 and 0.045% second session: F: 0.00 and 0.015% M: 0.00 and 0.00%	12(6F, 6M; 20–31)	Yes	60	A	30	0.02	Hits d′ β	No No No	NR NR NR	14
15) Miller (1984)	0.3 and 0.5 g/kg	25 0.03 and 0.045%	72(M; 19–21)	No	36	V	6	0.20	Hits F.a.s	No No	No No	15
16) Jansen et al. (1985)	0.7 g/kg	30 0.065%	12(M; 19–30)	Yes	60	V	62	0.03	Hits F.a.s RT SI/A′ RI/B″	Yes No Yes Yes No	NR NR NR NR NR	16
					60	V	62	0.30	Hits F.a.s RT SI/A′ RI/B″	No No No No No	NR NR NR NR NR	
17) Nachreiner et al. (1985)	0.27, 0.41, 0.68 g/kg (males); 0.22, 0.33, 0.55 g/kg (females)	30 0.02, 0.04 and 0.08%	16(8F, 8M; NR)	Yes	30	V	30	0.25	Hits F.a.s d′ β	No No No No	No Yes Yes No	17
18) Erwin et al. (1986)	0.8 g/kg	abt. 60 and 180 0.07 and 0.046%	24(M; 21–25)	No	5 5 30	V V V	30 30 60	0.40 0.40 0.016	Hits Hits Hits RT	Yes No Yes Yes	NR NR NR NR	18
19) Fagan et al. (1987)	0.2, 0.4, 0.8 g/kg	I: 0, 30, 60 120, 150, 180 II: 60 at 30 min: 0.015, 0.05 and 0.08% at 180 min: 0.00, 0.01 and 0.065%	8(M; 19–39)	Yes	I:8 II:60	V A	30 30	0.17 0.05	Errors Hits F.a.s	Yes No No	NR NR NR	19
20) Grzech-Sukalo et al. (1988)	BACs 0.03 and 0.06%	I:40 0.03 and 0.06%	8(F;M)	Yes	60	V	10	0.10	Hits F.a.s RT A′ β	Yes No Yes Yes No	NR NR NR NR NR	20
		II:160 0.00 and 0.03%	8(F;M)	Yes	60	V	10	0.10	Hits F.a.s RT	No No No	NR NR NR	

									A′	No	NR	
									β	No	NR	
21) Loudon et al. (1988)	0.8 g/kg	60, 180, 300 and 420 0.07, 0.04, 0.01 and 0.00%	12(NR; 29–43)	Yes	6.6	V	60	0.10	Hits	Yes	NR	21
22) Rohrbaugh et al. (1988)	0.45, 0.80, and 1.05 g/kg	90 and 180 0.03, 0.06 and 0.09% (both sessions)	12(M; 21–32)	Yes	8	V	60	0.25	Hits	Yes	Yes	22
									F.a.s	Yes	No	
									RT	Yes	No	
									d′/A′	Yes	Yes	
									β	No	No	
23) Linnoila et al. (1990)	0.8 g/kg	80 and 250 0.045 and 0.01%	8 (M; 21–24)	Yes	20	V	60	NR	Hits	No	NR	23
									F.a.s	No	NR	
									RT	No	NR	
24) Horne and Gibbons (1991)	BACs 0.035 and 0.07	30 0.035 and 0.07%	8 (F; 18–23)	Yes	60	A	30	0.25	Hits	Yes	NR	24
									F.a.s	No	NR	
									RT	Yes	NR	
									d′	Yes	NR	
									β	No	NR	
25) Roehrs et al. (1992)	0.5 g/kg	330 0.00%	12(M; 21–45)	Yes	40	A	NR	NR	RT	Yes	No	25
									Errors	No	No	
26) Smith et al. (1992)	0.34 g/kg	NR (abt. 120 and 210) 0.015 and 0.00%	16 (F+M; NR)	No	8	V	100	0.08	Hits	No	NR	26
									F.a.s	Yes	NR	
									RT	No	NR	
27) Lemon et al. (1993)	0.5, 0.75 and 1.0 g/kg	720 0.00%	65 (M; NR)	No	40	V	120	0.01	Hits	No	NR	27
28) Linnoila et al. (1993)	0.8 g/kg	80 and 250 0.06 and 0.025%	10 (M; 21–24)	Yes	20	V	60	NR	Hits	No	NR	28
									F.a.s.	No	NR	
									RT	No	NR	

[a] not reported
[b] false alarms

1. Group experiment. Auditorily presented digits had to be checked visually with series in a booklet, and detected discrepancies (targets), which varied, had to be marked, so stimuli were presented simultaneously to two senses for comparison. Results are of day 4 (alcohol alone). According to Colquhoun (1976, p. 74) similar results were obtained in two further (unpublished) experiments with different stimulus conditions.
2. Subjects were prisoners, half of them alcohol addicts. Expt I was performed in isolation, expt II was a group experiment with rewards and with the large dose only, besides the placebo; the tasks were of the Bakan type. In expt II the control groups did better than the addicts under alcohol; both groups improved with time, paralleling BALs. In a third (visual and visual-auditory) experiment, with a rapid rate of presentation (120/min), only two subjects were used: alcohol impaired performance, but here also there was a continuous improvement under alcohol.
3. The interpretation that alcohol affects divided attention rather than vigilance performance is questioned (see text).
4. Subjects participated in four sessions. In a separate "hangover" condition (alcohol taken the night before) vigilance detection was poorer (n.s.), but RTs in a complex monitoring and tracking task were faster.
5. There were no dose-dependent effects on level of performance with the Mackworth clock, but the largest dose (6 fl oz) aggravated the decrement with time of the smallest dose (2 fl oz) in the latter half of the session.
6. The significant difference in hits and RT was noted for the high dose only. Females detected less signals in all conditions, and were more affected than males by the low and medium doses of alcohol. Approximately 25% of all misses could be accounted for by prolonged eye lid closures, induced by alcohol and time on task.
7. The task was performed three times, the first session always was placebo, so conditions were not balanced. All three doses affected hits in the second session; in the third session the lowest dose had no effect.
8. The effect for hits in the 4-min task was noted in the first session (trial ×) and not in the second session, and with males only. The second task, requiring spatial comparisons, was much more affected by alcohol. There were no differences between morning or afternoon ingestion.
9. Earlier reported additive (synergistic) deleterious effects of age and alcohol could not be confirmed. Older men showed lower BACs than younger men.
10. The effect of alcohol was greatest with the low dose, but there was also an interaction with phase of the menstrual cycle.
11. Simultaneous cigarette smoking did not reduce the alcohol impairment, but smoking was a between-subjects factor in contrast to alcohol.

Table 1 Continued

12. The alcohol was ingested over 1.5 h in the evening and testing took place about 2 h later (the short task only) and the next morning (both tasks). A combination of alcohol and flunitrazepam impaired a divided attention task in the morning, even though neither drug alone impaired performance at that time.
13. Although hits and RT showed no effect of alcohol alone, a ratio score (hits/RT) showed significant impaired performance after alcohol. The 5-HT reuptake inhibitor zimeldine antagonized effects of alcohol. The Continuous Performance Task (CPT) was of the A-X type (the target was the digit 6 followed by the digit 4).
14. Group experiment. Compared with placebo there were no effects of alcohol, but the highest dose (32 ml) alone impaired performance when compared with the antidepressant bupropion. When the two drugs were co-administered, bupropion abolished impaired performance, but not the feelings of inebriation, after alcohol.
15. Alcohol did not affect performance, but subjects with a history of a family (parents) alcohol-problem exhibited worse performance (especially more false alarms) than subjects without such a history.
16. The effect of this moderate dose (BAC about 0.05%) was found only in the condition with a low signal probability. The task was of a dynamic type (moving stimulus), requiring eye movements.
17. False alarms decreased with time on task in the placebo condition only; d′ increased in the placebo condition, but decreased in the alcohol conditions. During the first part (10 min) of the task, performance was better under alcohol, but this advantage was reversed later in the task. Even very low doses of alcohol (BAC $< 0.02\%$) led to changes in performance. Compared with placebo, performance was even impaired when BAC could no longer be measured.
18. The two 5-min tasks differed in the nature of the stimuli used (digits vs spatial stimuli). Alcohol caused greater performance impairment than diazepam or buspirone, and the effects were still present in the second session, carried out two hours later. Alcohol effects on event-related potentials were similar to those of diazepam, but buspirone sometimes reversed the alcohol effects, e.g. on the P3.
19. The effects on a nonverbal Continuous Attention Test were noted only with the largest dose (0.8 g/kg) and this only 3 h after ingestion, in the "hangover" period, not in the other five test sessions.
20. The authors contrasted effects of alcohol in the early stage of elimination with those of an advanced stage (Expt I vs. II). In Expt II, carried out 2 h after expt I, hits and sensitivity were higher, without a decrement, there were more false alarms, and beta was lower (a more lax criterion).
21. On the Rapid Visual Information Processing task, an impairing effect was noted only at 3 h post-ingestion.
22. In the vigilance task degraded stimuli were used (blurred images of digits). At 30-min intervals after the loading dose three maintenance doses were given. Although the first run was given during the ascending limb of the BAC curve, and the second run (90 min later) during the descending limb, there were no differences between the two runs. The authors did not report which of the three doses of alcohol differed significantly from placebo.
23. The effect on hits approached significance 1 h after consumption with this CPT 6–4 (see 13).
24. For hits and RT the impairment was greater in the early afternoon than in the early evening.
25. When BAC had reached zero (6 h after drinking), RT was more affected in the afternoon than in the evening in the first part of this easy task.
26. False alarms on this repeated-numbers detection task increased during the first session (after approx. 2 h) but not during the second session (after about 3½ h).
27. Hangover effects were studied during a "morning after" session with a version of the Mackworth clock.
28. Same task as in 13 and 23.

two studies (nos 5 and 22) found a precipitated performance decline with respect to correct detections and two (nos 17 and 22) with respect to sensitivity. One of these studies (Rohrbaugh et al. 1988) is noteworthy because the task was so short as to preclude marked changes in BAC, so that time on task was not likely to be confounded with BAC changes. In only two of 15 comparisons, alcohol affected false alarms. In nine cases, the signal detection measures d' or A' ("sensitivity") and β or B'' ("response willingness") were reported: alcohol impaired sensitivity in four experiments, but in none of the comparisons response willingness was affected. The measure of speed, response latency to hits or RT, was impaired in 11 out of 22 comparisons.

BAC levels at the time of testing

Expressing sensitivity in terms of "effect" and "no effect" is quite meaningless when BAC levels at the time of testing are left out of consideration. In the third column of Table 1, BAC values at the start of the vigilance session are given. Where possible, direct measures of BAC provided by the authors were used, but in a number of cases BACs had to be estimated. The same variety of methods of reporting alcohol administration, noted by other reviewers, was encountered. Doses expressed in oz/lb and ml/kg were converted into g alcohol/kg body weight. BACs were expressed in mg alcohol per 100 ml blood and were calculated in the same way as described by Moskowitz and Robinson (1987), i.e. divide the total dose in grams by the estimated volume of distribution (the estimated amount of water in the body, for males 58% and for females 49%) and convert this to g alcohol per ml blood by multiplying by 0.806 (80.6% of blood is water); rate of metabolism (removal) was estimated at 0.015% per hour. Moskowitz and Robinson report that this procedure is a conservative estimation of BACs; if there is a bias it is one of reporting impairment at higher BACs rather than lower levels. Some BACs are rather crude estimates because authors sometimes provided insufficient data on body weight (the average male was then taken to weigh 75 kg, the female 55 kg), gender (e.g. study 21), gender subdivision (e.g. study 26) or percentage of alcohol in the beverage (e.g. study 26). So, the data in the third column of the table should be used with some caution.

Inspection of Table 1 shows that generalizations with respect to BACs cannot be made: often performance was impaired at 0.03% but sometimes performance was unimpaired at 0.10%, and this could occur in the *same* experiment where different vigilance tasks were used, so perhaps more interesting is the question of whether some types of task are more sensitive than other types.

Effects of task parameters

There are no striking effects of the task parameters: duration, modality, and event rate or of type of design (crossover versus parallel). Generally, tasks employing a high probability of occurrence of targets showed somewhat less sensitivity than tasks with a low signal probability, but only one study (no. 16) manipulated probability within one design. Type of stimuli used, not included in Table 1 as a category, may have a profound influence, however. In the many studies of one particular research group (Linnoila's), one type of vigilance task using spatially defined critical events (a pair of illuminated dots spaced either 48 or 60 mm apart) was sensitive to the effects of low doses of alcohol (BAC 0.03%) in five different studies (nos 6, 8, 9, 10 and 18), whereas another type of task, a CPT (continuous performance task) where the target was the occurrence of two consecutive numbers or the digit 6 followed by a 4, was insensitive to even high doses (BAC 0.10%) in six different studies (nos 9, 10, 12, 13, 23 and 28), albeit that some of these six studies were of shorter duration. The latter task (the CPT 6–4) is a version of the CPT A–X, for normal adults a very easy task, in which performance measures often show ceiling effects. This suggests that vigilance tasks can be either sensitive or insensitive depending on the type of stimuli being used and the associated (difficulty of the) type of processing involved. Tasks employing alphanumeric, familiar, well-learned stimuli, for which a phonetic-linguistic code is available, may be more resistant to the effects of alcohol than tasks using more "sensory" stimuli, e.g. spatial stimuli. It has earlier been shown that different types of vigilance tasks require different skills or abilities in the same subjects (Koelega et al. 1989). There are indications in the literature that spatial ability may be more impaired by alcohol than other functions (Frankenhaeuser et al. 1962; Myrsten et al. 1970) and Linnoila (1978) has suggested that spatial information processing may be more impaired than verbal information processing. Apart from the studies listed above (nos 6, 8, 9, 10 and 18), some other studies from Table 1 containing nonverbal stimuli (nos 5, 7, 16, 17, 19 and 20) also showed sensitivity to alcohol. So, the question is not so much at which dose alcohol degrades vigilance performance but rather which types of task are impaired already at low doses.

Time-dose-response characteristics

Another aspect of the studies from Table 1 concerns the time-dose-response characteristics, and the so-called "Mellanby effect", formulated more than 70 years ago (1919), i.e., differential effects of alcohol pertaining to the ascending and descending limb of the BAC. There is no simple linear dependence on BAC irrespective of dose, time since ingestion, and time on task. The level of blood alcohol following alcohol ingestion follows a pattern of change known as the absorption-elimination curve, in which BACs ascend, reach a "plateau", and then descend. Any level of BAC occurs twice, once in the ascending (absorption) phase, and once in the descending (elimination) phase of the curve. One would expect that the effect of alcohol on performance would be identical at corresponding measurement points; however, it is well known that the effects in the absorption phase are different from those in the eliminination phase, so there is no direct relation between BAC and effect on performance. Most authors have reported that the effect of a given level of blood alcohol is greater in the absorption phase, as if there is a "surprise attack" on the brain, followed by acute tolerance (a decrease of the impairment during the elimination phase), but most studies failed to control for a learning effect and examined performance first during the rising curve and then during the falling curve. However, in lengthy vigilance tasks there is also an interaction with time on the task and several authors have reported that the effects of small doses of alcohol increase as a function of time, despite the fact thatthe BAC was lower, and falling (Colquhoun 1976; Nachreiner et al. 1985; Grzech-Sukalo et al. 1988). The latter authors reported impairing effects on sensory functions in the early elimination phase, and on decision making in a later elimination phase.

Inspection of Table 1 shows that the question of whether performance is more impaired during the ascending limb cannot be answered. A large majority of the studies from Table 1 did not measure performance during the ascending limb. We have an incomplete picture of the effects of alcohol on vigilance performance: the time from the last drink to maximal BACs usually ranges from 30–90 min, so the effects are essentially confined to the descending limb. To get a full picture, tasks should be administered closer to the time of drinking and the time course of performance should be reported in all investigations. Another strategy is to use short tasks to preclude changes in BAC, so that time on task effects are not confounded with changes in BAC, as was done by Rohrbaugh et al. (1988).

Positive, facilitating, effects with low doses of alcohol were not found in the vigilance studies considered in the present review, but the doses used may not have been low enough. Moskowitz et al. (1985) also failed to find support for the so-called biphasic effect of alcohol. Likewise, there was no evidence of residual sedation when BAC has reached zero, some 4 h after ingestion (nos 14, 21, 23, 25, 26, 28) or the next morning (nos 12 and 27); but see the note on study 25 in Table 1.

Effects on impulsivity and interaction of alcohol with smoking

Alcohol may also affect vigilance performance in another way than by direct action on the CNS during experiments with alcohol. There are reports that vigilance tasks are more poorly performed by *non*-alcoholics either with a history of family (parents) alcohol problems (Miller 1984), or with a DWI (Driving While Intoxicated) history of prior arrests (Koch and Morguet 1985). Both groups made significantly more false alarms than controls without parental alcohol problems, or without any alcohol delicts while driving, respectively. Note that in these studies alcohol was not a factor: in the Miller study the effect also occurred in the placebo condition, and Koch and Morguet did not use alcohol. The production of more false alarms may reflect a somewhat disinhibited, more impulsive, behavior, a greater tendency to take chances, or a low tolerance for boredom, as has also been described for the behavior of attention-deficit hyperactivity disordered (ADHD) children in vigilance tasks. In fact, there is a higher incidence of ADHD in the children of alcoholics.

Finally, in real-life situations, alcohol often increases the amount and rate of cigarette smoking in smokers, and there are reports that smoking diminishes the alcohol-induced performance deterioration in a subject-paced vigilance task (Michel and Bättig 1989), in selective-attention and divided-attention tasks (Leigh et al. 1977), in visual discrimination (Tong et al. 1974), in choice reaction time (Lyon et al. 1975; Kerr et al. 1991), and in tracking (Kerr et al. 1991). Myrsten and Andersson (1973) also reported that smoking counteracted alcohol-induced impairment in simple-and choice- RT tasks, but also that heart rate increased and hand steadiness deteriorated. These findings, together with factors such as tolerance and effects of prior ingestion of food, illustrate that, at least in smokers, in operational circumstances the effects of alcohol on behavior are hard to predict.

In what way may alcohol affect performance?

The precise mode(s) of action of alcohol on neurotransmitters in the brain is not yet clear, but recent evidence supports the premise that in low concentrations alcohol has selective effects on particular neurotransmitters in specific brain areas. Alcohol inhibits the function of the NMDA (*N*-methyl-D-aspartate) subtype of glutamate receptor-gated ion channels, potentiates the actions of $GABA_A$ agonists under specific conditions (e.g. phosphorylation of a subspecies of the gamma subunit), and also affects the function of $5\text{-}HT_3$ receptors and certain voltage sensitive calcium channels. Dopamine release in the nucleus accumbens by alcohol is probably modulated by potentiation of serotonin at 5-HT_3 receptors (Tabakoff and Hoffman 1993).

Does the literature provide indications how the impairing effects of alcohol on performance are brought about? Reviewing the literature, Carpenter (1962) noted that "little progress has been made in developing a knowledge of how and in what way alcohol affects behavior". This observation recurs 30 years later in the recent review by Finnigan and Hammersley (1992), who state that there is no theory as to how and why alcohol impairs driving or other natural skilled performance.

There is a large amount of literature on the question of whether alcohol affects specific functions more than other functions (whether motor, sensory, or cognitive). Most early literature reviews indicated that basic sensory-perceptual processes (such as visual acuity) are minimally or not all affected, but some studies report significant effects on saccadic eye movements, eye tracking, visual field, accommodation and convergence (Stapleton et al. 1986; Hill and Toffolon 1990) and on precortical (peripheral, retinal) processing of traffic signs (Avant 1990). Many authors have reported that motor functions are more impaired than cognitive or intellectual functions (e.g. Carpenter 1962; Myrsten et al. 1970; Starmer and Bird 1984), but Vogel-Sprott (1979) stated that this only holds for the descending limb of the BAC, during rising BAC exactly the opposite would occur. Linnoila et al. (1986) propose that the primary effect of alcohol centers on response organization and that there may be a greater effect on right hemisphere functions, associated with spatial information processing. Moskowitz (1984) stated that it is not merely the overload requirement that is important in the effects of alcohol, and Moskowitz and Robinson (1987) concluded that *specific* behavioral areas relevant to driving differ considerably in their susceptibility to impairment, but Maylor and Rabbitt (1993) asserted that alcohol has a *general* effect on information processing rather than specific effects; the important question is not *which* processes are involved but *how much* processing is required, the deficit is constant, the implication being that it is not necessary to know which specific processes are required by a task such as driving. However, the idea that only the amount of processing required is the crucial factor seems to be at odds with results showing that there was no effect of level of work load and task demand on performance after alcohol intake (Chiles and Jennings 1970, Ranney and Gawron 1986). Fisk and Schneider (1982) proposed that the mode of processing is more important than load per se: automatic (effortless, highly practiced) processing would be rather insensitive to impairing effects of alcohol, but controlled (effortful, capacity limited) processing would be highly sensitive. However, Linnoila et al. (1983) found a disruption of alcohol in automatic but not in controlled processes and Maylor and Rabbitt (1988) reported identical effects for the two types of processing.

All this serves to illustrate that knowledge about how alcohol affects performance is imperfect and that the literature does not provide guidelines to understand in what way alcohol may exert its impairing effects in vigilance tasks. Other approaches are necessary to make progress. Johnston (1982), having established that a causal link exists between alcohol and crash occurrence, attempted to enhance understanding of the nature of this causal mechanism by studying in detail the circumstances of alcohol-related crashes. Noting that most crashes occurred on rural roads with certain speed limits, it appeared that more alcohol-related crashes than "sober" crashes occurred on curves, which forges a link with knowledge of the effects of alcohol on skilled performance in the laboratory. In negotiating a curve we have to do with a divided-attention task: tracking of the curve path and perception of the degree of curvature to enable appropriate speed selection. Johnston suggests that drivers pay more attention to the steering task and that perception of the relevant curvature cues suffers, resulting in a curve entry speed that is far too high. West et al. (1993) attempted to assess why intake of alcohol increases risk of accidents when driving and examined the effects of alcohol on driving speed and time taken to detect occasional hazards, two aspects of driving correlating with accident risk. The authors suggested that at least part of the excess risk is attributable to an increase in the time taken to detect and respond to infrequent traffic hazards, but this still leaves open to question whether or not the increase in hazard perception latency reflects an increase in time to identify targets, in (higher level) processing time, or in response organization/execution.

Analyses of different types of alcohol-related crashes, such as performed by Johnston (1982), may enhance our understanding of the mechanisms through which alcohol impairment causes accidents, but this understanding is, as yet, quite crude. Two major principles that seem to have been established are that the ability to time-share in a divided-attention task is seriously impaired and that information processing is slower, but that rate of switching between sources of information or retaining information in immediate memory are relatively unimpaired (Moskowitz 1973). The information compiled in Table 1 of the present review can only in a very modest way contribute to knowledge about how alcohol impairs performance. It appears that length of the session (increasing fatigue and boredom), probability of occurrence of critical signals, and rate of presentation of stimuli (high or low) may not be important factors in the impairing effects of alcohol and that the visual modality is not more affected than the auditory one, suggesting impairment of central factors. Response latency to correct detections (RT) is as often impaired as is accuracy of performance (sensitivity and correct detections) and there is no effect of alcohol on measures of cautiousness of responding (false alarms or β, willingness to respond or response criterion). The effects seem to be most pronounced in tasks employing nonverbal stimuli. From the lack of effect on measures of response decision behavior, a lack which alcohol shares with benzodiazepines and stimulant drugs, it cannot be concluded that alcohol does not affect risk taking behavior. These measures may bear no relationship to a possibly lowered ability to assess risk in the driving environment.

Rationales for choosing particular tests in batteries: the issues of validity and sensitivity

It was earlier stated (Koelega 1993), that not every vigilance task measures the same aspect of attention and information processing and if changes due to drugs are to be interpreted in terms of "attention", performance on a sustained attention task should not be limited by perceptual ability, memory, or information-processing speed. Tables with detailed data on various versions of (vigilance) tasks and their sensitivity may contribute to information on utility and quality and thus to decisions to use a particular (vigilance) test. The evidence collected in the present review indicates that some types of vigilance task should be included in any test battery (besides some types of divided-attention tasks as previously mentioned).

The relevance of laboratory results is, apart from low sensitivity and reliability, reduced by limited validity of the tests, i.e. limited predictability of the behavior (e.g. the nature of driving a car) under interest. With respect to driving performance there are no truly predictive tests, whether laboratory tasks or performance in simulators. In the study of driving-related skills very few investigators have addressed the question of criterion and validity of the laboratory tests used, an exception being Häkkinen (1976) who followed the accident behavior of drivers over long periods (mean length 17 years) and reported that accidents correlated highest with tests of attention, followed by involuntary control of motor function. Earlier reviewers unanimously agreed that the main effect of low to moderate doses of alcohol is on attention and information processing, both rather vague, catchall phrases, permitting a great variety of meanings to be associated with them, and thus a great variety of tests to measure them. One aspect concerns attentional capacity, which may not always be sufficiently taxed by performance of a single task, although there are vigilance tasks exceeding capacity such as those bombarding the subject with rapidly presented degraded, barely discriminable stimuli, but these tasks are a parody of real-life activities, as in driving. Divided-attention tasks, performing several tasks at the same time, may exceed capacity but this depends on the tasks' demands: e.g. driving and conversation do not require full attention, but conversation is usually halted in backing and parallel parking or other attention demanding situations. Laboratory divided-attention tasks are highly sensitive to low doses of alcohol (Moskowitz and Robinson 1987), but it was previously mentioned that not all types of task are equally sensitive. However, an advantage of divided-attention tasks is that in single-task performance the effects of alcohol are often underestimated even if there is a significant impairing effect, because diminished capacity is compensated by focusing attention exclusively on this task and this may obscure impairment of other important peripheral tasks such as they occur in driving, flying, in overall system safety.

Another aspect of attention related to driving is the ability to remain alert in boring, monotonous, deactivating situations that do not invite concentrated, compensatory effort. Depressant action of (sedative) drugs may manifest itself especially in tasks designed to resemble these conditions, i.e. in vigilance tasks. Erwin et al. (1978) stated that the serial presentation of an endless train of meaningless (neutral) stimuli interrupted by infrequent and randomly occurring stimuli, such as characterizes the vigilance task, has an analogue in highway driving with neutral stimuli such as broken-line lane dividers, expansion strips etc. And Linnoila (1978) explained that in his laboratory boring (vigilance) tasks under low illumination conditions (analogous to night time driving) were used on the basis of clues provided by epidemiological research concerning alcohol and traffic accidents. These considerations suggest that (sensitive types of) vigilance and divided-attention tasks should always be included in test batteries.

An additional advantage of having a vigilance task in a test battery is that most types of vigilance task do no require practice or sophisticated skills to achieve a stable baseline. This has long since been common knowledge to vigilance researchers, but it has again been shown in a study by McClelland (1987), who investigated the effect of practice on a number of tests used in batteries. There were exponential learning curves for choice RT, simple RT, fusion threshold, a manipulative motor task, visual analogue scales and especially for digit span which even after ten practice sessions showed improvement; the other measures required at least four pre-study training sessions. There were no practice effects at all on hits and RT of a vigilance task (rapid visual information processing or RVIP), time estimation, and directly measured body sway, and McClelland concluded that with respect to training and learning, these tests are ideal for use in psychopharmacological studies.

Other drugs than alcohol, and alcohol in high doses, may affect other aspects of abilities than merely "attention" and information processing, and therefore test batteries should address a broader range of functioning. Tiplady (1991) states that the influence of alcohol in the choice of tests should be considerable, a comprehensive battery should include tests known to be capable of detecting moderate doses of alcohol in view of the importance of alcohol in road accidents. Baker et al. (1985), giving recommendations for the development and use of valid and reliable tests, have also concluded that behavioral tests should be able to detect the effects of moderate doses of alcohol. The latter authors do not recommend the use of (digit span) memory tests and flicker fusion.

No attempt is made to establish the relative sensitivity of vigilance tasks, as was done in the review of stimulant drugs on vigilance (Koelega 1993), the reason being that not many studies from Table 1 used batteries and when they did the tasks differed widely from study to study, resulting in a meagre database for quantification. However, with respect to the issue of sensitivity to alcohol, a few points can be made regarding some widely employed tests other than vigilance. Digit span memory/recall should not be included in a battery (Baker et al. 1985; McClelland 1987); the latter author reports that the test has also been shown to be insensitive to the effects of benzodiazepines. Critical flicker frequency (CFF) has repeatedly been found to be insensitive to effects of alcohol (Moskowitz and Robinson 1987). Finnigan and Hammersley (1992) also report that during the period 1980–1991, CFF showed impairment to alcohol in only 20% of the cases (Table 4.2). The authors suggest that there may be more studies finding no effect, publication is probably biased towards studies reporting effects of alcohol. Some studies not included by Finnigan and Hammersley also reported insensitivity of CFF (Mattila et al. 1982; Tedeschi et al. 1984; Aranko et al. 1985; Jansen et al. 1985). Millar et al. (1992) also mention half a dozen of studies finding no effect with CFF. The presence of the Digit Symbol Substitution Test (DSST) in a battery has earlier been criticized (Koelega 1989, 1993) because of its moderate sensitivity and the uncertainty which of many mental functions are affected. Whereas Foltin and Evans (1993) propose to use the DSST as a "benchmark" task because "it is known to be sensitive to drug effects" and has a large database, the task has repeatedly been shown to be insensitive to moderate doses of alcohol (e.g. Maisto et al. 1981; Bond et al. 1991) or to show the inverse of visuomotor error scores in the same experiment (Streufert et al. 1992). There is uncertainty surrounding use of reaction time tests. Howat et al. (1991) concluded in their review that tests of simple RT are not directly relevant to traffic safety. Moskowitz and Sharma (1974) stated that, contrary to popular belief, alcohol does not materially affect RT. Earlier, Moskowitz (1973) had suggested that reaction time experimentation does not define a meaningful behavioral segment. In the review of Moskowitz and Robinson (1987) it was concluded that for RT impairment appeared at higher BACs than in other areas. Finnigan and Hammersley (1992), however, noted that alcohol does affect RT and that there were more effects for simple RT than for choice-RT (CRT). Shillito et al. (1974) and Tedeschi et al. (1984) concluded that CRT is not sensitive to the effects of alcohol. Linnoila (1973) and Linnoila and Mattila (1973) even noted that, in the same experiment, impairment of divided attention went together with improved CRT performance after alcohol ingestion. It has already been mentioned that McClelland (1987) found learning curves for both simple and choice-RT.

All this is not to suggest that these tests should no longer be used. Generalization on the basis of less-than-exhaustive reviews should be rejected here as it has been done for vigilance in the present study. But investigators, having employed a test battery for many years without critical evaluation of its constituents, should be aware of questions of validity (e.g. DSST), learning effects (e.g. digit span memory) and sensitivity (e.g. CFF). If tests that are insensitive to alcohol show impairment with other drugs or in a combination of drugs, the extent of the impact on behavior is probably highly underestimated.

Time-dependent effects of alcohol and legal limits for driving

Some studies from Table 1 reported time-dependent effects of alcohol. Horne and Gibbons (1991) found greater vigilance impairment in the early afternoon than in the early evening, the BAC levels being the same for afternoon and evening. Roehrs et al. (1992) noted the same phenomenon when BAC levels were zero (5 h postconsumption). This suggests that the effects of alcohol differ with time of day and possibly follow a circadian rhythm. This has earlier been claimed for other tasks than vigilance. Rutenfranz and Singer (1967) had six subjects perform a divided-attention task and reported that during the elimination phase of alcohol intake, performance after midnight (between 2400 and 0630 hours) was much worse than between 1200 and 1830 hours; in this experiment there was no control group to control for fatigue during the night. Jones (1974) found more cognitive impairment after alcohol ingestion in the afternoon than in the evening, but this was established in different experiments with different subjects. Lawrence et al. (1983) found greater alcohol-induced impairment in the morning than in the early evening and Horne and Baumber (1991) showed that driving in a car simulator was more impaired in the early afternoon than in the early evening, BAC levels being the same.

Circadian variations in the pharmacokinetics of alcohol (e.g. in absorption and removal rate) have also been reported (Minors and Waterhouse 1980) but the circadian variation in susceptibility (chronesthesy), in the *effects* of alcohol, does not seem to be dependent on chronokinetics, meaning that the intensity of the changes cannot be deduced from the BAC level

(Reinberg 1992). Reinberg had subjects perform at 0700, 1100, 1900, and 2300 hours (at weekly intervals) and noted that performance was most impaired after the late (2300 hours) ingestion; the author suggested that the changes in effects may be related to the sleep-wake rhythm.

Such time-of-day phenomena are relevant to car driving: in analyses of car accidents, two clear peaks are evident, one at about 0300 hours, and the other at about 1500 hours, corresponding with the temporal structure of sleepiness, the after-midnight and mid-afternoon dips in alertness. Zomer and Lavie (1990) showed this for the period 1984–1989 in Israel. Leger (1994) reaches the same conclusion for the USA: more than 54% of all motor-vehicle accidents occurred at night, and performance errors in general also showed the same two-peak pattern. Johnston (1982) reported that in Australia 75% of the alcohol-related crashes occurred at night compared with 35% of the "sober" crashes. Modell and Mountz (1990) reported that a disproportionate number of alcohol-related flying accidents also occurred at night and that the detrimental effects of alcohol on oculovestibular function of pilots are particularly pronounced at low ambient-light levels, such as encountered during night flight. That light levels are important was shown more than 30 years ago by Mortimer (1963) who had subjects perform a simulated driving task under daylight and night illumination. At a BAC level of 0.068% there was a large decrement of performance but even at the very low peak concentration of 0.012% performance was significantly impaired under night illumination conditions combined with glare (simulated car head lamps). The author suggested that a double standard be instituted: separate legal limits for daylight and night driving.

In view of the accident peaks during the endogenous nadirs in alertness, the hours of maximum sleepiness, it seems obvious that sleepiness enters as a co-factor in the great majority of alcohol-related accidents. Horne and Baumber (1991) concluded that early afternoon driving performance was so adversely affected by alcohol to be at a dangerous level, although BAC levels were *within* the UK legal limit; thus, this limit is too high for safe driving in the afternoon. The marked reduction in alertness and related performance deficits that normally occur at night, and to a smaller extent in the early afternoon, are worsened by alcohol. Walsh et al. (1991) showed that a moderate dose of alcohol ingested at 2130 hours *increases* physiological sleepiness from 0100 to 0500 hours, even when the alcohol had been eliminated from the blood. Enhanced sleepiness "potentiates" the normally occurring impairing effects of alcohol on performance. The combination of alcohol, sleepiness, and night illumination (together with conditions of glare and sometimes rain), is an extremely dangerous one.

Although Mitchell (1985) in a review concluded that there is an absence of documented impairment of behavioral skills at BACs below 0.05%, it is by now clear from the literature on human performance that low doses of alcohol (between 0.02% and 0.05%) can considerably impair level of performance (Moskowitz et al. 1985; Moskowitz and Robinson 1987; Modell and Mountz 1990; Howat et al. 1991) or can aggravate the normally occurring decrement with time-on-task (Nachreiner et al. 1985; Rohrbaugh et al. 1988). The capacity demands in the latter task were those that are needed to encode degraded visual stimuli, the sort of demands sometimes needed in "real life", e.g. when driving in the dark when it is raining. Grüner et al. (1964) noted the impairment at low BACs already 30 years ago and called this the "problem of the small doses". Kennedy et al. (1993) reported that on nine tests, greater changes in cognitive function occurred between placebo and 0.05% than between 0.05% and 0.10%. Ideally, the allowable BAC should be reduced to zero or 0.01%, but there is a limit on the workload for the police when the number of arrests increases considerably. Because most alcohol is taken in the evening, the implication for legislators is to lower the legal limit for driving after midnight to, for example, 0.02%, at any rate from Friday night till Monday morning because alcohol is more frequently involved in fatal accidents on weekends than on weekdays. Since young drivers are highly overrepresented in accident statistics, one should consider to lower the statutory BAC for the young (e.g. < 23) to 0.02% at all times.

The various countries in the European Community differ widely with respect to the BAC at which a driver commits an offence. Although there is no safe BAC for driving or flying, all states should adopt a uniform BAC of at least 0.05%, some current BAC limits (e.g. 0.08%) concerning drinking and driving are far too generous, have been set on the basis of data from older studies failing to examine lower BACs. Moskowitz and Robinson (1987) explained the recent trends toward the universal detection of impairment at much lower BACs than in the past (corroborated for vigilance in the present review) to be a result of three factors: a) a more sophisticated selection of behavioral tasks, especially information processing and attention, b) refined methodology, handling, presentation and measurement of drug treatments, and c) the inclusion of lower doses in experiments. But it should be kept in mind that even with BACs of 0.05%, the probability of being involved in a crash increases by 100% over a zero BAC and for young and inexperienced drivers (and drinkers) this probability increases several hundred percent (Howat et al.1991).

Conclusions

Although it is often stated that vigilance tasks are rather insensitive instruments to assess the effects of alcohol, it appears that some types of these tasks, especially those requiring some form of nonverbal, spatial information processing, are very sensitive to low doses of alcohol. Most vigilance tasks have been performed during the descending limb of the BAC curve, sometimes even late in the elimination phase. In about half of the published experiments (for larger-sized samples about 70%), overall level of performance as well as response latency (RT) appeared to be impaired. Some studies have reported a more rapid decline under alcohol. The sensitive types of both vigilance tasks and divided-attention tasks should be part of test batteries, but the usefulness of some other tasks (DSST, CFF, digit span memory etc.) is questioned. The literature on human performance provides evidence suggesting that current BAC limits for driving should be considerably lowered for driving after midnight and for young and inexperienced drivers.

References

Aranko K, Seppälä T, Pellinen J, Mattila MJ (1985) Interaction of diazepam or lorazepam with alcohol. Eur J Clin Pharmacol 28:559–565

Avant LL (1990) Alcohol impairs visual presence/absence detection more for females than for males. Percept Psychophysics 48:285–290

Baker SJ, Chrzan GJ, Park CN, Saunders JH (1985) Validation of human behavioral tests using ethanol as a CNS depressant model. Neurobehav Toxicol Teratol 7:257–261

Billings CE, Wick RL, Gerke RJ, Chase RC (1973) Effects of ethyl alcohol on pilot performance. Aerospace Med 44:379–382

Bond A, Silveira JC, Lader M (1991) Effects of single doses of alprazolam and alcohol alone and in combination on psychological performance. Hum Psychopharmacol 6:219–228

Carpenter JA (1962) Effects of alcohol on some psychological processes: a critical review with special reference to automobile driving skill. Q J Stud Alcohol 23:274–314

Chiles WD, Jennings AE (1970) Effects of alcohol on complex performance. Hum Fact 12:605–612

Cohen MJ, Schandler SL, Naliboff BD (1983) Psychophysiological measures from intoxicated and detoxified alcoholics. J Stud Alcohol 44:271–282

Colquhoun WP (1962a) Effects of hyoscine and meclozine on vigilance and short-term memory. Br J Indust Med 19:287–296

Colquhoun WP (1962b) Effects of a weak dose of alcohol and of certain other factors on performance in a vigilance task. Bull Centr Etud Rech Psycho-Techn (Paris) 11:27–44

Colquhoun WP (1976) Estimation of critical blood-alcohol level in relation to tasks of sustained attention. In: Horváth M (ed) Adverse effects of environmental chemicals and psychotropic drugs, vol. 2. Elsevier, Amsterdam, pp 69–83

Davies DR, Parasuraman R (1982) The psychology of vigilance. Academic Press, London

Docter RF, Naitoh P, Smith JC (1966) Electroencephalographic changes and vigilance behavior during experimentally induced intoxication with alcoholic subjects. Psychosom Med 28: 605–615

Erwin CW, Wiener EL, Linnoila MI, Truscott TR (1978) Alcohol-induced drowsiness and vigilance performance. J Stud Alcohol 39:505–516

Erwin CW, Linnoila M, Hartwell J, Erwin A, Guthrie S (1986) Effects of buspirone and diazepam, alone and in combination with alcohol, on skilled performance and evoked potentials. J Clin Psychopharmacol 6:199–209

Fagan D, Tiplady B, Scott DB (1987) Effects of ethanol on psychomotor performance. Br J Anaesth 59:961–965

Finnigan F, Hammersley RH (1992) The effects of alcohol on performance. In: Smith AP, Jones DM (eds) Handbook of human performance, vol 2. Academic Press, London, pp 73–126

Fisk AD, Schneider W (1982) Type of task practice and time-sharing activities predict performance deficits due to alcohol ingestion. Proc Hum Fact Soc 21:926–930

Foltin RW, Evans SM (1993) Performance effects of drugs of abuse: a methodological survey. Hum Psychopharmacol 8: 9–19

Frankenhaeuser M, Myrsten A-L, Järpe G (1962) Effects of a moderate dose of alcohol on intellectual functions. Psychopharmacologia 3:344–351.

Grüner O, Ludwig O, Domer H (1964) Dependence of alcohol-induced impairment of attention on blood alcohol level at low concentrations. Blutalkohol 3:445–452

Grzech-Sukalo H, Hedden I, Nachreiner F (1988) Differential effects of small doses of alcohol on signal detection performance at two stages in the process of elimination. Atemalkohol 4.1–2: 7–33

Gustafson R (1986) Effect of small doses of alcohol and signal intensity on simple auditory reaction time in a monotonous test situation. Percept Mot Skills 63:539–543

Häkkinen S (1976) Traffic accidents and psychomotor test performance. Mod Probl Pharmacopsychiatry 11:51–56

Hamilton MJ, Bush MS, Peck AW (1984) The effect of bupropion, a new antidepressant drug, and alcohol and their interaction in man. Eur J Clin Pharmacol 27:75–80

Hill JC, Toffolon G (1990) Effect of alcohol on sensory and sensorimotor visual functions. J Stud Alcohol 51:108–113

Horne JA, Baumber CJ (1991) Time-of-day effects of alcohol intake on simulated driving performance in women. Ergonomics 34:1377–1383

Horne JA, Gibbons H (1991) Effects on vigilance performance and sleepiness of alcohol given in the early afternoon ("post lunch") vs. early evening. Ergonomics 34:67–77

Horváth M, Frantík E, Peprník M, Beneš V (1978) Dissociation of perceived and real effect of ethanol on vigilance performance. Act Nerv Super 20:89–91

Howat P, Sleet D, Smith I (1991) Alcohol and driving: is the 0.05% blood alcohol concentration limit justified? Drug Alcohol Rev 10:151–166

Jansen AAI, de Gier JJ, Slangen JL (1985) Alcohol effects on signal detection performance. Neuropsychobiology 14:83–87

Jellinek EM, McFarland RA (1940) Analysis of psychological experiments on the effects of alcohol. Q J Stud Alcohol 1:272–371

Johnston IR (1982) The role of alcohol in road crashes. Ergonomics 25:941–946

Jones BM (1974) Circadian variation in the effects of alcohol on cognitive performance. Q J Stud Alcohol 35:1212–1219

Kennedy RS, Turnage JJ, Wilkes RL, Dunlap WP (1993) Effects of graded dosages of alcohol on nine computerized repeated-measures tests. Ergonomics 36:1195–1222

Kerr JS, Sherwood N, Hindmarch I (1991) Separate and combined effects of the social drugs on psychomotor performance. Psychopharmacology 104:113–119

Koch M, Morguet M (1985) Investigation in the use of a vigilance test in psycho-medical assessment. Blutalkohol 22:391–396

Koelega HS (1989) Benzodiazepines and vigilance performance: a review. Psychopharmacology 98:145–156

Koelega HS (1993) Stimulant drugs and vigilance performance: a review. Psychopharmacology 111:1–16

Koelega HS, Brinkman J-A, Hendriks L, Verbaten MN (1989) Processing demands, effort, and individual differences in four different vigilance tasks. Hum Fact 31:45–62

Kraepelin E (1892) On the effect of some drugs on simple psychological events. Gustav Fisher, Jena

Kuitunen T, Mattila MJ, Seppala T (1990) Actions and interactions of hypnotics on human performance: single doses

of zopiclone, triazolam and alcohol. Int Clin Pychopharmacol 5:115–130
Lawrence NW, Herbert M, Jeffcoate WJ (1983) Circadian variation in effects of ethanol in man. Pharmacol Biochem Behav 18 [Suppl 1]:555–558
Leger D (1994) The cost of sleep-related accidents: a report for the national commission on sleep disorders research. Sleep 17: 84–93
Leigh G, Tong JE, Campbell JA (1977) Effects of ethanol and tobacco on divided attention. J Stud Alcohol 38:1233–1239
Lemon J, Chesher G, Fox A, Greeley J, Nabke C (1993) Investigation of the "hangover" effects of an acute dose of alcohol on psychomotor performance. Alcohol Clin Exp Res 17:665–668
Levine JM, Kramer GG, Levine EN (1975) Effects of alcohol on human performance: an integration of research findings based on an abilities classification. J Appl Psychol 60:285–293
Linnoila M (1973) Drug effects on psychomotor skills related to driving: interaction of atropine, glycopyrrhonium and alcohol. Eur J Clin Pharmacol 6:107–112
Linnoila M (1974) Effect of drugs and alcohol on psychomotor skills related to driving. Ann Clin Res 6:7–18
Linnoila M (1978) Psychomotor effects of drugs and alcohol on healthy volunteers and psychiatric patients. In Olive G (ed) Advances in pharmacology and therapeutics, vol 8. Pergamon Press, Oxford, pp 235–249
Linnoila M, Mattila MJ (1973) Effects of isoniazid on psychomotor skills related to driving. J Clin Pharmacol 13:343–350
Linnoila M, Erwin CW, Cleveland WP, Logue PE, Gentry WD (1978) Effects of alcohol on psychomotor performance of men and women. J Stud Alcohol 39:745–758
Linnoila M, Erwin CW, Ramm D, Cleveland WP (1980a) Effects of age and alcohol on psychomotor performance of men. J Stud Alcohol 41:488–495
Linnoila M, Erwin CW, Ramm D, Cleveland WP, Brendle A (1980b) Effects of alcohol on psychomotor performance of women: interaction with menstrual cycle. Alcohol Clin Exp Res 4:302–305
Linnoila M, Erwin CW, Brendle A, Logue P (1981) Effects of alcohol and flunitrazepam on mood and performance in healthy young men. J Clin Pharmacol 21:430–435
Linnoila M, Johnson J, Dubyoski T, Ross R, Buchsbaum M, Potter WZ, Weingartner H (1983) Effects of amitriptyline, desipramine and zimeldine, alone and in combination with ethanol, on information processing and memory in healthy volunteers. Acta Psychiatr Scand [Suppl] 308:175–181
Linnoila M, Stapleton JM, Lister R, Guthrie S, Eckardt M (1986) Effects of alcohol on accident risk. Pathologist 40:36–41
Linnoila M, Stapleton JM, Lister R, Moss H, Lane E, Granger A, Greenblatt DJ, Eckardt MJ (1990) Effects of adinazolam and diazepam, alone and in combination with ethanol, on psychomotor and cognitive performance and on autonomic nervous system reactivity in healthy volunteers. Eur J Clin Pharmacol 38:371–377
Linnoila M, Stapleton JM, George DT, Lane E, Eckardt MJ (1993) Effects of fluvoxamine, alone and in combination with ethanol, on psychomotor and cognitive performance and on autonomic nervous system reactivity in healthy volunteers. J Clin Psychopharmacol 13:175–180
Loudon JM, McClelland GR, Pilgrim AJ (1988) Denbufylline and ethanol: effects on psychomotor performance. Br J Clin Pharmacol 25:123P
Ludwig AM, Stark LH (1975) "Arousal" and alcoholism: psychophysiological responses to alcohol. Adv Exp Med Biol 59:515–536
Lyon RJ, Tong JE, Leigh G, Clare G (1975) The influence of alcohol and tobacco on the components of choice reaction time. J Stud Alcohol 36:587–596
Maisto SA, Connors GJ, Ruff C, Watson D (1981) Alcohol and volitional control on affect/sensation, cognitive and perceptual-motor measures. Curr Psychol Res 1:235–250
Marks DF, MacAvoy MG (1989) Divided attention performance in cannabis users and non-users following alcohol and cannabis separately and in combination. Psychopharmacology 99: 397–401
Mattila MJ, Aranko K, Seppala T (1982) Acute effects of buspirone and alcohol on psychomotor skills. J Clin Psychiatry 43: 56–61
Maylor EA, Rabbitt PMA (1988) Amount of practice and degree of attentional control have no influence on the adverse effect of alcohol in word categorization and visual search tasks. Percept Psychophys 44:117–126
Maylor EA, Rabbitt PMA (1993) Alcohol, reaction time and memory: a meta-analysis. Br J Psychol 84:301–317
McClelland GR (1987) The effects of practice on measures of performance. Hum Psychopharmacol 2:109–118
McClelland GR, Raptopoulos P (1985) Psychomotor effects of paroxetine and amitriptyline alone and in combination with ethanol. Br J Clin Pharmacol 19:578P
Mellanby E (1919) Spec Rep Ser Med Res Counc, London, No. 31
Michel Ch, Bättig K (1989) Separate and combined psychophysiological effects of cigarette smoking and alcohol consumption. Psychopharmacology 97:65–73
Miles C, Porter K, Jones DM (1986) The interactive effects of alcohol and mood on dual-task performance. Psychopharmacology 89:432–435
Millar K, Hammersley RH, Finnigan F (1992) Reduction of alcohol-induced performance impairment by prior ingestion of food. Br J Psychol 83:261–278
Miller RC (1984) The effect of low doses of alcohol on human behavior. PhD thesis, University of Texas at Austin
Minors DS, Waterhouse JM (1980) Aspects of chronopharmacokinetics and chronergy of ethanol in healthy man. Chronobiologia 7:465–480
Mitchell MC (1985) Alcohol-induced impairment of central nervous system function: behavioral skills involved in driving. J Stud Alc Suppl 10:109–116
Modell JG, Mountz JM (1990) Drinking and flying. The problem of alcohol use by pilots. N Engl J Med 323:455–461
Mortimer RG (1963) Effect of low blood-alcohol concentrations in simulated day and night driving. Percept Mot Skills 17:399–408
Moskowitz H (1973) Laboratory studies of the effects of alcohol on some variables related to driving. J Safety Res 5:185–199
Moskowitz H (1984) Attention tasks as skills performance measures of drug effects. Br J Clin Pharmacol 18:51S–61S
Moskowitz H, DePry D (1968) Differential effect of alcohol on auditory vigilance and divided-attention tasks. Q J Stud Alcohol 29:54–63
Moskowitz H, Robinson CD (1987) Effects of low doses of alcohol on driving-related skills: a review of the evidence. Tech Rep US Dept Transp, Washington DC
Moskowitz H, Sharma S (1974) Effects of alcohol on peripheral vision as a function of attention. Hum Fact 16:174–180
Moskowitz H, Burns MM, Williams AF (1985) Skills performance at low blood alcohol levels. J Stud Alcohol 46:482–485
Myrsten A-L, Andersson K (1973) Interaction between effects of alcohol intake and cigarette smoking. Rep Psychol Lab Univer Stockholm No. 402
Myrsten A-L, Kelly M, Neri A, Rydberg U (1970) Acute effects and after-effects of alcohol on psychological and physiological functions. Rep Psychol Lab Univer Stockholm No. 314
Nachreiner F, Grzech-Sukalo H, Baer K (1985) Alcohol effects in signal detection. Z Arb Wiss 39:237–242
O'Boyle DJ, Binns AS, Sumner JJ (1994) On the efficacy of alcohol placebos in inducing feelings of intoxication. Psychopharmacology 115:229–236
Parrott AC (1991) Performance tests in human psychopharmacology (3): construct validity and test interpretation. Hum Psychopharmacol 6: 197–207
Pearson RG (1968) Alcohol-hypoxia effects upon operator tracking, monitoring, and reaction time. Aerospace Med 39:303–307

Pearson RG, Neal GL (1970) Operator performance as a function of drug, hypoxia, individual, and task factors. Aerospace Med 41:154–158

Perrine MW (1973) Alcohol influences on driving-related behavior: a critical review of laboratory studies of neurophysiological, neuromuscular and sensory activity. J Safety Res 5:165–184

Putz-Anderson V, Setzer JV, Croxton JS (1981) Effects of alcohol, caffeine and methyl chloride on man. Psychol Rep 48:715–725

Ranney TA, Gawron VJ (1986) Task demand and alcohol effects on simulated driving performance. Proc Hum Fact Soc 30th Ann Meeting, pp 265–269

Reinberg A (1992) Circadian changes in psychologic effects of ethanol. Neuropsychopharmacology 7:149–156

Roehrs T, Zwyghuizen-Doorenbos A, Knox M, Moskowitz H, Roth T (1992) Sedating effects of ethanol and time of drinking. Alcohol Clin Exp Res 16:553–557

Rohrbaugh JW, Stapleton JM, Parasuraman R, Frowein HW, Adinoff B, Varner JL, Zubovic EA, Lane EA, Eckardt MJ, Linnoila M (1988) Alcohol intoxication reduces visual sustained attention. Psychopharmacology 96:442–446

Rutenfranz J, Singer R (1967) Investigations on the dependence of alcohol effects on time of day. Int Z Angew Physiol 24:1–17

Shillito ML, King LE, Cameron C (1974) Effects of alcohol on choice reaction time. Q J Stud Alcohol 35:1023–1034

Smith A, Kendrick A, Maben A (1992) Effects of caffeine, lunch and alcohol on human performance, mood and cardiovascular function. Proc Nutr Soc 51:325–333

Stapleton JM, Guthrie S, Linnoila M (1986) Effects of alcohol and other psychotropic drugs on eye movements: relevance to traffic safety. J Stud Alcohol 47: 426–432

Starmer GA, Bird KD (1984) Investigating drug-ethanol interactions. Br J Clin Pharmacol 18:27S–35S

Streufert S, Pogash R, Roache J, Gingrich D, Landis R, Severs W, Lonardi L, Kantner A (1992) Effects of alcohol intoxication on risk taking, strategy, and error rate in visuomotor performance. J Appl Psychol 77:515–524

Streufert S, Pogash R, Roache J, Severs W, Gingrich D, Landis R, Lonardi L, Kantner A (1994) Alcohol and managerial performance. J Stud Alcohol 55:230–238

Tabakoff B, Hoffman PL (1993) The neurochemistry of alcohol. Curr Opin Psychiatry 6:388–394

Talland GA (1966) Effects of alcohol on performance in continuous attention tasks. Psychosom Med 28:596–604

Talland GA, Mendelson JH, Ryack P (1964) Experimentally induced chronic intoxication and withdrawal in alcoholics. Tests of attention. Q J Stud Alcohol Suppl 2:74–86

Tedeschi G, Smith AT, Richens A (1984) Effect of meptazinol and ethanol on human psychomotor performance and mood ratings. Hum Toxicol 3:37–43

Tiplady B (1991) Alcohol as a comparator. In: Klepper ID, Sanders LD, Rosen M (eds) Ambulatory anaesthesia and sedation. Blackwell, Oxford, pp 26–37

Tong JE, Knott VJ, McGraw DJ, Leigh G (1974) Alcohol, visual discrimination and heart rate. Q J Stud Alcohol 35:1003–1022

Tong JE, Henderson PR, Chipperfield GA (1980) Effects of ethanol and tobacco on auditory vigilance performance. Addict Behav 5:153–158

Vogel-Sprott MD (1979) Acute recovery and tolerance to low doses of alcohol: differences in cognitive and motor skill performance. Psychopharmacology 61:287–291

Walsh JK, Humm T, Muehlbach MJ, Sugerman JL, Schweitzer PK (1991) Sedative effects of ethanol at night. J Stud Alcohol 52:597–600

Ward TB, Lewis SN (1987) The influence of alcohol and loud music on analytic and holistic processing. Percept Psychophys 41: 179–186

Wesnes K, Warburton DM (1983) Stress and drugs. In: Hockey GRJ (ed) Stress and fatigue in human performance. Wiley, Chichester, pp 203–238

Wesnes K, Warburton DM, Surman HC (1976) The effects of alcohol on the ability to detect signals in a continuous visual vigilance task. Unpublished manuscript, University of Reading

West R, Wilding J, French D, Kemp R, Irving A (1993) Effect of low and moderate doses of alcohol on driving hazard perception latency and driving speed. Addiction 88:527–532

Yesavage JA, Leirer VO (1986) Hangover effects on aircraft pilots 14 hours after alcohol ingestion: a preliminary report. Am J Psychiatry 143:1546–1550

Zomer J, Lavie P (1990) Sleep-related automobile accidents – when and who? In Horne J (ed) Sleep '90. Pontenagel Press, Bochum, pp 448–451