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BLACK TIMES: TEMPORAL DETERMINANTS OF TRANSPORT SAFETY

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Abstract—This paper is concerned with whether transport accident risk tends to peak at particular times, in relation to both time of day and time on task, and with the underlying causes of such peaks. Macro-analyses confirmed the presence of a clear circadian (ca 24 hour) rhythm in road accident risk with a major peak at ca 03:00 but suggested that this rhythm could not be entirely accounted for in terms of drivers falling asleep at the wheel. Sleep propensity clearly shows a pronounced circadian rhythm and performance efficiency in wakeful subjects shows a similar trend implying that the 03:00 road accident peak may simply reflect lowered performance capabilities. However, there are 'residual' peaks in accidents at certain times of day that are difficult to account for in terms of circadian rhythmicity. It is suggested that these may reflect a time on task effect which shows a pronounced, but transient, 2–4 hour peak in risk. Only when individuals had been on duty for 12 hours or more did the risk exceed that found during the 2–4 hour peak. While an explanation for this transient peak is offered, the underlying reason for it is, as yet, uncertain and clearly warrants investigation in view of its practical implications. It is concluded that there are 'black times' when accidents are far more likely and that there is a strong need to investigate possible countermeasures. © 1997 Elsevier Science Ltd.

Keywords—Accidents, Injuries, Shiftwork, Time of day, Shift duration, Time on task

INTRODUCTION

This paper is concerned with how accident risk in transport operations varies over time and with the underlying reasons for this variation. It is clear that all accidents must occur at a certain point in both time and space. If accidents tend to cluster at particular places or times then this may reflect a heightened risk, and this is exemplified in the well accepted concept of accident 'black spots' on roads. This paper reviews evidence suggesting that we should pay equal attention to accident 'black times'. In particular, it will concentrate on two potentially important contributors to accident 'black times', namely the time of the (24-hour) day and the length of time that an individual has been driving for when an accident occurs.

TIME OF DAY EFFECTS IN ACCIDENT RISK

The basic trend

Road transport. Over the past decade or so, a number of studies have examined road vehicle accident frequencies as a function of time of day. These studies, the earlier of which were reviewed by Mitler et al. (1988), include Langlois et al. (1985), Hamelin (1987), van Ouwerkerk (1987), Lavie (1991) and Horne and Reyner (1995) all of whom have reported relatively continuous (e.g. hourly or 2-hourly) measures. Further, they have either 'corrected' their trends to take account of exposure, for example, Hamelin (1987) or traffic density, for example, Langlois et al. (1985) or have confined their attention to single vehicle, for example, van Ouwerkerk (1987) or 'sleep-related' accidents, for example, Lavie (1991) and in some cases have omitted those in which alcohol may have played a role, for example, Horne and Reyner (1995). Some studies have confined their attention to professional drivers (e.g. Hamelin, 1987) while Langlois et al. (1985) provide separate trends for commercial and passenger vehicles.

In order to perform a 'macro-analysis'[1] of the trends provided by these studies the data were read

[1]This term is used here to refer to an analysis based on a z-score transformation of the means obtained from published studies. Unlike the more normal meta-analysis it takes no account of the size of the data sets on which these means are based. In its simplest form it is thus a measure of the concordance or consistency across studies.
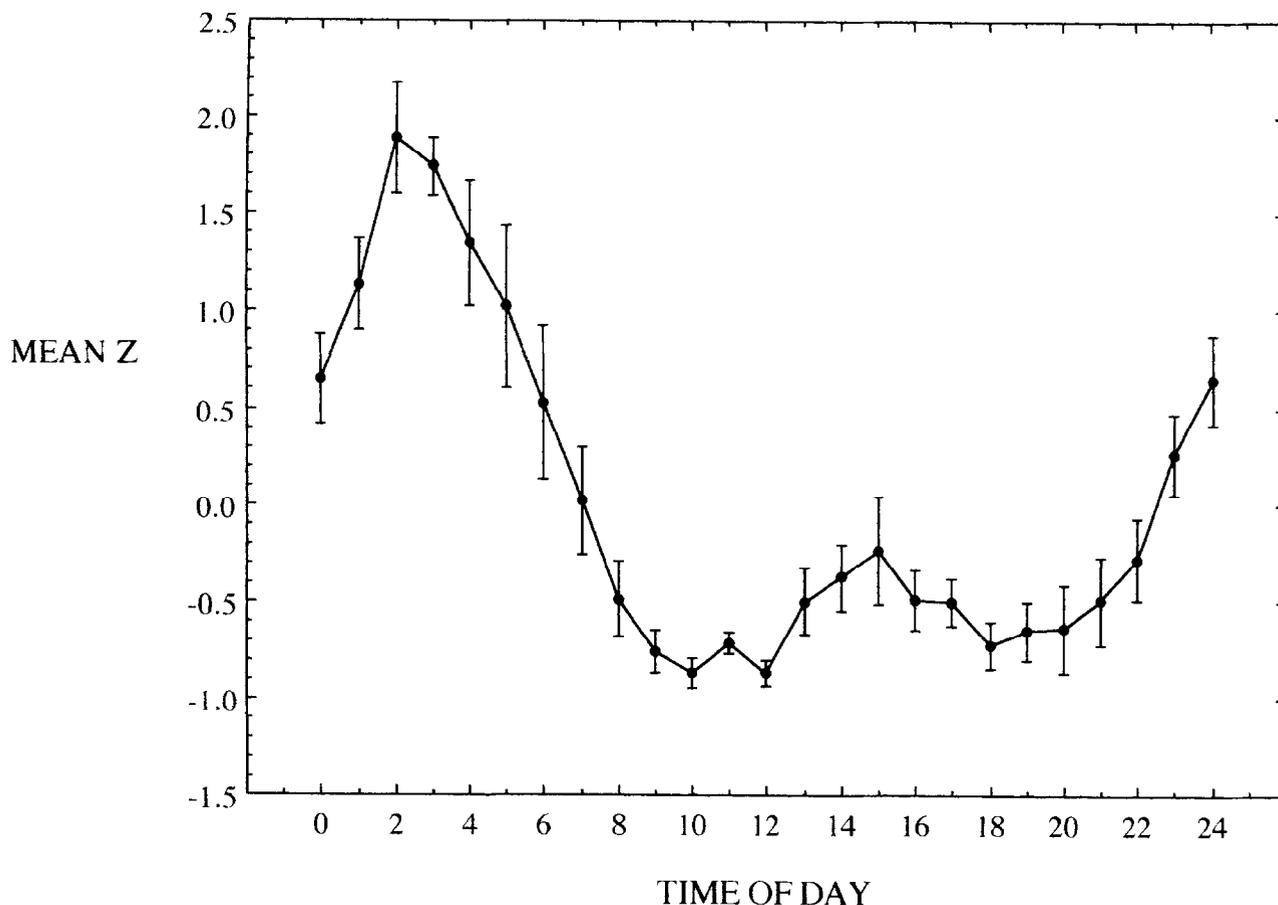
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Fig. 1. The mean trend (and standard errors) in road traffic accident risk over the 24-hour day derived from six published trends (see text for details of studies). Note that in this and subsequent figures the value for midnight has been plotted at both 0 and 24 hours to emphasize the cyclic nature of the trend.

from the published tables or figures and hourly values were linearly interpolated for those studies providing less frequent readings. A 'Z transformation' was then performed on the 24 (hourly) values produced for each study and subsequent analyses were based on these Z transformed values. It should be noted that this procedure gives equal weight to each trend, irrespective of the number of accidents on which it is based. The main disadvantage with this is that it might be argued to give undue weight to small data sets. However, this has to be offset against the advantages that it is less prone to distortion by a bias in a large data set and that it allows an estimate of the consistency across data. Finally, it should be noted that the composite trend provided by Mitler et al. (1988) was omitted since it very largely reflected those of Langlois et al. (1985), while the two trends reported by Langlois et al. (1985) for passenger and commercial vehicles were considered separately.

An analysis of variance indicated that there was a highly reliable time of day effect in these Z trans-

formed scores [$F(23,115) = 14.183$, $p = 0.0005^2$]. The mean Z score at each time of day together with the standard errors of these means (across studies) are shown in Fig. 1. Across these six trends, accident risk was clearly highest in the early hours of the morning when it was about two standard deviations higher (i.e. there was a mean z-score of ca 2.0) than the overall, 24-hour, mean. There was also a secondary, relatively minor, 'peak' in risk in the early afternoon, corresponding to the 'post-lunch dip' that has been found in the performance of some prolonged, monotonous tasks (e.g. Blake, 1971). It is also noteworthy that there was considerable consistency across the six trends, despite differences in whether the drivers were professional ones, and this is reflected in the relatively small standard errors of the mean z-scores.

[2]Throughout this paper the Greenhouse-Geisser correction for sphericity has been applied when reporting probabilities associated with F values.
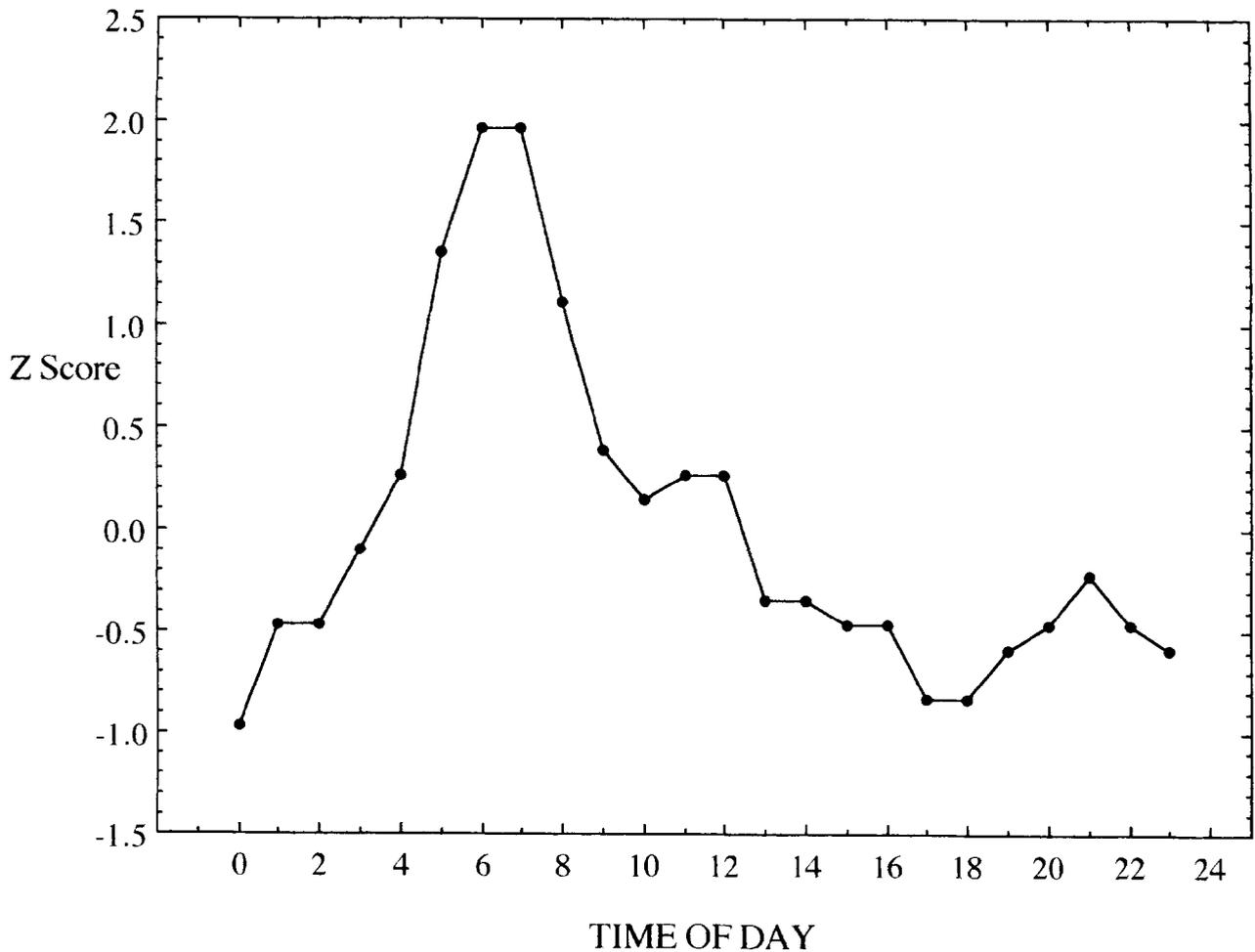
Fig. 2. The trend in ship collisions over the 24-hour day (see text for further details).

Maritime operations. A not dissimilar time of day effect in accident risk, but with a rather later peak, has been observed in the collisions between ships at sea. This is based on a sample of 123 collision claims (totalling $79 million) made between 1987 and 1991 (U.K. P and I club, 1992). It is worth noting that >80% of these collisions occurred when the ship was 'underway', that is, was not involved in close quarter manoeuvring such as anchoring or berthing, but that only a minority (22%) occurred in 'open water'. A χ^2 test based on 4-hourly intervals (corresponding to the 'watches', i.e. 00:00–04:00, etc.) of collision frequencies revealed a highly significant effect of time of day ($\chi^2 = 25.796$, d.f. = 5, $p < 0.001$). In order to facilitate a direct comparison with Fig. 1, the hourly collision frequency data was Z transformed and then smoothed with a three-point running mean (see Fig. 2). The general impression to be gained from Fig. 2 is that although the time of day effect in these collisions is fairly similar to that obtained for road traffic accidents, the peak in risk occurs ca

4 hours later at 06:00–07:00. Indeed, a simple cross-correlation between the curves shown in Figs. 1 and 2 accounted for <1% of the variance, but when the trend shown in Fig. 2 was advanced by 4 hours the cross correlation then accounted for >80% ($r = 0.909$, d.f. = 22, $p < 0.001$) of the variance. Further, as with the road traffic accidents, the risk in collisions at the peak was about two standard deviations higher than the overall, 24-hour, mean. While the reason for the delayed peak in this data set is unclear, a similar trend but with a somewhat earlier peak in ship collisions and groundings was reported by Filor (1996). Thus it would appear that the 24-hour patterning of accident risk (Fig. 1) may be common to both road accidents and marine collisions and groundings.

The trends shown in both Figs 1 and 2 confound a number of potential underlying causes for the increased risk in the early hours of the morning. The task of driving, or navigating, is qualitatively different during the dark, while the level of non-specific stimu-
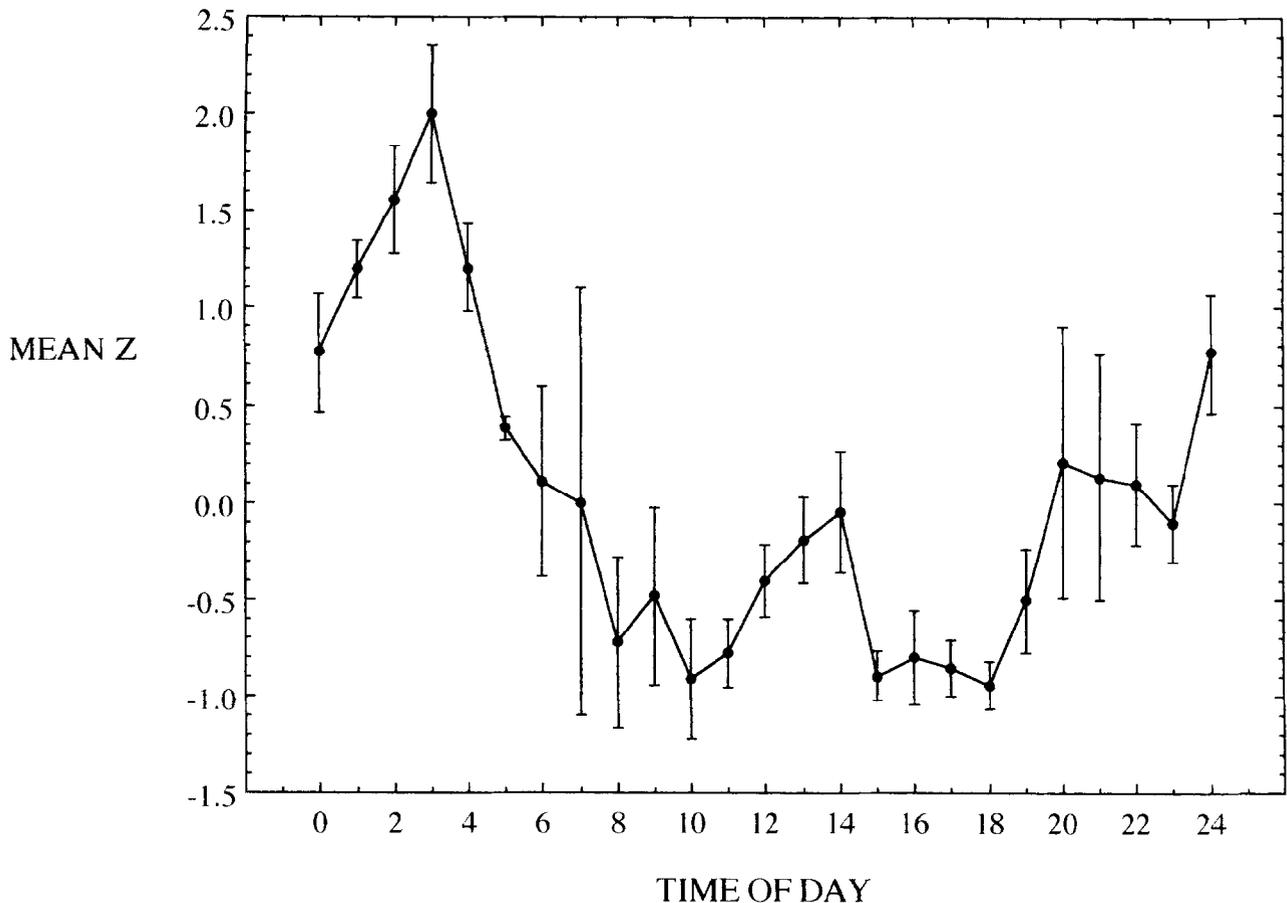
Fig. 3. The mean trend (and standard errors) in industrial performance measures over the 24-hour day derived from three published studies (see text for details of studies).

lation from visual input is clearly very much reduced, that is, monotony is increased. Further, the individuals concerned must have been awake for much longer than normal, or have slept at an unusual time of day, or have woken extremely early. In short, this peak in risk occurs at a time when the task is different, monotony is increased, and the individuals would normally be asleep.

Industrial situations. It is clearly of interest to determine whether a similar peak in risk, or 'trough' in performance capabilities, occurs in more controlled situations where the individuals' task and environmental conditions vary less across the 24-hour day. On the face of it, many industrial situations would appear to meet these requirements, but in fact they seldom do so. Supervision and maintenance are often reduced at night, lighting levels and other environmental factors such as noise and temperature may vary considerably, and even the nature of the job may change. Thus, for example, in the steel industry 'long runs' of a particular product are often saved for the night shift, while large batches of routine computer jobs are also often saved for the night.

Despite these caveats, conditions in many industrial situations are, arguably, more constant than in most transport situations, while the individuals concerned are usually on a fairly regular shift system and are accustomed to sleeping during the day between night shifts.

No published studies appear to have provided hourly accident rates over the 24-hour day from industrial shiftworkers in conditions where the *a priori* risk appeared to be constant. However, three early studies provided such data for other real-job performance measures, namely the delay in answering calls by switchboard operators (Browne, 1949), errors in reading meters (Bjerner and Swensson, 1953) and the time taken by 'spinners' to tie broken threads in the textile industry (Wojtczak-Jaroszowa and Pawlowska-Skyba, 1967). As with the vehicle accident rates, the hourly readings from these three studies were Z-transformed and the hourly means and standard errors across these studies are shown in Fig. 3. It should be noted that a high mean value reflects slow or inaccurate performance.

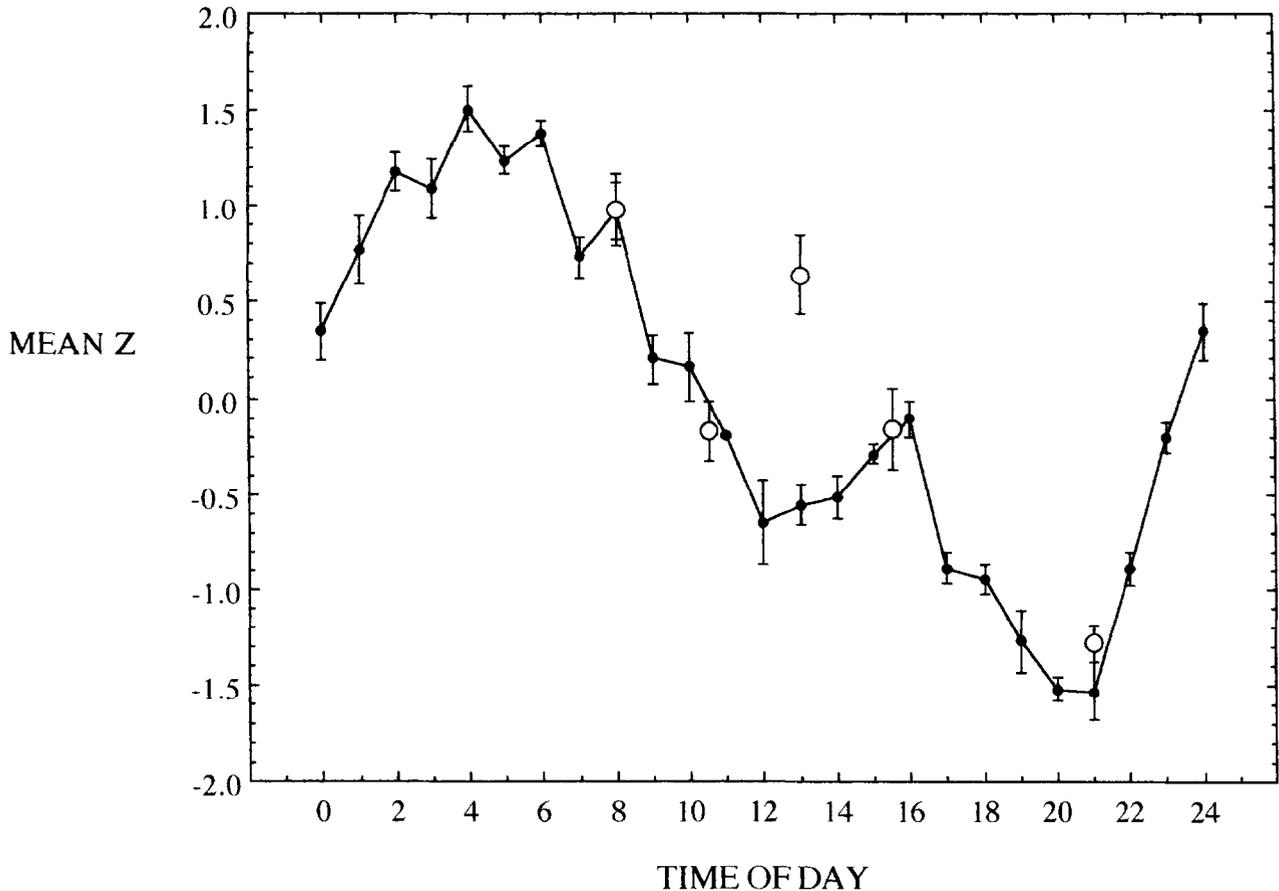It is very obvious from Fig. 3 that the 24-hour

Fig. 4. The mean trend (and standard errors) in sleep propensity over the 24-hour day, derived from the various trends reported by Lavie (1986), overlaid with the mean (large open points) and standard errors of the various performance tests used by Blake (1967).

trend in real job performance is similar to that in road accidents (Fig. 1). Performance was clearly worst at ca 03:00 when the mean value was almost exactly two standard deviations worse than the 24-hour mean. The cross correlation between the trends shown in Figs 1 and 3 accounted for >80% of the variance ($r = 0.896$, d.f. $= 22$, $p < 0.001$), while an analysis of variance confirmed that there was no evidence of any interaction between time of day and type of study (road accident versus job performance) [$F(23,161) = 0.843$, $p = 0.476$], but a highly reliable main effect of time of day [$F(23,161) = 15.205$, $p < 0.0001$].

Thus it would appear that the early morning peak in vehicle accident risk is not only highly consistent across studies, but is also extremely similar to the performance of industrial shiftworkers whose tasks and environments are considerably more consistent across the 24-hour day. This clearly suggests, but does not prove, that the underlying cause of the increased risk is related to the state of the individuals concerned rather than to environmental or task differences.

The underlying cause(s)

The most obvious underlying cause, frequently cited by authors in this area (e.g. Mitler et al., 1988), stems from the fact that the human species habitually sleeps at night and is awake and active during daylight hours, that is, it is diurnal in nature. Like all other species it has evolved in a world subject to pronounced 24-hour changes in environmental conditions, and especially in the level of illumination and temperature. The ability to anticipate, rather than merely to respond to, these changes had a clear adaptive significance for early life forms and has resulted in evolution of an endogenous 'body clock'. This clock is at least partially responsible for the pronounced circadian (Latin, *circa diem*—around a day) rhythms found in all our physiological and biochemical processes as well as for the rather more obvious alternation between our sleep and wakefulness. There is thus a very real sense in which we are not only biologically 'designed' to be a terrestrial rather than aquatic species, but also a diurnal rather than a nocturnal one.

Our body clock is 'set' to wake us up in the

morning and to send us to sleep at night. Perhaps the most detailed evidence for this comes from the seminal studies of Peretz Lavie (e.g. Lavie, 1986) in which students lived on a 'A 20-minute day' for at least 24 hours. They were required to be awake and active for 13 minutes and to then lie on a bed for 7 minutes, under a variety of conditions. Some subjects were allowed a normal sleep the night before while others were deprived of sleep the previous night, while some were asked to try to sleep during their 7 minutes in bed, while others were asked to resist falling asleep during their 7 minutes in bed. The time of day at which the study started was also varied in order to balance out differences in the extent of sleep deprivation across the 24-hour day. Under all conditions, the proportion of time in bed that the subjects actually spent asleep was measured using EEG recordings and taken as a measure of 'sleep propensity'.

Since the results were essentially the same under the various conditions, the present author calculated the mean hourly values for each condition and then Z-transformed them to facilitate comparison with the trends shown in Figs 1–3. The mean values, and standard errors across the different conditions, are shown in Fig. 4 in which high values represents a greater proportion of the 7-minute periods being spent asleep. An analysis of variance based on the Z transformed scores from the different conditions confirmed that there was a highly reliable time of day effect [$F(23,161) = 57.459$, $p < 0.0001$]. Inspection of Fig. 4 indicates that, like accident risk, sleep propensity was clearly highest in the early hours of the morning and showed a secondary, minor peak in the early afternoon. It is noteworthy that an extremely similar trend is shown by the 2-hourly sleep propensity measures of Zulley (1990).

Before considering how well this trend in sleep propensity might account for those in accident risk and real job performance it should be emphasized that it is similar to the circadian rhythm found in the prolonged performance of a variety of relatively simple tasks. Thus Blake (1967) tested highly practised subjects at five times of day (from 08:00 to 21:00) on a range of fairly prolonged (12–60 minute) tasks under laboratory conditions in which subjects would have been prevented from falling asleep. Blake found reliable time of day effects in eight different measures, namely speed and gaps on a serial reaction time task, vigilance detections, two and eight category card sorting speed, letter cancellation speed, calculation speed and digit span.

With the exception of digit span, which is known to show a morning peak (Folkard, 1983) and was thus excluded, all the measures showed a fairly similar

trend over the day. The five scores on each measure were thus Z transformed, and, where appropriate, the sign changed so that more positive scores consistently represented poorer performance. An analysis of variance based on these Z scores confirmed the presence of a highly reliable effect of time of day [$F(4,24) = 19.909$, $p = 0.0004$]. The means and standard errors (across measures) are also shown in Fig. 4. It is obvious from this figure that, with the exception of the 13:00 value, the data were similar to the trend in sleep propensity. Further, it seems probable that the high mean Z score, that is, poor performance, at 13:00 simply reflected an acute response to the ingestion of the large, early lunch taken by these subjects (Smith and Kendrick, 1992). Thus any parallelism found between sleep propensity and accident risk need not imply that those involved fell asleep, but may simply reflect a reduced speed and increased error rate in prolonged performance.

Despite this, the apparent parallelism between road traffic accidents and sleep propensity has been noted by a number of authors (e.g. Mitler et al., 1988; Lavie, 1991; Horne and Reyner, 1995) and has been used to argue that the early morning peak in road traffic accidents is, at least very largely, due to drivers falling asleep at the wheel. Indeed, in view of the fact that some of the studies summarized in Fig. 1 (e.g. Horne and Reyner, 1995) have confined their attention to sleep-related accidents it would be surprising if the two trends were not similar. However, cross correlations between this sleep propensity function (Fig. 4) and the trend in road traffic accidents (Fig. 1) accounted for only 54.0% of the variance. Analysis of variance confirmed that the sleep propensity function differed (i.e. there was a reliable interaction) from the trend in road traffic accidents [$F(23,276) = 7.405$, $p = 0.0002$].

There appears to be two main reasons why the trend in road traffic safety might differ from the sleep propensity function. The first is that Lavie's subjects were all 'healthy young adults' aged between 22 and 26 who may habitually have gone to sleep later than the general population and hence had a rather late peak in their sleep propensity function. The second is that sleep propensity, while clearly contributing to the trend shown in Fig. 1, may not be the only temporal factor underlying it.

In order to test for the former, the trend in road traffic risk was shifted in 1 hour steps from 4 hours earlier to 4 hours later and the cross correlation with the sleep propensity function re-computed at each stage. The maximum cross correlation was obtained when it was shifted later by 2 hours when it accounted for 73.6% of the variance. This improvement in the
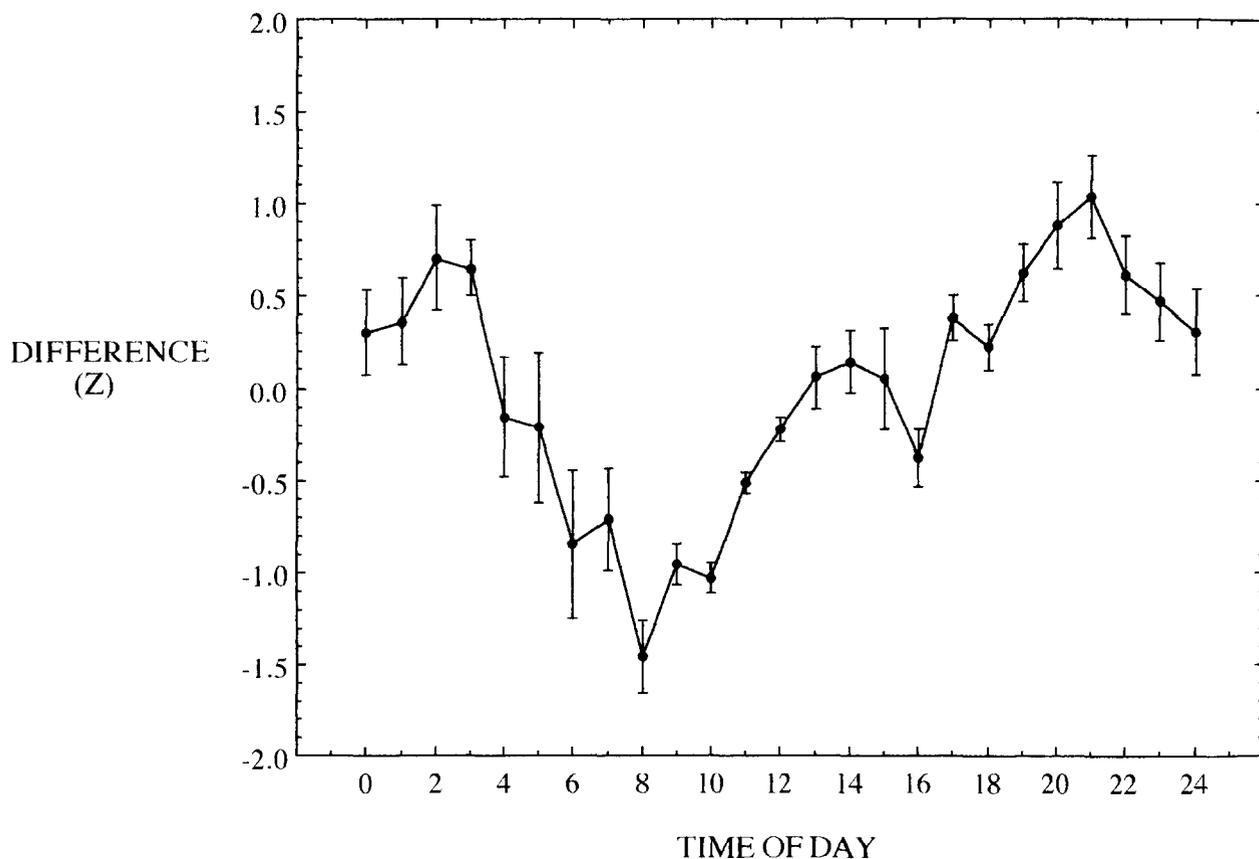
Fig. 5. The mean difference scores (and standard errors) obtained when the sleep propensity function (Fig. 4) is subtracted from the various trends in road traffic accidents (Fig. 1). Note that this reveals 'residual' peaks in risk at ca 02:00, 14:00 and 21:00.

cross-correlation is, of course, circular since the procedure followed was designed to maximize it.

The more important question is whether the sleep propensity function adequately accounts for the optimally shifted trend in road accidents, or whether there is evidence for a residual, non-random, deviation. To test for this, the individual hourly results from each of the studies contributing to the trend in road accidents were shifted later by 2 hours and a further analysis of variance was then used to compare the shifted trends with the sleep propensity function. There was a reliable difference (i.e. interaction) between the sleep propensity function and the optimally shifted trends [$F(23,276)=4.019$, $p=0.0105$].

The conclusion to be drawn from this residual interaction is that the difference between the sleep propensity function and the trend in road traffic is not entirely due to Lavie's use of subjects who may have had a rather late peak in sleep propensity. Rather, it seems clear that differences in the timing of the sleep propensity function are insufficient by themselves to account for the trends observed in road traffic accidents. In order to gain some insight into the nature of this insufficiency the main sleep propen-

sity function (Fig. 4) was subtracted from each of the individual trends in road traffic accidents. This subtraction technique was based on the un-shifted sleep propensity function and assumes that the effects of sleep propensity and any other underlying factors are additive. An analysis of variance confirmed that there was a main effect of time of day [$F(23,115)=$ 8.399, $p=0.0040$] in these difference scores. It is noteworthy that even when the sleep propensity function had been optimally shifted before subtraction there was still a main effect of time of day [$F(23,115)=4.559$, $p=0.0291$] in the difference scores. The mean difference scores between the normal trends in road traffic accidents and sleep propensity are plotted in Fig. 5 together with their standard errors.

It is clear from inspection of Fig. 5 that there was a fairly systematic trend in the difference scores across the 24-hour day. Road accidents were less frequent than would be expected from the sleep propensity trend at 08:00 and rather higher than might be expected at ca 02:00 and 21:00. There was also a suggestion of a somewhat less pronounced peak in the 'residual' risk of road accidents at ca

Fig. 6. The mean relative risk (and standard errors) in the first and second 4 hours of duty expressed relative to the overall mean for the first 8 hours (see text for details of the studies).

14:00. Thus it seems that the pronounced time of day effect in accident risk cannot be entirely accounted for in terms of the circadian rhythm in sleep propensity or performance capability. Rather there would appear to be at least one other, time related, factor that contributes to the pronounced variations in accident risk across the 24-hour day. One possibility, given that the start times of road journeys are likely to 'cluster' at certain times of day, is that time into journey effects may contribute to the overall time of 24-hour day effects in a fairly systematic manner.

TIME ON SHIFT EFFECTS IN ACCIDENT RISK

The basic trend

In comparison to the effects of time of day, very few studies have examined the risk of accidents as a function of the length of time that the individual has been driving for. This presumably reflects on the fact that most road accident records do not contain this information. There have, however, been two pub-

lished studies that have examined professional drivers' risk in this way, as well as a large, but as yet unpublished, study of British Rail drivers' involvement in 'signals passed at danger' (SPADs).

Pokorny et al. (1981) examined the accident risk of bus drivers, having corrected for kilometres driven, while Hamelin (1987) examined the accident risk of lorry drivers, having corrected for 'exposure'. While neither study was able to correct for traffic density, it is noteworthy that many of Hamelin's, but not Pokorny et al.'s, drivers were on a fairly irregular schedule which might have effectively balanced out time on shift effects across time of day, and hence across the timing of 'rush hours'. In addition, in an extensive analysis of data collected over a 5-year period, Wharf (1993, unpublished) reported the incidence of SPADs per million driver hours in British Rail train drivers.

Pokorny et al. (1981) noted a distinct peak in the accident risk of bus drivers on the early shift that occurred in the third or fourth hour of their work spell. This transient peak in risk appeared to be
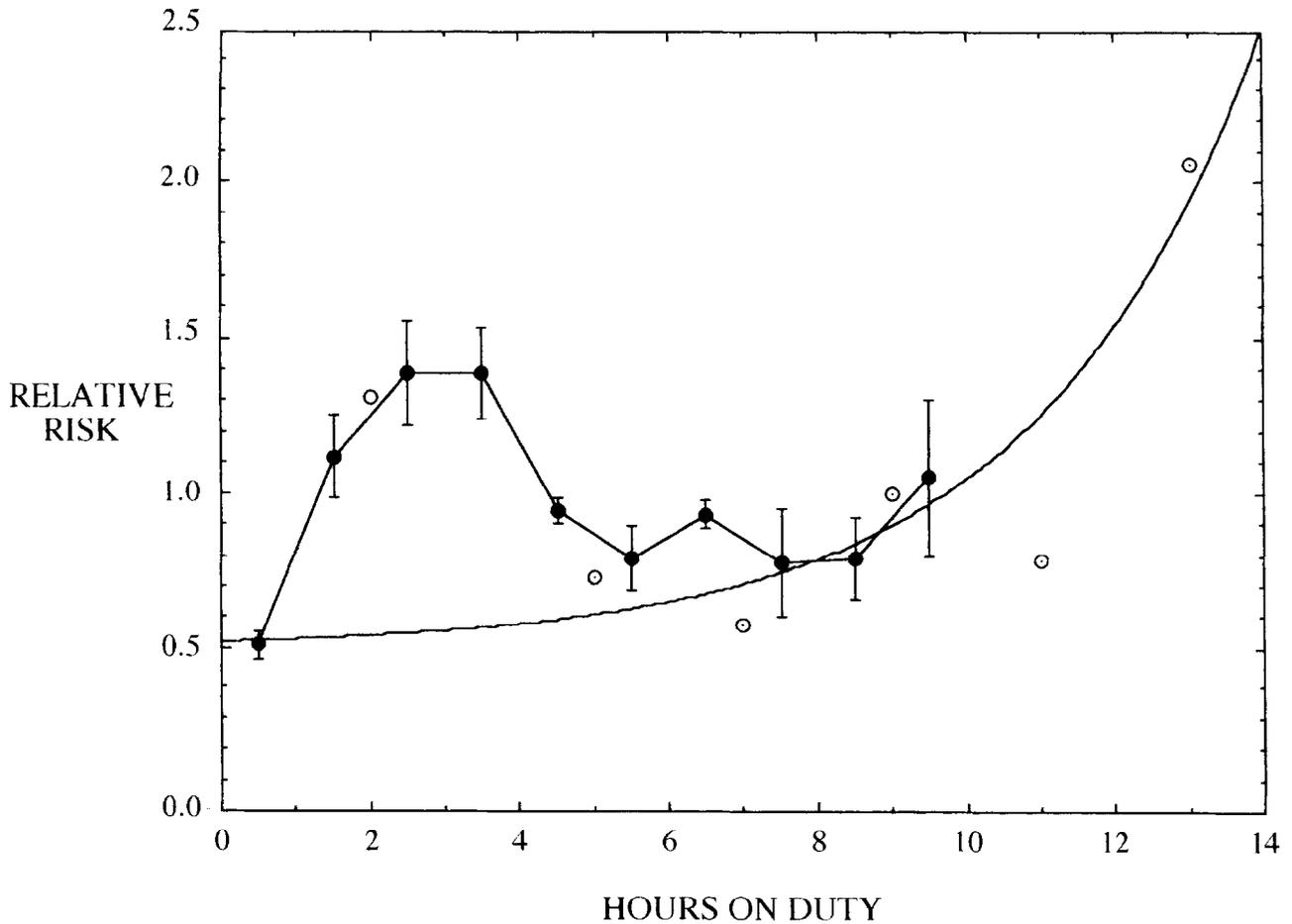
Fig. 7. The mean hourly relative risk rates (and standard errors) derived from Pokorny et al. (1981) and Wharf (1993) (●). The open circles are derived from Hamelin (1987) and represent the relative risk over the first 4 hours, then 2-hourly values up to 12 hours, and finally the relative risk associated with duties of >12 hours. Also shown is an exponential curve fitted to all the data points except those from the second to fifth hour on duty (see text for further details).

unaffected by the precise time (from 05:00 to 08:00) at which the drivers started work, suggesting that it was not due to either the individuals' circadian rhythms or to the morning peak in traffic density. It was followed by a period of relatively low risk and only when the drivers had been working for >8 hours did risk start increasing again. Similarly Hamelin (1987) examined lorry drivers' accident risk as a function of how long had elapsed from their last rest break of at least 6 hours. He noted that the risk in the first 4 hours was higher than in *all* subsequent hours unless the drivers had been working for >12 hours. Finally, Wharf (1993) found a distinct peak in hourly SPAD rates in the second and third hours of duty followed by a relatively low level for up to 12 hours of duty. However, the failure of SPADs to show an increase towards the end of a 12-hour duty may well reflect on the various restrictions placed on work hours of British Rail drivers. Thus the number of hours they can drive for during

any one duty period is limited to considerably <12 hours (with the precise value depending on the type of train) and hence longer duties must have involved considerable periods of non-driving. Wharf (1993) found this temporal patterning of SPADs to be fairly consistent across four different types of depot (freight, intercity, etc.) and also reported similar trends in operating incidents and personal accidents occurring to trackside workers.

Unfortunately, whereas Pokorny et al. (1981) and Wharf (1993) provided hourly values, Hamelin (1987) provided only a single value for the first 4 hours followed by 2-hourly values for subsequent times and thus statistical comparisons were necessarily limited to the first versus second period of 4 hours on duty. In order to equate the unit of measurement across trends, and hence give equal weight to each trend, the risk in any given period of time was expressed relative to the mean risk for the first 8 hours. This procedure, rather than z-transformation
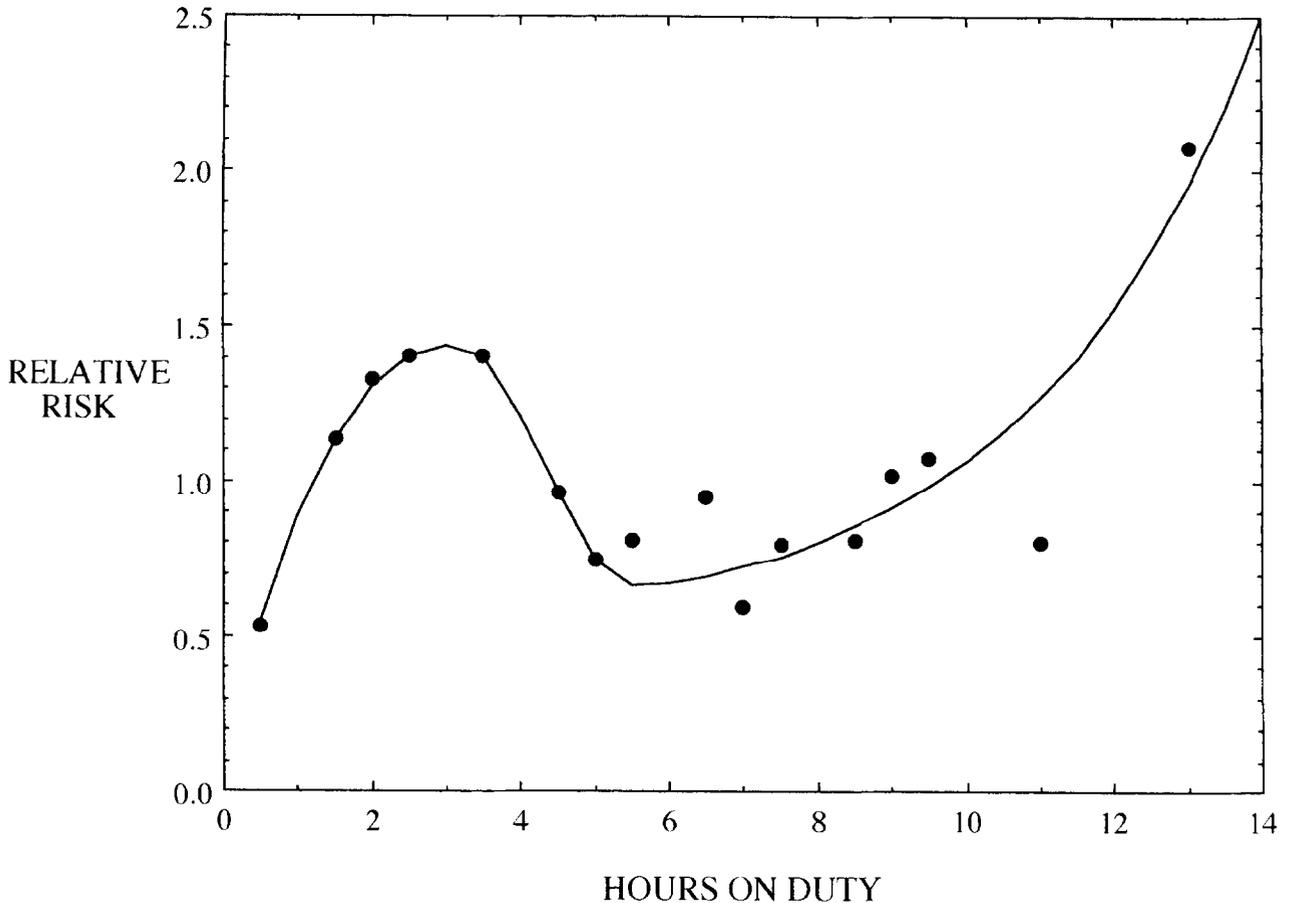
Fig. 8. The smooth curve fitted to the various data points shown in Fig. 7.

(as above), was used since it allows the direct comparison of trends over different lengths of duty period. A two-tailed, related t-test confirmed that there was a highly reliable reduction in relative risk from the first 4 hours to the second four hours on duty [t(d.f. = 7) = 3.565, p = 0.0091]. The mean relative risks and standard errors (across the eight trends) are shown in Fig. 6.

It is clear from this figure that risk decreased by nearly 30% from the first 4 hours to the second 4 hours on duty. This substantial decrease in risk over time is of particular interest since it is the opposite trend to that which would be predicted from our current knowledge of 'time on task' effects and, indeed, runs counter to everyday expectations. Fatigue and vigilance decrement theories would, of course, both predict a monotonic increase in risk over time on task. It is thus clearly of interest to examine this trend in more detail. The mean (and standard errors) hourly relative risk values for the first 10 hours reported by Pokorny et al. (1981) and Wharf (1993) are plotted (filled circles) in Fig. 7 together with the available values from Hamelin

(1987). Also shown is an exponential curve that was fitted to all the data points except those for the second to the fifth hours.

Two major points arise from inspection of Fig. 7. First, it is clear that the increased risk during the first 4 hours was due to a transient increase in risk in the second to fourth (or fifth) hour on duty. Risk was relatively low during the first hour and decreased substantially following the fourth hour on duty. Secondly, when this transient peak in risk was ignored, the remaining points were reasonably well described as an exponential increase in risk over hours on duty (r = 0.838, d.f. = 9, p < 0.01). However, not until the twelfth and subsequent hours on duty did the relative risk per hour due to this exponential function exceed that during the third and fourth hours.

Clearly the transient 2–4 hour peak in accident risk will be the major determinant of relative risk due to time on task in all but extremely prolonged transport operations. Indeed, if it is assumed that the transient 2–4 hour peak is unaffected by the length of a duty, it is possible to use the data shown in
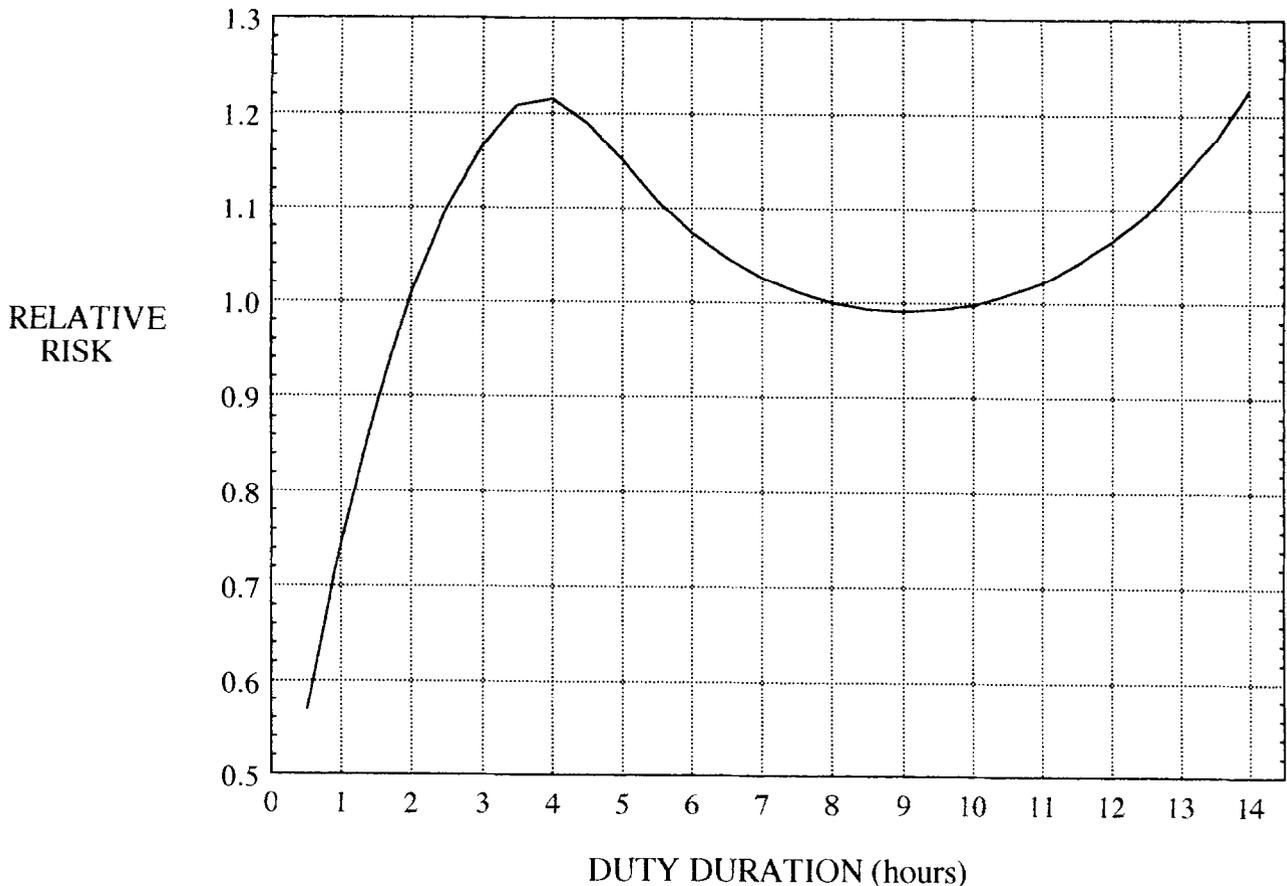
Fig. 9. The estimated overall relative risk associated with duties of different lengths. Note that these relative risks are expressed relative to that on an 8 hour duty.

Fig. 7 to estimate the overall risk on duties of different lengths by averaging the relative risk in each hour. To illustrate this, a smooth curve incorporating both the transient peak and exponential function shown in Fig. 7 was fitted to the raw data points. This provided a reliable fit to the data ($r = 0.916$, d.f. = 14, $p < 0.001$) and is shown in Fig. 8 together with the raw data points. Half-hourly estimates of risk were then interpolated from this smooth curve and used to 'predict' the overall risk of accidents on duties of different lengths relative to that for an 8-hour duty.

This is illustrated in Fig. 9, inspection of which suggests that, with the exception of duties of less than ca 2.5 hours duration, the safest duty durations may lie in the region of 8–10 hours. Duties that are of either lesser or greater duration than this are predicted to be associated with an increased risk. Indeed, it is noteworthy that the predicted risk on 4 hour duties, which are common in seafarers and are also used in some public transport operations to cover 'rush hours', would appear to have a 20% increased risk relative to 8 hour duties. Further, it would appear that only when duty periods are extended to 14 hours

or more will the overall risk exceed that on 4 hour duties!

It must be emphasized that these conclusions regarding the relative risk of different lengths of duty period should be treated with considerable caution since they are based on rather limited data. The author's aim is simply to draw attention to the potentially important practical implications of the transient 2–4 hour peak in risk with a view to encouraging further research in this area.

The underlying cause(s)

The potential importance of this transient 2–4 hour peak in risk has only recently been recognized. Pokorny et al. (1981), who failed to find this transient peak in drivers on the late shift, offered no explanation as to why it might have occurred on the early shift. Similarly, Hamelin (1987) offered no explanation as to why it occurred in his data other than the possibility that it reflected an artefact due to his manner of correcting for exposure. In contrast,
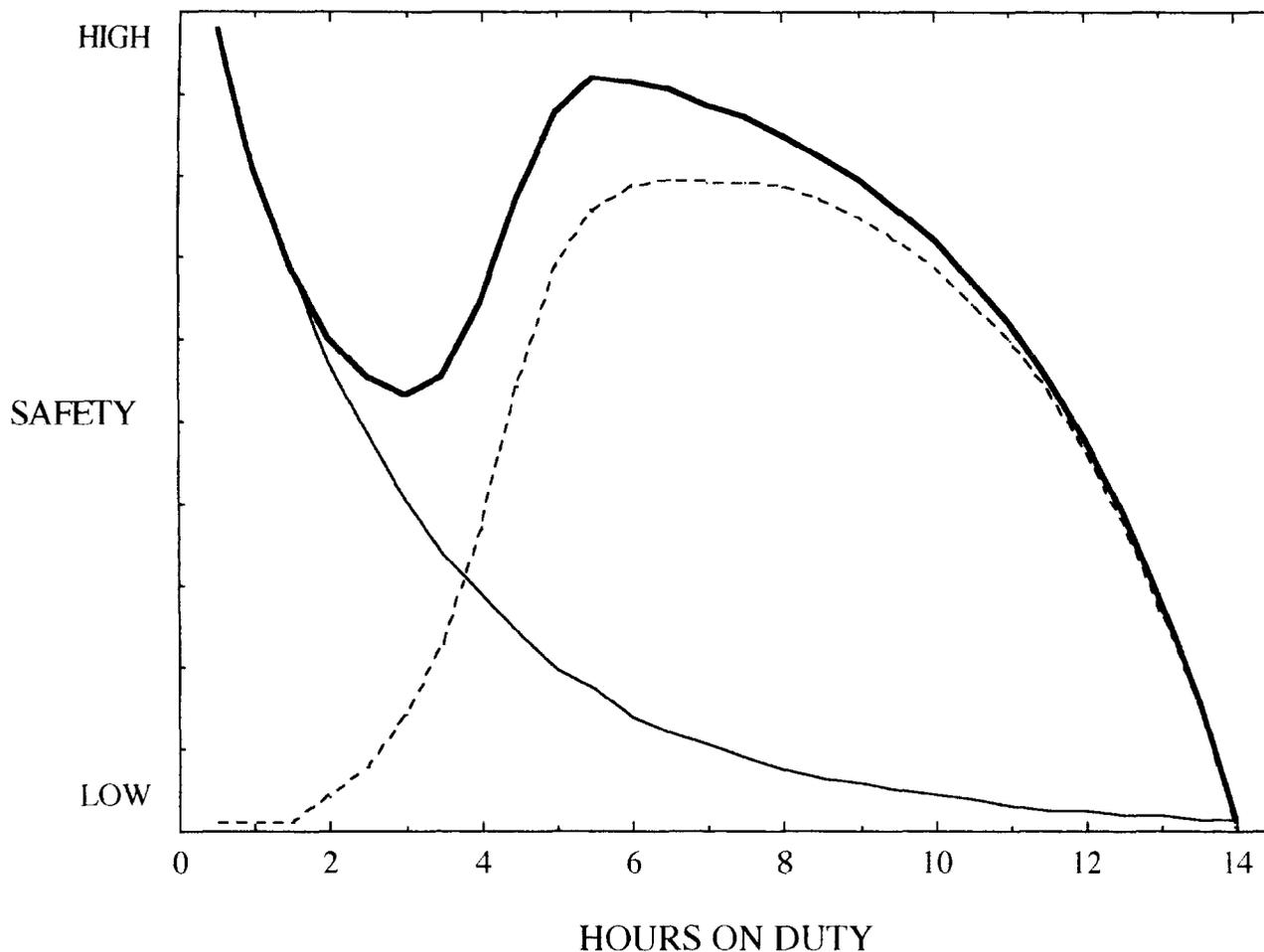
Fig. 10. Schematic figure illustrating how the complex trend in safety (inverted risk, bold line) may reflect the additive influence of two simple trends (see text).

Wharf (1993) recognized its potential importance and reported that it was a robust effect that was unaffected by the start time of the (rail) drivers duty period, while Folkard and Totterdell (1991) and Folkard (1996) reported a remarkably similar and consistent transient peak in their reviews of industrial occupational injury rates over the course of work shifts (e.g. Goldmark and Hopkins, 1920; Levin et al., 1985). Nevertheless, the fact that the consistency and potential importance of the transient 2–4 hour peak in risk has only recently been recognized means that there appear to be no published studies aimed at elucidating its underlying causes. It is, however, noteworthy that Murrell (1971) reports a similar transient peak in the irregularity of subjects' performance on a simulated industrial task even though most potential contaminating factors were kept constant. Murrell actually comments that whereas the increase in irregularity over time on task had been predicted, "what had not been predicted was an improvement in regularity

after a further 1/2 hours work" (Murrell, 1971, p. 258).

Indeed, current theories of time on task effects would predict a simple, monotonic trend over time in performance capabilities or relative risk. Neither vigilance nor fatigue theories would appear to be capable of explaining the rather complex trend in risk shown in Fig. 8. The most obvious explanation for the complex curve shown in Fig. 8 would appear to be that it reflects the product of two underlying trends over time. One possibility, originally suggested by the author's colleague Natalia Sytnik based on the ideas of Schneider and Shiffrin (1977) is that at the start of a period of duty safety is largely dependent on effortful, controlled processing of incoming information but that this cannot be sustained over prolonged periods and decreases monotonically over time from the start of a duty. More prolonged performance may place greater reliance on less effortful, automated processing, but it may take some time for individuals

to 'reautomatize' the complex skills involved. The efficiency of automated processing may subsequently decrease again over more prolonged duties due to increasing fatigue.

These ideas are illustrated in Fig. 10 in which the trend in risk over time (Fig. 8) has been inverted to represent the trend in safety over time (bold line). If we make the simple assumptions: (1) that at the start of a duty safety depends entirely on effortful, controlled processing; (2) that the contribution of controlled processing to overall safety shows an exponential decrease over time (solid line); and (3) that controlled and automated processing are additive in their influence on safety, then it is possible to estimate the contribution of automated processing by subtraction (dashed line). That is, we can estimate the time course of automated processing by subtracting our hypothesized trend in controlled processing from the trend in safety. Inspection of Fig. 10 suggests that this process results in a fairly 'sensible' estimate of the time course in automated processing. However, this clearly does not mean that the explanation of the transient 2–4 hour peak in risk in terms of reautomization is valid. All it suggests is that this explanation is a feasible one that warrants experimental investigation.

DISCUSSION

Perhaps the most important conclusion to emerge from the findings reviewed in this paper is that there are consistent temporal peaks in accident risk, or 'black times', associated with both time of day and time on task. When traffic density is controlled for, accident risk shows a major peak at ca 03:00 and a secondary one at ca 15:00. This time of day effect in accident risk is extremely similar to that found in industrial performance measures, suggesting that it may be due to the individuals' circadian rhythms rather than to the very different driving conditions pertaining at night. Sleep propensity shows a marked circadian rhythm which, during daylight hours, shows a very similar trend to that in performance efficiency on a range of tasks. However, detailed analysis suggests that these circadian rhythms are insufficient to account for the variation in accident risk over the 24-hour day. In particular, there would appear to be three 'residual' peaks in risk at ca 02:00, 14:00 and 21:00 that cannot be accounted for in terms of the known circadian rhythm in sleep propensity.

It is possible that these three 'residual' peaks may reflect time on task effects since it is clear that the start time of journeys will tend to cluster around certain times of day. Although few studies have examined time on task effects in transport safety, those that have tend to find a similar trend to that observed in occupational injuries, for example, Folkard (1996). Surprisingly, risk does not show a monotonic increase over time on task. Rather, there is a transient 2–4 hour peak in risk superimposed on an otherwise exponential increase in risk over time on task. The nature of this trend is such that only when individuals have been working for ca 12 hours or more will their risk rise above that found during the 2–4 hour peak. This implies that there may be an optimal duration of task to minimize risk and that, with the exception of duties of up to 2.5 hours, the safest duration may be ca 8–10 hours. While there appear to be no published studies on the underlying cause(s) of the transient 2–4 hour peak in risk, it may reflect on the need to 'reautomatize' even highly learned complex skills during the first few hours of any period of duty. Clearly there is a strong need for further research aimed at both elucidating the underlying cause(s) of this 2–4 hour transient peak and determining whether it is indeed responsible for the 'residual' time of day peaks in accident risk.

In conclusion, there would appear to be consistent evidence to support the view that particular times are associated with a substantial increase in the risk of accidents, that is, that there are 'Black Times'. While there is a clear need for further research on the underlying cause(s), particularly in relation to the transient 2–4 hour peak, it is equally clear that the magnitude of these effects warrants urgent attention being paid to the identification and development of potential countermeasures.

REFERENCES

Bjerner, B. and Swensson, A. (1953) Shiftwork and rhythm. *Acta Med. Scand.* **278**, 102–107.

Blake, M.J.F. (1967) Time of day effects on performance in a range of tasks. *Psychon. Sci.* **9**, 349–350.

Blake, M.J.F. (1971) Temperament and time of day. In *Biological Rhythms and Human Performance*, ed. W.P. Colquhoun, pp. 109–148. Academic Press, London.

Browne, R.C. (1949) The day and night performance of teleprinter switchboard operators. *Occup. Psychol.* **23**, 121–126.

Filor, C.W. (1996) The original "twenty-four hour society": issues of fatigue and accidents at sea. In *Proceedings of the Second International Conference on Fatigue and Transportation*, Fremantle, Australia, 11–16 February 1996.

Folkard, S. (1983) Diurnal variation. In *Stress and Fatigue in Human Performance*, ed. G.R.J. Hockey, pp. 245–272. Wiley, Chichester.

Folkard, S. (1996) Effects on performance efficiency. In *Shiftwork: Problems and Solutions*, eds W.P. Colquhoun, G. Costa, S. Folkard and P. Knauth, pp. 65–87. Peter Lang, Frankfurt am Main.

Folkard, S. and Totterdell, P. (1991) Circadian variations

in performance. Implications for abnormal work hours. Paper presented at the *International Symposium on Shift-work and Job Demands*, Paris, France, 11–12 July 1991.

Goldmark, J. and Hopkins, M.D. (1920) Comparison of an eight-hour plant and a ten-hour plant. Public Health Bulletin No. 106, Government Printing Office, Washington.

Hamelin, P. (1987) Lorry drivers' time habits in work and their involvement in traffic accidents. *Ergonomics* **30**, 1323–1333.

Horne, J.A. and Reyner, L.A. (1995) Driver sleepiness. *J. Sleep Res.* **4**(suppl 2), 23–29.

Langlois, P.H., Smolensky, M.H., Hisi, B.P. and Weir, F.W. (1985) Temporal patterns of reported single-vehicle car and truck accidents in Texas, USA during 1980–1983. *Chronobiol. Int.* **2**, 131–146.

Lavie, P. (1986) Ultrashort sleep-waking schedule III. "Gates" and "forbidden zones" for sleep. *Electroencephalography Clin. Neurophysiol.* **63**, 414–425.

Lavie, P. (1991) The 24-hour sleep propensity function (SPF): practical and theoretical implications. In *Sleep, Sleepiness and Performance*, ed. T.H. Monk, pp. 65–93. Wiley, Chichester.

Levin, L., Oler, J. and Whiteside, J.R. (1985) Injury incidence rates in a paint company on rotating production shifts. *Accid. Anal. Prev.* **17**, 67–73.

Mitler, M.M., Carskadon, M.A., Czeisler, C.A., Dement, W.C., Dinges, D.F. and Graeber, R.C. (1988) Catastrophes, sleep, and public policy: consensus report. *Sleep* **11**, 100–109.

Murrell, K.F.H. (1971) Industrial work rhythms. In

Biological Rhythms and Human Performance, ed. W.P. Colquhoun. Academic Press, London.

van Ouwerkerk, F. (1987) Relationships between road transport working conditions, fatigue, health and traffic safety. Verkeerskundig Studiecentrum, Traffic Research Centre, The Netherlands.

Pokorny, M.L.I., Blom, D.H.J. and von Leeuwen, P. (1981) Analysis of traffic accident data (from busdrivers)—an alternative approach (II). In *Night and Shift Work: Biological and Social Aspects*, eds A. Reinberg, N. Vieux and P. Andlauer, pp. 279–286. Pergamon Press, Oxford.

Schneider, W. and Shiffrin, R.M. (1977) Controlled and automated human information processing: I. Detection, search, and attention. *Psychol. Rev.* **84**, 1–66.

Smith, A.P. and Kendrick, A.M. (1992) Meals and performance. In *Handbook of Human Performance*: Vol. II Health and performance, eds A.P. Smith and D.M. Jones, pp. 1–23. Academic Press, London.

U.K. P and I Club (1992) Analysis of major claims. Report by the United Kingdom Steam Ship Assurance Association (Bermuda) Ltd, London, U.K.

Wharf, H.L. (1993) Safety evaluation of working hours. *Presentation by British rail to European Railways.* UIC Paris, France, 7 December 1993.

Wojtczak-Jaroszowa, J. and Pawlowska-Skyba, K. (1967) Night and shift work. I: Circadian variations in work. *Med. Pr.* **18**.

Zulley, J. (1990) Day and night sleep: the bedrest condition. In *Sleep*, ed. J. Horne, Vol. 90, pp. 319–323. Pontenagel Press, Bochum.