Trends in The Risk of Accidents and Injuries and Their Implications for Models of Fatigue and Performance

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Models based on measures of fatigue and performance make the implicit assumption that they will be successful in predicting risk. The present paper reviews the available literature on shiftwork safety in which real measures of accidents or injuries could be pinpointed in time and in which the a priori risk appeared to be constant. Three main problems for the models emerged from this review: 1) risk was significantly higher on the afternoon shift than on the morning shift; 2) the dominant peak in risk over the course of the night shift occurred at about midnight; and 3) risk increased substantially over spans of four successive nights. It is suggested that the relationship between risk and fatigue may be non-linear, that models may have overestimated the recovery during short sleeps, and that day sleeps between night shifts may be less recuperative than normally timed night sleeps of the same length.

Keywords: safety, accidents, injuries, shiftwork, mathematical models, fatigue, performance.

CONCERN WITH SAFETY underlies the development of most, if not all, the models that have been developed to predict variations in sleepiness, alertness, fatigue*, and/or performance on abnormal sleep/wake schedules. However, they all appear to make the implicit assumption that if they can account for the trends in one or more of these measures, they will be successful in predicting risk in real life situations. The fact that this may not necessarily be true is evidenced by the fact that the 24-h curve in sleep propensity accounts for only about 54% of the risk of single vehicle accidents (4). However, it is certainly the case that in many shiftworking situations, safety is one of the primary concerns of both the employees and their employers, and this is particularly true in situations such as transport or the nuclear power industry where there may be a high public or environmental hazard.

Unlike health problems, accidents and injuries can, at least in theory, be attributed to a particular point within a shift system and, hence, can be used to identify particularly problematic features of shift systems. However, shift-related differences in injury or accident rates often reflect methodological confounds, such as the type of work performed and the workers' experience. Studies such as that of L. Smith et al. (20), where the a priori risk was constant, are rare. Further, supervision is usually decreased at night, and in some countries (e.g., the United States) night-shift workers tend to be less experienced than day workers because of a "seniority" system in allocating shiftworkers to permanent shifts. True shift differences may also be masked by the fact that the day shift typically has the heaviest workload, while maintenance and repair activities are often reserved for the night shift (3,20); the type of work performed may also vary across different types of shift systems (21).

Regardless of these issues, however, the potential risk for serious error and accidents or injuries on the night shift should not be underestimated. The infamous industrial mishaps at Three Mile Island, Bhopal, and Chernobyl, as well as the Exxon Valdez disaster, all occurred during the night shift, and shift schedules and fatigue were cited as major contributing factors to each incident (14). It also seems that, relative to day workers, night workers may be more frequently involved in accidents while driving home after work (11). Sleep deprivation, fatigue, and circadian malaise are the obvious culprits in most of these unfortunate incidents.

Unfortunately, as indicated above, many published studies of injury or accident risk have failed to ensure that the a priori risk is constant. Thus, in many organizations, the number of individuals at work is not constant over the 24-h day while the level of supervision may vary substantially. Further, in most shiftworking situations, the nature of the job actually being performed can vary considerably across the 24-h day because longer, and hence safer, runs are kept for the night shift. This practice may be official policy within the company, or may simply be condoned or ignored by management. Either way, it means that accident or injury rates cannot legitimately be compared across the shifts since fewer incidents** would be expected on the night shift.

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* Note that for the sake of brevity the terms "sleepiness," "alertness," and "fatigue" are used interchangeably in this paper.

** The term "incidents" is used from here on to refer to both

TABLE I. SUMMARY OF THE STUDIES OF INCIDENTS ACROSS THE THREE SHIFTS.

Author(s)	Industry	Location	Measure	Total Number (over 3 shifts)	Relative Risk Values (by shift)		
					Morning	Afternoon	Night
Wanat (1962)	Coal Mining	Underground	Injuries	3699	1.00	1.23	1.36
		Above ground	Injuries	1328	1.00	1.51	1.57
Quaas & Tunsch (1972)	Metallurgic Plant	N/A	Injuries	1415	1.00	1.12	1.29
		N/A	Accidents	688	1.00	1.00	1.24
Levin et al. (1985)	Paint Manufacturing	N/A	Injuries	119	1.00	1.14	1.26
Smith et al. (1994)	Engineering	Site 1	Injuries	2461	1.00	1.08	1.21
		Site 2	Injuries	2139	1.00	1.23	1.20
Wharf (1995)	Coal Mining	"Industrial"	Injuries	≈1970	1.00	1.10	1.32
				Mean =	1.00	1.18	1.31
				(SEM)=	(0.00)	(0.05)	(0.04)

Indeed, even in those few industrial situations where the a priori risk would appear to be constant across the 24-h day, there remains the problem that the probability of actually reporting an injury or accident that occurs may vary. Thus, for example, in a recent study[†] of injury rates in an engineering company where the a priori risk of injuries appeared to be constant, we discovered that substantially fewer injuries were reported on the night shift than during the day. Further investigation revealed that when members of the predominantly male work force reported an injury during the day, they were treated by a female nurse at the on-site, occupational health clinic. However, this clinic was closed at night when first-aid cover was provided by the male security guards at the gatehouse situated at the entrance to the works. It seems highly probable that this dissuaded many members of the work force from reporting less serious injuries on the night shift. Indeed, the nursing sister at the occupational health clinic also commented that the number of injuries reported during the day varied substantially depending on which nurse was on duty.

When these contaminating factors are controlled for, there appear to be three reasonably consistent trends in incidents associated with the night shift. The present paper is concerned with reviewing the evidence on these trends and with the extent to which they correspond to the trends known to exist in the various measures that have been used to validate the various mathematical models.

Risk Across the Different Shifts

The first consistent trend relates to the relative risk of incidents on the morning, afternoon, and night shifts on 8-h shift systems. There are several studies of which the author is aware that are based on relatively large numbers of incidents that appear to have overcome the potential contaminating factors, and that have reported incident rates separately for the morning, afternoon, and night shifts. It should be noted that the studies for this and the subsequent trends considered differed from one another in terms of their location, industry, and both the numbers of incidents reported and the size of the population in which they occurred. In all probability, they also differed in terms of the criteria used in determining whether an incident was recorded. Direct comparisons between studies are, therefore, meaningless, but valid comparisons can be made within each study.

Two forms of analyses were used to examine the various trends considered in this paper. First, a repeated-measures analysis of variance was based on the relative risk values calculated for each data set. This form of analysis gives equal weight to each of the studies, despite differences in the total number of incidents reported, and essentially determines whether the trends reported in the various studies are similar to one another (4). The main disadvantage with this first form of analysis is that it would give undue weight to an atypical trend reported in a study based on only a small number of incidents. Secondly, a Chi-square analysis was based on the summed frequency of incidents, giving equal weight to injuries and accidents. This second form of analysis essentially weights the studies according to the number of incidents reported, but suffers from the disadvantages 1) of using Chi-squares with large data sets; and 2) that undue weight would be given to a study reporting an atypical trend if it was based on a large number of incidents. In the present paper, both forms of analyses were used in an attempt to surmount the shortcomings associated with each form by itself. Thus, if both analyses resulted in similar conclusions, this would indicate that the conclusions were independent of the assumptions underlying each form of analysis.

The main details of the studies relating to the trend across the three shifts are summarized in **Table I**, together with the overall number of incidents reported and the relative risk on each of the three shifts, the risk on the morning shift having been set at 1.0. It should be noted that while in some of these studies there were equal numbers of shiftworkers on each shift (15,20), in the others the authors had to correct the data to take account of any inequalities (8,27,28). In addition, three of the studies report two separate sets of data for different areas or types of incident, giving a total of eight data sets across the three shifts. Further, while some of the studies give no precise details of the shift system in use, many of them involved a total of only 4 d on each shift before a span of rest days (15,20).

accidents and injuries.

[†] Unpublished study by Joanne Hill and Simon Folkard, 2002.

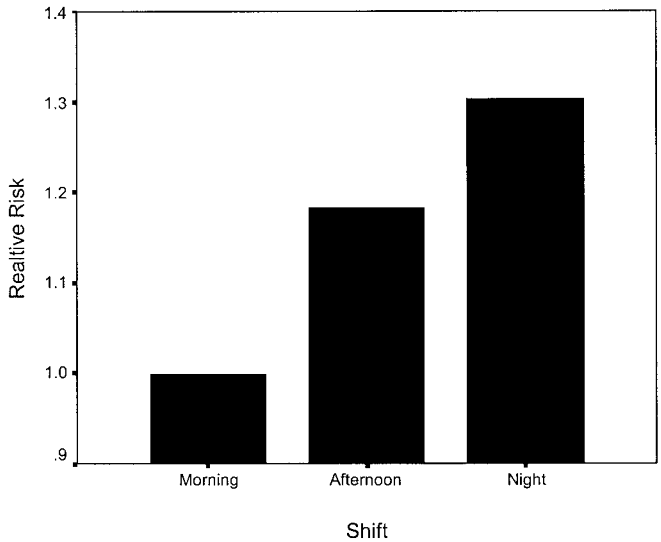

Fig. 1. The relative risk across the three shifts.

With respect to the trend across the three shifts, the repeated-measures analysis of variance based on the relative risk values for each data yielded a highly significant main effect of shift [F (2,14) = 25.239, p < 0.001], indicating considerable consistency across the data sets. The Chi-squared test based on the summed frequencies across the eight data sets for the three shifts also yielded a highly significant effect of shift (χ^2 = 159.369, df = 2, p < 0.001). Based on these summed frequencies, risk increased in an approximately linear fashion across the three shifts, showing an increased risk of 18.3% on the afternoon shift, and of 30.4% on the night shift, relative to that on the morning shift, and this is shown in **Fig. 1**. Note that these values are very similar to the averaged relative risk values shown in Table I.

The conclusion to be drawn would appear to be that in situations where the a priori risk would appear to be constant across the three shifts, there is a consistent tendency for the relative risk of incidents to be higher on the afternoon shift than on the morning shift, and for it to be highest on the night shift. There is good evidence that, on average, alertness and performance measures are typically lower at night than during the day, and this is in line with the predictions of the mathematical models that have been developed. However, alertness and performance measures are also typically higher on average on the afternoon shift than on the morning shift, despite the presence of a post-lunch dip in some measures, and again this is reflected in the current models based on fatigue and performance measures. It is thus difficult to reconcile the increased risk on the afternoon shift relative to the morning shift with either the trends in alertness and performance, or with the predictions of the available models.

In an earlier paper (5) that reported a similar trend across the three shifts, based on a sub-sample of the studies reviewed here, we drew attention to this problem in accounting for the trend in risk across the three shifts. In that paper we showed that one way of accounting for the trend in relative risk across the three shifts was to assume that the phase of the circadian component of the three-process model showed immediate and complete adjustment to the time at which shiftworkers typically wake up prior to each shift. However, there are two problems with this assumption. First, it is clearly counter to the evidence that the adjustment of circadian rhythms to night work is slow, and is typically of the order of 1 h $\cdot$ d^{-1}, and this is reflected in the models that allow for circadian adjustment. Secondly, it would appear that even most permanent nightworkers fail to show evidence of any substantial circadian adjustment to their night shifts (7,16–19). Thus it would appear that the trend across the three shifts is inconsistent with measures of fatigue and performance, and hence, the current models have problems in accounting for it. The reason or reasons for this remains unclear, but it is clear that in their present form the models will consistently underestimate the risk on the afternoon shift.

Risk Over the Course of the Night Shift

Many authors have shown that fatigue increases, or alertness and performance decreases, over the course of the night shift (6,23). However, studies of incident rates over the course of the night shift have found a rather different pattern to that which might be expected, and this brings us to the second reasonably consistent trend in risk on the night shift. In 1923, Vernon reported one of the earlier studies in this area (24). He examined trends during the night shift in the frequency of cuts treated at a surgery in two munitions factories and found that, far from increasing over the course of the night shift, the injury rates actually decreased substantially over at least the first few hours of it. Vernon also reported an indirect measure of productivity, namely the power consumed by the plant, and noted that although this roughly paralleled risk during the day shift, it failed to do so at night. From this observation he concluded that while productivity may have been the major determinant of risk on the day shift, some other factor must have determined risk at night (24). Vernon fails to indicate what he thought this other factor might be, but given the decreasing trend in risk from the start of the night shift, it is difficult to account for it simply in terms of fatigue.

More recent studies have also provided hourly incident rates over the course of the night shift and these, together with that of Vernon (24), are summarized in **Table II**. As before, the frequency of incidents for each hour was expressed relative to that for the first hour in each study in order to enable a comparison across the studies. A repeated-measures analysis of variance based on these relative risk values for the ten data sets yielded a significant main effect of hour on shift [F (7,63) = 3.446, p < 0.01], indicating some consistency across the data sets. A Chi-square test was then based on the summed frequencies across the 10 data sets for each hour of the shift and this yielded a highly significant effect of hour on shift (χ^2= 224.757, df = 7, p < 0.001).

Using these summed values, risk rose by about 20% from the first to the second hour, but then fell by a total of about 50%, and in an approximately linear

TABLE II. SUMMARY OF THE STUDIES OF INCIDENTS OVER THE COURSE OF THE NIGHT SHIFT.

Author(s)	Industry	Measure	Total Number (over 8 h)	Relative Risk Values (by hour on shift) 1st	2nd	3rd	4th	5th	6th	7th	8th
Vernon (1923)	Munitions	Accidents	666	1.00	0.74	0.58	0.74	0.62	0.56	0.56	0.54
Adams et al. (1981)	Coal Mining	Injuries	829	1.00	1.18	1.16	0.60	0.41	0.60	0.85	0.67
Ong et al. (1987)	Steel Mill	Injuries	150	1.00	0.52	0.71	0.36	0.58	0.61	0.45	0.61
Wagner (1988)	Iron Mining	Accidents	775	1.00	1.66	1.20	1.39	0.91	0.87	0.83	0.76
Smith et al. (1994)	Engineering	Injuries	902	1.00	0.97	0.97	1.00	1.00	0.94	0.84	0.68
Åkerstedt (1995)	All Occupations	Injuries	≈2500	1.00	0.93	0.94	0.99	1.00	0.87	0.68	0.33
Wharf (1995)	Coal Mining	Accidents	777	1.00	1.92	1.98	1.75	2.34	1.98	1.07	0.69
Macdonald et al. (1997)	Steel Manufacturing	Injuries	774	1.00	1.47	1.12	1.02	0.80	1.29	0.90	1.00
Smith et al. (1997)	Engineering	Injuries	657	1.00	1.18	1.13	1.13	0.99	1.01	0.86	0.93
Tucker et al. (2001)	Engineering	Accidents	274	1.00	1.35	0.70	0.92	0.49	1.00	1.16	0.78
			Mean =	1.00	1.19	1.05	0.99	0.91	0.97	0.82	0.70
			(SEM)=	(0.00)	(0.13)	(0.12)	(0.12)	(0.17)	(0.13)	(0.07)	(0.06)

fashion, to reach a minimum at the end of the shift, and this is shown in **Fig. 2**. Again, it is noteworthy that a similar trend was shown by the averaged relative risk values presented in Table II. It is notable that there was a slight increase in risk between 03:00 and 04:00 when performance and alertness are thought to be at their lowest ebb, but that this effect was relatively small compared with the substantial decrease in risk over most of the night. This trend in risk over the night shift is clearly inconsistent with predictions from the current models since the fatigue and performance measures on which they are based would suggest that the maximum risk should occur in the early hours of the morning.

Risk Over Successive Night Shifts

The third and final consistent trend in accident risk is during successive night shifts. The author is aware of a total of seven studies[‡] that have reported incident frequencies separately for each night over a span of at least four successive night shifts and these are summarized in **Table III**. As before, in order to compare across these studies, the frequency of incidents on each night was expressed relative to that on the first night shift. A

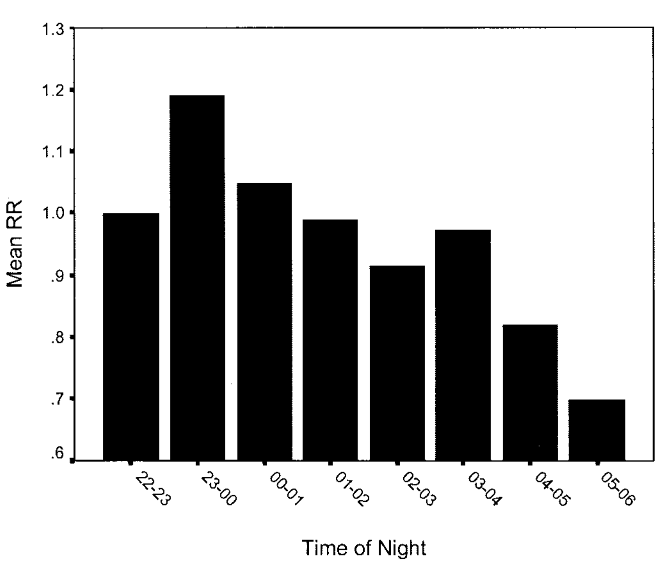

Fig. 2. The relative risk over the course of the night shift.

repeated-measures analysis of variance based on these relative risk values for the seven data sets yielded a highly significant main effect of successive shifts [$F(3,18)=8.208$, $p < 0.001$], indicating some consistency across the data sets.

A Chi-squared test was then based on the summed frequencies across the seven studies for the four successive night shifts and this yielded a significant effect of successive shifts ($\chi^2 = 55.584$, df = 3, $p < 0.001$). These summed values were, therefore, used to estimate the risk on the successive night shifts relative to the first such shift and the results are shown in **Fig. 3**. On average, risk was about 6% higher on the second night, 17% higher on the third night, and 36% higher on the fourth night. Again, a similar, if somewhat larger, trend can be seen in the averaged relative risk values shown in Table III.

Two important questions arise over this substantial increase in risk over four successive night shifts. The first is what happens to risk over longer spans of successive night shifts, but there is a paucity of data relating to this. Only two of the studies report incident rates for a span of more than four night shifts, and both these were based on relatively small numbers of incidents. Nevertheless, it is noteworthy that both these studies (25,26) showed a decrease in risk from the fourth to the fifth night shift, and this decrease was maintained until the seventh, and final, night shift in Wagner's study (26).

It is also the case that two of the studies shown in Table III (15,22) actually showed a slight decrease in risk from the third to the fourth night shift, but these decreases need to be considered in the light of the decreases shown by the other smaller studies between the first and second, and second and third, night shifts. Thus, only the two largest studies (20,21) showed a progressive increase in risk over all four successive night shifts, presumably reflecting on their greater reliability. Thus while it remains a possibility that over longer spans of night shifts risk may actually start to

[‡] Note that the study reported by Monk & Wagner, 1989 (11) was not included since the data reported in that paper was a subset of that reported by Wagner, 1988 (26).

TABLE III. SUMMARY OF THE STUDIES OF INCIDENTS ACROSS SUCCESSIVE NIGHT SHIFTS.

Author(s)	Industry	Measure	Total Number (over 1st 4 nights)	Relative Risk Values (by successive nights) 1st	2nd	3rd	4th
Quaas & Tunsch (1972)	Metallurgic Plant	Accidents	261	1.00	1.38	1.79	1.71
Vinogradova et al. (1975)	Dockers	Accidents	272	1.00	1.24	1.11	1.60
Wagner (1988)	Iron Mining	Accidents	442	1.00	0.75	0.80	1.26
Smith et al. (1994)	Engineering	Injuries	1686	1.00	1.05	1.12	1.16
Smith et al. (1997)	Engineering	Injuries	842	1.00	1.08	1.27	1.76
Tucker et al. (2001)	Engineering	Injuries	291	1.00	1.30	1.57	1.32
Oginski et al. (2000)	Steel Mill	Injuries	63	1.00	1.00	1.21	1.29
			Mean=	1.00	1.11	1.27	1.44
			(SEM)=	(0.00)	(0.08)	(0.12)	(0.09)

decrease after the fourth night, to date there is no good evidence to indicate that this is actually the case.

The second important question is whether the increase in risk over successive shifts is confined to the night shift, or whether it might be general to all shifts and represent an accumulation of fatigue over successive workdays. Of the seven studies listed in Table III, five also reported the risk over successive morning or day shifts, and these are summarized in **Table IV**. As before, in order to compare across these studies, the frequency of incidents on each shift was expressed relative to that on the first morning/day shift. A repeated-measures analysis of variance based on these relative risk values for the five data sets indicated that there was no evidence of a main effect of successive shifts [F (3,12) = 0.789, p = 0.523], suggesting that there was relatively little consistency across the data sets. However, this may simply have reflected on the relatively small number of incidents involved in some of the studies.

As before, a Chi-squared test was then based on the summed frequencies across the five studies for the four successive shifts and this yielded a significant effect of successive shifts ($\chi^2 = 10.092$, df = 3, p = 0.018). These summed values were, therefore, used to estimate the risk on the successive morning/day shifts relative to the first such shift and the results are shown in **Fig. 4**. Note that the same scale has been used for this figure as that used in Fig. 3 so that direct comparisons can be made.

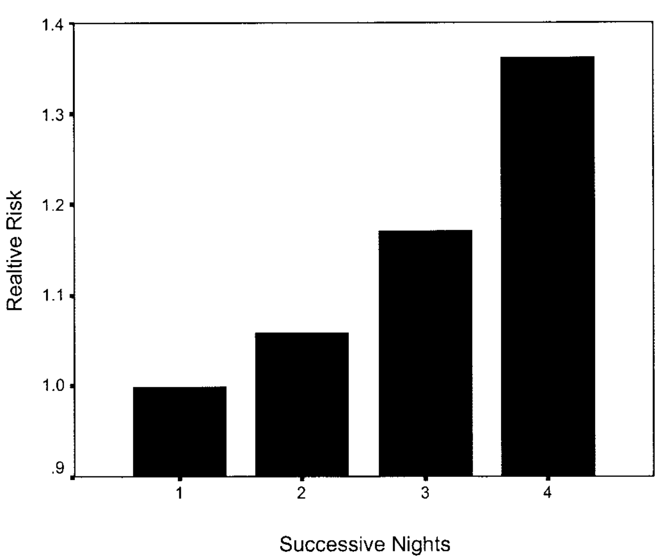

Fig. 3. The relative risk over four successive night shifts.

On average, risk was about 2% higher on the second morning/day, 7% higher on the third morning/day, and 17% higher on the fourth morning/day shift than on the first shift. Inspection of the averaged relative risk values shown in Table IV also suggests that risk increased over at least the first three successive morning/day shifts, although these mean values showed a decrease from the third to the fourth day.

Clearly there was some evidence, albeit relatively inconsistent compared with the other trends reported in this paper, that risk did increase over successive morning/day shifts. However, the important point is that this increase was substantially smaller than that over successive night shifts (compare Figs. 3 and 4). Thus, there is some evidence for an increase in risk over successive workdays, irrespective of the type of shift, but also evidence that this increase is substantially larger on the night shift than on the morning/day shift.

The increases in the risk of incidents over successive day and night shifts is inconsistent with the results of at least some studies of rated alertness that have found alertness to remain relatively constant over spans of successive shifts (5). Indeed, most of the models fail to include a cumulative fatigue effect and would have difficulty in accounting for it, especially since they assume an exponential recovery during sleep that results in little, if any effect, of successive shortened sleeps. In fact, there is good reason to suggest that some models would actually predict that risk should be higher on the first night shift than on the second in view of the increased period of wakefulness prior to the first night shift.

Implications for Models

It is clear that the trends in risk derived from these "macro-analyses" (4) of published studies of incident frequencies are very different from the trends in alertness and performance on which current models are based. The finding that risk on the afternoon shift is higher than that on the morning shift, despite both ratings of alertness and the performance of various tasks showing the opposite effect, suggests that the relationship between risk and alertness or performance may be non-linear. Such a suggestion might also account for the trend in risk over the course of the night shift.

One possible hypothesis is that the risk of incidents may actually be relatively high when people feel very

TABLE IV. SUMMARY OF THE STUDIES OF INCIDENTS ACROSS SUCCESSIVE MORNING/DAY SHIFTS.

Author(s)	Industry	Measure	Total Number (over 1st 4 d)	Relative Risk Values (by successive days)			
				1st	2nd	3rd	4th
Quaas & Tunsch (1972)	Metallurgic Plant	Accidents	169	1.00	1.21	0.93	0.79
Smith et al. (1994)	Engineering	Injuries	1372	1.00	0.98	1.05	1.11
Smith et al. (1997)	Engineering	Injuries	761	1.00	1.09	1.04	1.45
Tucker et al. (2001)	Engineering	Injuries	297	1.00	0.88	1.22	0.97
Oginski et al. (2000)	Steel Mill	Injuries	85	1.00	1.12	1.59	1.29
			Mean=	1.00	1.06	1.17	1.12
			(SEM)=	(0.00)	(0.06)	(0.12)	(0.12)

alert, simply because they are overconfident and fail to "self-monitor" sufficiently. As alertness decreases from these high levels, individuals may become more cautious in the performance of their work, and engage in more controlled processing of information, and hence safety may actually improve. However, when alertness drops too far, or fatigue increases too far, they may again fail to self-monitor sufficiently due to their high fatigue level and hence risk may increase again. A hypothetical curve illustrating this idea is shown in **Fig. 5**.

A non-linear relationship between fatigue (or alertness) and risk, such as that shown in Fig. 5, might be able to account for both the trend in risk over the three shifts, and for the trend over the course of the night shift. However, if this non-linear relationship is to be incorporated into our models, we would clearly need to establish its precise nature using one of the standardized rating scales and relative risk. Such an undertaking may be possible on the bases of the trends in risk provided in this paper, given that we have normative data for the timing of sleep and other variables on the various shifts. Indeed, it is arguable that if the incorporation of this relationship into a model improved its ability to predict the trends in risk described in this paper, it should also improve its ability to predict actual risk on the wide variety of abnormal sleep/wake schedules encountered in transport operations.

However, it seems improbable that the increase in risk over successive day/morning or night shifts is due to a non-linear relationship between alertness and risk. Rather it would appear that there may be two additional factors that need to be incorporated into the models. The first is a cumulative effect over successive shifts, independently of whether the shift is a morning/day shift or a night shift. This could be modeled directly as a cumulative fatigue effect over successive shifts, or perhaps more parsimoniously as a consequence of the reduced sleep durations typically associated with both types of shift.

Currently, models assume that the recovery of alertness over a period of sleep shows an exponential function such that most of the recovery has occurred within the first few hours of sleep. Consequently, the sleep durations of six or more hours typically associated with morning/day and night shifts result in very little cumulative effect over successive shifts. Clearly the increase in risk over successive shifts suggests that recovery may be far from complete following these shortened sleeps, and that we may need to revise our estimates of the recovery function during sleep.

Likewise, the greater increase in risk over successive night shifts relative to that over successive morning/day shifts, despite sleep durations between these shifts often being similar, might be taken to suggest that the recovery of alertness during a day sleep following a

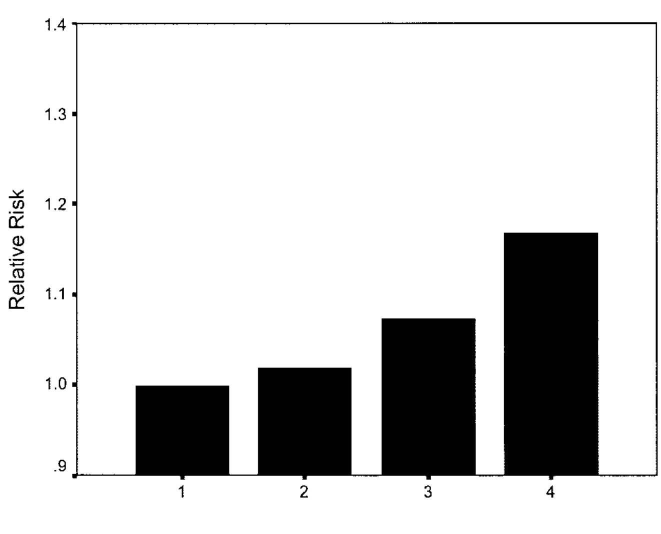

Fig. 4. The relative risk over four successive morning/day shifts.

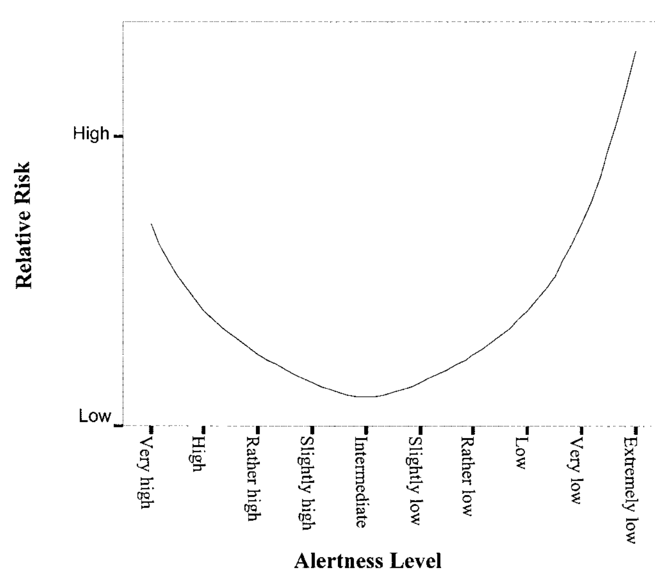

Fig. 5. A hypothetical non-linear relationship between relative risk and alertness.

night shift may be rather less than that during a normal night sleep. Thus, sleeps that occur at abnormal times of day may be less restorative than those at night, even if the sleep duration is the same.

In conclusion, it would seem that the reasonably well-established trends in the relative risk of incidents in shiftworking situations are inconsistent with those in fatigue and performance. One reason for this may be that the relationship between fatigue and risk is non-linear, with risk being relatively high when people are highly alert, simply because they are overconfident and fail to "self-monitor" sufficiently. However, it would also appear that measures of fatigue and performance, and hence current models, also underestimate the build-up in the risk of incidents over successive shifts. This latter failure may be due to an overestimation of the recovery that occurs over both shortened sleeps and day sleeps.

If we are to refine the current models to enable them to predict risk, there would thus appear to be three factors that may need to be taken into account. First, we may need to incorporate a non-linear relationship between fatigue, as measured by subjective ratings or performance tasks, and relative risk, such as that hypothesized in Fig. 5. Secondly, we may need to add a cumulative fatigue effect, although this may be accomplishable by refining our estimates of the recovery that occurs during shortened sleeps. Finally, we may need to take into account of the time of day at which a sleep occurs in determining its recovery value, with day sleeps yielding less recovery than normal night sleeps of the same duration.

Finally, it should be emphasized that our knowledge of the trends in relative risk is rather limited, and that there is a strong need for further carefully controlled epidemiological studies of the various factors that may effect fatigue and risk such as the frequency and length of rest-breaks and the occurrence of quick returns between shifts. Such studies might also allow the development of models based directly on relative risk, rather than on fatigue and performance measures. In principle, this would be possible on the bases of the trends reported in this paper, although such a model would be of rather limited scope. Its refinement would clearly require further epidemiological studies of incidents to explore the various other factors that may impact on risk.

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