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The development of a fatigue / risk index for shiftworkers

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The development of a fatigue / risk index for shiftworkers

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This report describes the work carried out to revise and update the HSE Fatigue Index (FI). Extensive changes have been made to the previous version, incorporating recent information relating to a variety of issues including cumulative fatigue, time of day, shift length, the effect of breaks and the recovery from a sequence of shifts. In addition, a review has been carried out of trends in risk related to shift work, and this has enabled the final version to incorporate two separate indices, one related to fatigue (the Fatigue Index) and the other to risk (the Risk Index). While the two indices are similar in many respects they diverge in others. The main differences are due to the different trends with respect to time of day in fatigue and risk. The index has been implemented in the form of a spreadsheet, the design of which has incorporated feedback from users of the previous index.

Further work has been undertaken to determine whether a separate FI would be required for permanent night workers. It was concluded that suitability of the FI would depend on the degree of adaptation to the night shift.

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HSE BOOKS

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1 EXECUTIVE SUMMARY

This report describes the work carried out for the HSE, under contract number 6062, to revise and update the HSE Fatigue Index (FI). The work was undertaken by QinetiQ in collaboration with SFA (Simon Folkard Associates).

The previous version of the FI has been widely used by the rail sector and has become increasingly used in other areas of British industry. However, various issues have been identified which have led to a requirement to revise the index. Some issues have arisen as a result of the incorporation of the index into a spreadsheet, whereas it was originally designed for manual use. This has enabled more complex calculations to be performed than were envisaged in the previous version.

Feedback from existing users has identified other issues that needed to be addressed. Some of these were concerned with the way the calculations were performed and the perceived inadequacy of the handling of factors such as breaks and task complexity. Others were concerned with the user interface provided by the spreadsheet and factors related to the input and output of information.

A literature review has been undertaken to identify areas where new information has become available since the construction of the previous index. This has been supplemented by data collected by, or made available to, members of the project team during the intervening period. The new information covers a wide range of issues, from the development of cumulative fatigue, the impact of breaks, time of day and shift length to the time required to recover from a sequence of duties.

A further development, since the release of the previous version of the FI, has been the increase in information concerning trends in risk related to shiftwork. An extensive review of this information has been carried out, and this has enabled an index to be constructed that is entirely related to risk, rather than to fatigue and performance. The new index therefore consists of two separate individual indices, one related to fatigue (the 'Fatigue Index') and one related to risk (the 'Risk Index'). While the two indices are similar in many respects, they diverge in others. The main differences are due to the different time of day effect: the peak in risk occurs close to midnight, whereas the peak in fatigue tends to occur some five hours later, in the early morning.

In the spreadsheet that has been produced to incorporate the new Index, both the risk and the fatigue indices are expressed in terms of three individual components:

1. A cumulative component. This relates to the way in which individual duty periods or shifts are put together to form a complete schedule. The cumulative component associated with a particular shift depends on the pattern of work immediately preceding that shift.
2. A component associated with duty timing, i.e. the effect of start time, shift length and the time of day throughout the shift.
3. A job type / breaks component. This relates to the content of the shift, in terms of the activity being undertaken and the provision of breaks during the shift.

A review was undertaken to determine whether a separate Fatigue Index was required to cater for permanent night workers. It was concluded that the current index could be applied directly to the majority of shift workers who, based on the phase of their melatonin rhythm, showed little adaptation to permanent night work. However, the index would need to be adapted for the 30% of workers who showed at least some adjustment.

2 DEVELOPMENT OF A NEW FATIGUE INDEX

2.1 THE REQUIREMENT

The development of the HSE Fatigue Index (FI) arose from the requirement to assess the risks from fatigue associated with rotating shift patterns and, in particular, the requirement to provide guidance in support of the Railway (Safety Critical Work) Regulations.

Since the development of the previous version in 1999, the FI has been widely used by the rail sector and it is now being increasingly used in other areas e.g. by the police and by the nuclear and chemical industries. However, a number of issues have arisen associated with its use, and various shortcomings have been identified, which have highlighted the desirability of revising the index. In addition, a considerable quantity of new information on fatigue and risk has become available since the previous version was constructed. The timing of the revised Index also coincides with the new Railway and Other Guided Transport Systems (Safety) Regulations (ROGS) 2006. The new Index will be used in the update of guidance to accompany these regulations.

Specifically, the aims of the current project were to:

- review current users of the FI spreadsheet to identify problems and uncertainties that need to be addressed;
- bring the Index up to date in terms of the published literature on fatigue and risk;
- update the spreadsheet on which the index is presented, together with the accompanying user instructions;
- investigate the feasibility of developing a second index designed to assess patterns involving a high proportion of night working, especially permanent night working.

2.2 BACKGROUND

The HSE has developed a method of assessing the risk arising from fatigue associated with work patterns for safety critical workers. The methodology involved the calculation of a ‘Fatigue Index’ and it was intended that the index could be used to provide an assessment of changes in work patterns and to determine whether any particular aspect of the work pattern was likely to increase levels of fatigue.

This initial Fatigue Index included six factors associated with the development of fatigue, namely: the length of the shift, the interval between shifts, the number of rest days, the quality of the rest breaks, the variability of the shifts, and the time of day. Each of the six factors was scored independently and the composite score was used to provide an overall index of fatigue.

The HSE commissioned QinetiQ (then known as the Defence Evaluation and Research Agency) to carry out an assessment of this initial version of the Fatigue Index to identify its strengths and weaknesses. It was concluded that, whilst it contained many of the important factors which relate to fatigue, the method of calculation was in many cases difficult to apply and the individual factors did not always reflect current knowledge concerning the development of fatigue. Subsequently, based on information from various studies of shift workers, the FI was revised. The revised version retained five of the original six factors (time of day, shift duration, rest periods, breaks and cumulative fatigue), the scores from each of which were summed to provide an overall index for the pattern of work. One feature of the index was that, like its predecessor, it was designed for manual calculation. This inevitably restricted the extent to which it was able to represent the full complexity of the issues related to fatigue.

Subsequently, further work was commissioned to convert this revised index into a spreadsheet format. This version has been used widely throughout British Industry to assess and compare patterns of working. However, it has been recognised that there are areas where the FI is deficient and where improvements could be made. In many cases, this was due to the simplicity of the calculations which were designed to be carried out with pencil and paper. The use of a spreadsheet permits more complex calculations which can therefore reflect more accurately the interaction between the various factors influencing fatigue.

One aim of the current project was therefore to develop a more up to date version of the FI which would take account of current knowledge and understanding of factors associated with the development of fatigue in the shift work environment. It was recognised that, with the increasing complexity of the calculations that would be required, it was no longer appropriate to calculate the scores manually. The decision was made, therefore, that the new index would be available only in a spreadsheet format.

A further development, since the release of the previous version of the FI, has been the increase in information concerning trends in risk related to shiftwork. For the construction of a new index, therefore, it was proposed to investigate the extent to which the output of the index could be expressed in terms of the relative risk associated with different patterns of work.

In the remainder of this section, the stages leading to the development of the new index are summarized. Section 2.3 provides an outline of the information on which the index was based, and the construction of the index is described in section 2.4. Further details are provided in the various appendices.

2.3 INFORMATION USED IN THE DEVELOPMENT OF THE NEW INDEX

Changes to the index were based on the following sources of information:

- feedback from existing users of the FI;
- recent information relating to fatigue and shift work;
- incident risk relating to train drivers;
- literature relating to incident risk.

2.3.1 Feedback from existing users of the FI

As part of the process of revising the FI, a number of existing users were asked to provide feedback on their experiences of using the index. Various groups were identified by the HSE and these were approached by QinetiQ and asked if they would like to contribute to the project. Through this process it was hoped to gain greater insight into the way in which the FI was used in practice, its ease of use and its limitations. This information has been used to guide the development of the new index.

Feedback was obtained from 12 of the 17 different groups who had been identified as users of the index. The main reason for companies failing to contribute was that the contact information was out of date (e.g. the person concerned had left the company). Predominantly, the 12 companies who did provide feedback came from the rail industry but, in addition, the bus, chemical, nuclear and offshore industries were also represented. The comments can be classified into three main areas:

- the calculation of the index;
- the user interface;
- other issues which were strictly outside the scope of the current project.

With one exception, all the user groups were using the Excel spreadsheet version of the FI.

Calculations: Some of the factors contained within the spreadsheet were poorly understood by the users and this led to some not being used or being used inconsistently. In particular, the task complexity was identified as a problem, with only 58% of companies understanding how it was intended to be used.

Others factors (e.g. breaks, travelling time) were felt to be too variable and the effort required to represent them within the spreadsheet was too high. The factor related to breaks (F4) was not widely used, and one of the reasons given was that it was unclear how to input meal breaks within a duty. Where information relating to breaks was incorporated, there were comments about how little effect omitting a break had on the output.

Four user groups commented that the index seemed to give undue credit for a single rest day, particularly when it followed the night shift.

User interface: Many groups commented that data entry was cumbersome, particularly when entering start and end times. The spreadsheet required the user to separate hours and minutes using a colon, which added greatly to the time taken to enter data. It was also suggested that the ability to enter a sequence of duties using a batch method, i.e. by importing data from another source, would be a useful addition to the spreadsheet.

The existing version of the spreadsheet included a graphical representation of the output data. Some users commented that it would be useful to be able to specify how much information was plotted and how each component contributes to the overall score. In this way it would be possible to identify more easily the main factor which needed to be addressed.

Other feedback related to the need for more guidance on the use of the FI. For example, there were requests to provide more detailed guidance information, and to include details of its limitations, and the interpretation of the numerical output. The HSE has provided guidance on 'acceptable' or threshold scores, i.e. when attempts should be made to modify the schedule of work. Many users suggested it would be useful to provide more information about the use of these threshold scores and that a warning should be provided when the FI exceeded these scores.

Comments outside the scope of the project: Many of the user groups who provided feedback were from the rail industry. As a result many of the issues raised related specifically to the use of the FI within the confines of the rail environment e.g. ensuring that the schedules did not exceed the Hidden rules, and the inclusion of diagram numbers. However, as the FI is designed to be applied in a wide variety of types of work in different industries, such developments fall outside the scope of the current programme of work.

2.3.2 Recent information relating to fatigue and shift work

Since the development of the previous version of the FI, further information relating to fatigue and shift work has become available. This includes results published in the open literature, as well as data collected by members of the project team. This information covers a wide range of issues, from the development of cumulative fatigue, the impact of breaks, time of day and shift length, to the time required to recover from a sequence of duties.

One of the areas that has been more extensively investigated is that of cumulative fatigue. Recent studies of the impact of chronic sleep reduction, over a period of one to two weeks, have provided greater insight into how fatigue accumulates over several days and, to a certain extent, into the pattern of recovery. Other data have become available relating to time of day, and in particular to early starts, and these have established the trend in alertness associated with duties starting at different times of day. In addition, there is more information on the impact of time of day on sleep duration. Further published data relating to breaks have confirmed previous findings that breaks are beneficial although the optimum timing and duration have yet to be established.

A more detailed account of the information used is given in Appendix A.

2.3.3 Incident risk relating to train drivers

To help in the evaluation of the risks associated with fatigue, information was obtained on the incidence in the railway industry of signals passed at danger (SPADs). Incident data were obtained both from London Underground (LUL) and the Rail Safety and Standards Board (RSSB). However, it was not possible to use the LUL data, as there were ambiguities and inconsistencies in the way the data were recorded.

The information collected by RSSB for each SPAD included the timing of the SPAD event, the timing of the duty period in which the SPAD occurred, the time of any scheduled break within that duty and the pattern of duty over the previous 12 days. A total of 2119 incidents over five years between January 1998 and May 2003 were analysed. In the course of the project, information on 450 more recent SPADs was provided by RSSB. However, this information was limited to the previous pattern of duty, and there was no indication whether the driver concerned was implicated in the SPAD.

After correcting, as far as was possible, for exposure to risk, several trends in the data were evident. It appeared that the risk was higher overnight compared with during the day, and that it increased with both time on task and the number of consecutive days. The results were broadly consistent with the conclusions from the literature review of the risks associated with different patterns of work (see section 2.3.4). However, they were not incorporated directly into the index. Instead, it is suggested that a more comprehensive review of these data could form the part of the subsequent validation of the Index.

2.3.4 Literature relating to incident risk

A review of the literature on the risk of injuries and accidents relating to shift work was undertaken to determine whether there was a link between accident risk and the patterns and timing of work. Full details of the review are given in Appendix B.

The review highlighted the shortage of good epidemiological studies investigating accident risk in the workplace that also controlled for the *a priori* risk. Nevertheless, from the studies that did manage to take account of confounding factors, it was possible to identify consistent trends that could form the basis of a ‘risk index’. Trends in the relative risk of accidents have been identified for the following factors:

- shift type (morning, afternoon, and night shift) for 8 hour shifts;
- time on duty throughout the course of the night shift;
- time of day;
- consecutive day shifts;
- consecutive night shifts;
- consecutive hours on duty.

Some additional information on relative risk is also available for the effect of breaks, prophylactic naps and the direction of rotation.

When the review was completed, it became clear that there were considerable differences between trends in fatigue related to patterns of work and the similar trends in risk. While it may be possible, in the long term, to reconcile many, if not all, of these differences, it was decided that the new version of the Index should include two separate indices, one related to fatigue (the Fatigue Index) and one related to risk (the Risk Index (RI)). The user is therefore able to decide on which index to place the greater weight. In the general situation, it would be wise to ensure that neither index reaches a high value.

2.4 THE CALCULATION OF THE FATIGUE / RISK INDEX

The previous HSE Fatigue Index has been updated in the form of a Fatigue and Risk Index. The significance of the name change is that, as indicated above, the new index consists of two separate indices, one of which is related to fatigue, and which therefore corresponds more closely with the previous index, whereas the other is related to risk.

The outputs from the two indices are on two different scales, and both differ from the scale used in the previous version. The Fatigue Index is now expressed in terms of the average probability, multiplied by 100, of a high score (specifically a value of eight or nine on the Karolinska Sleepiness Scale (KSS)), and therefore takes a value between zero and 100. The KSS is a nine-point scale ranging from one (extremely alert) to nine (extremely sleepy – fighting sleep). It has been extensively validated, and high scores are known to be associated with a high frequency of microsleeps[1].

The output from the Risk Index represents the relative risk of the occurrence of an incident on a particular shift. As with the Fatigue Index, the risk is averaged over the entire shift. A level of one represents the average risk on a typical two-day, two-night, four-off schedule, involving 12-hour shifts starting at 08:00 and 20:00. A value of two represents a doubling of risk.

It should be noted that there are some large differences in the output from the two indices, and a shift with a high value on one index is not always assigned a high value on the other. This is an inevitable consequence of the different information from which the two indices have been constructed and, in particular, of the differential effect of time of day. Whereas both fatigue and risk are highest on the night shift, the risk of an incident occurring on the afternoon shift is higher than on the morning shift. This contrasts with fatigue which tends to be higher on a morning than on an afternoon shift.

There are also considerable differences between the new version of the Fatigue Index and the previous one. Many of these relate to the estimation of cumulative fatigue and the weighting given, for example, to long sequences of consecutive shifts, both during the day and overnight. When the previous index was constructed, it was made clear that information on cumulative fatigue was very sparse, and that the output from the index should be treated with extreme caution. Since that time, more information has become available and, while considerable uncertainties remain, it is now possible to derive more plausible estimates. Nevertheless, it must be stressed that information from field studies to support estimates over long periods of consecutive shifts is still not available.

Both the Fatigue and the Risk Index are constructed from three separate components, namely:

- A cumulative component. This relates to the way in which individual duty periods or shifts are put together to form a complete schedule. The cumulative component

[1] Akerstedt T, Gillberg M (1990). Subjective and objective sleepiness in the active individual. Int J Neurosci 52(1-2): 29-37.

associated with a particular shift depends on the pattern of work immediately preceding that shift.

- A component associated with duty timing, i.e. the effect of start time, shift length and the time of day throughout the shift.
- A job type / breaks component. This relates to the content of the shift, in terms of the activity being undertaken and the provision of breaks during the shift.

More detailed accounts of the derivation of the two indices are given in Appendix C (the Fatigue Index) and Appendix D (the Risk Index).

3 THE FEASIBILITY OF DEVELOPING A FATIGUE INDEX FOR PERMANENT NIGHT WORKERS

3.1 BACKGROUND

The FI was designed to assess rotating schedules and it is not necessarily the most appropriate tool for the assessment of schedules involving prolonged or permanent night working. Therefore, as part of this programme of research, the feasibility of developing a FI for permanent night workers was investigated.

One of the key issues in this investigation was whether, and in what circumstances, individuals adjust to the night shift. If the majority of permanent night workers fail to adapt to permanent night work, then it may be possible to use the existing index. However, if individuals are able to adjust to the night shift, then it would almost certainly be necessary to develop a separate FI specifically to cater for this situation. To address this issue, a literature review was undertaken to determine the extent to which individuals adapt to the night shift.

3.2 THE LITERATURE REVIEW

The review of the literature on the adjustment to permanent night shifts concentrated on the secretion profile of the hormone melatonin (a well known marker of the endogenous body clock) and evidence of its adjustment to night work. Whilst a large number of papers were identified only six were considered to be relevant.

Data from these papers indicated that 7% (6 out of 85 individuals) of permanent night workers showed good adjustment to the night shift. A further 22% (19 out of 85) of workers showed evidence of some level of adjustment, which may have been of benefit to night workers in coping with consecutive night shifts. However, over two thirds did not show evidence of a significant adjustment. Overall, there was no suggestion of a gender difference in the adjustment to night work.

It was concluded that in the majority of cases (around 70%), the FI would be an appropriate assessment tool for permanent night workers. However, for around 30% of permanent night workers, the FI would be inappropriate. Indeed, for these individuals, the existing FI is likely to be too limiting, as they should be able to cope with longer sequences of consecutive nights than those who fail to adjust.

It is suggested that it would be possible to devise a FI for permanent night workers but such an Index would need to take account of the degree of adjustment to night work. One way of assessing adjustment to the night shift would be to develop a self-administered questionnaire, the output of which would be used to determine which version of the Index would be applicable to any given individual. Details of the literature review are provided in Appendix E.

4 CONCLUSIONS AND RECOMMENDATIONS

Updating the FI has involved the incorporation of data that were previously unavailable and this information has led to improvements in the way in which different factors are represented. In particular, the development of cumulative fatigue, the effect of duty start time and time of day, and also the effect of breaks and workload (although evidence in these latter two areas is relatively sparse) have all been refined.

The investigation of factors directly related to risk has enabled a Risk Index (RI) to be developed which directly reflects the influence of the work schedule on risk as opposed to fatigue. However, there are discrepancies between the effects of risk and fatigue and these are largely due to the differences in time of day effects on the two factors. This has led to the requirement for two separate indices within the new spreadsheet.

In the near future, it may be possible to incorporate both risk and fatigue into a single index. However, this would require further research. In the meantime, users of the index are advised to keep both risk and fatigue within reasonable limits.

It would be possible to devise a FI for permanent night workers but such an index would need to take account of the degree of adjustment to night work, as the degree of adaptation varies widely between individuals.

It is recommended that both indices are validated with respect to accident/incident data.

The Fatigue and Risk Indices enable the user to compare the impact of different patterns of working and in the current format they provide an average value for each duty period. If the indices are to be used in the post-event analyses (e.g. incident/accident investigation), then the index should be modified to accept time-specific inputs e.g. the time of the incident itself, the intensity of work, and the pattern of work and breaks during the shift immediately prior to the incident.

A LITERATURE REVIEW OF SHIFT WORK AND FATIGUE

A.1 BACKGROUND

A previous project (Rogers et al, 1999), which led to the development of the FI, included an extensive review of the literature relating to fatigue and shift work. To ensure that the proposed revisions to the FI were based on the most recent information, an update of this review was undertaken. It involved the identification of new data that had been published in the intervening period i.e. since 1999. Two main sources of information were used:

- Open literature
- Information held by the project team

The review has been structured by considering separately the various factors related to scheduling that were thought to be relevant and may influence the development of the FI. The key factors were:

- development of cumulative fatigue;
- recovery provided by breaks in activity within a shift;
- time of day;
- time on task (i.e. time on task without a break);
- the duration of a duty period;
- the duration of the period between two consecutive duties;
- recovery required after a long sequence of duties;
- the intensity of the work undertaken;
- the direction and speed of rotation
- the variability in the pattern of work.

In the following sections these factors are discussed in greater detail, along with a summary of the main findings.

A.2 SEARCH CRITERIA

The search of the open literature involved using PsycINFO, Web of Science, PubMed, Science Direct and Google Scholar search engines. The review was limited to English language papers, and papers published from 1999 onwards.

Data held by the project team were used to provide additional information, where appropriate. This information fell into three main areas:

- field studies of civil aircrew where information on time of day, cumulative fatigue and duty period duration were collected;
- field studies of train drivers which included data on fatigue and risk of accidents, cumulative fatigue, workload and time of day.

Terms used in the various searches included ‘shiftwork’, ‘shift work’, ‘work schedule’, ‘work hour’, ‘perform*’, ‘alert’, ‘sleep*’, ‘fatigue*’, ‘cumulative fatigue’, ‘time on task’, ‘shift length’, ‘duty length’, ‘time of day’, ‘rest break’, ‘rest period’, ‘quick return’, ‘early start’, ‘shift pattern’, ‘direction shift rotation’, ‘speed shift rotation’, ‘variab*’. Using these terms to search the various databases produced over 6,000 hits. After duplicate papers were removed, a review of the abstracts was completed and the number of references was reduced to 109. This reduction was based on a number of factors. The main criterion was whether the information could influence the further development of the Fatigue Index. Other issues were the relevance of the information and whether it fell into one of the categories identified above. A number of the studies provided complementary information to that which had previously been included in the Fatigue Index and therefore these papers were not included in this review. Other papers did not provide sufficient detail or data on which to quantify any changes to the FI and are not discussed within the current review.

The number of papers was further reduced by completing a more in-depth review. Finally, some 50 papers were considered of which the most relevant are discussed in greater detail in the following sections. Some of these papers are mentioned in several sections as the information contributes to a number of different issues.

A.3 CUMULATIVE FATIGUE

Cumulative fatigue is the accumulation of fatigue associated with working over successive days or weeks and is the main area where more information has become available. Cumulative fatigue is a key issue for the current project as it is important that the FI represents with reasonable accuracy the increase in fatigue associated with working over a number of days or weeks.

At the time of the previous review there was very little information available in this area. Since then a number of studies have been undertaken, of which two in particular (Belenky et al, 2003; Van Dongen et al, 2003) have provided useful information about the accumulation of fatigue over successive days and, in particular, the link with sleep loss. These two laboratory-based studies investigated the impact of sleep restriction over a period of one (Belenky et al, 2003) or two weeks (Van Dongen et al, 2003). This is a situation many shift workers may experience, for example, when working consecutive early shifts.

Limiting sleep to six hours or less over successive nights resulted in a cumulative dose-dependent deficit in performance (Van Dongen et al, 2003). Individuals who obtained less than four hours sleep per night showed increasing lapses in performance, and reduced speed and accuracy when completing performance tasks, whereas those who obtained seven hours sleep or more were able to maintain levels of performance over 14 consecutive days.

Whilst the performance measures indicated an increase in lapses and response times with reduced amounts of sleep, some of the subjective measures (subjective sleepiness) suggested that there may be some adaptation to chronic sleep deprivation (Van Dongen et al, 2003). Even at the end of a 14-day period of sleep restriction, some participants only reported feeling slightly sleepy.

The authors proposed that it is the excessive wakefulness beyond a maximum point which best explains the reduced alertness and poor performance. They investigated the relationship between the cumulative amount of time spent awake during the study (termed ‘cumulative wake extension’) and performance deficits. The profile of performance deficits more closely followed the profile for cumulative wake extension rather than sleep loss. Based on the study data, it was suggested that the critical period of continuous wakefulness beyond which lapses in performance would be expected to increase was approximately 16 hours. Therefore, it is suggested that the average amount of sleep required per 24 hours is 8.2 hours. This is an interesting finding which is of relevance to shift workers, particularly those working early starts, late finishes or night shifts, where sleep is normally reduced well below eight hours.

Four hours has been suggested as the minimum amount of sleep at which performance can be sustained (Belenky et al, 2003), although this will result in performance at a reduced level compared to those who are able to sleep for eight hours. Clearly, four hours sleep would not be recommended for shift workers.

In a laboratory study, a slow build up of sleep loss led to fewer decrements in performance and alertness than a rapid accumulation (Drake et al, 2001). Rapid sleep loss (no sleep for one night) produced greater impairment on tests of performance, memory and alertness than a slow (six hours time in bed (TIB) for four nights) sleep loss condition. Changes from the control condition (eight hours TIB for four nights) to the last day of each condition indicated a linear relationship between rate of sleep loss and impairment.

For construction workers participating in a field study, there was no difference in cumulative fatigue when comparisons were made between an 84-hour working week (seven days x 12-hour shifts) and a 40-hour working week (five days x eight-hour shifts) (Persson et al, 2003). There were no significant differences in sleepiness or fatigue between the two groups but for the 84-hour group there was an increase in subjective levels of sleepiness across the start of successive test days.

Based on laboratory data, it has been suggested that individuals adapt to the night shift across consecutive duties (Lamond et al, 2003). Whilst the first night can result in the greatest impairment in performance (Lamond et al, 2004), adaptation of sleep and performance can occur as the week progresses (Lamond et al, 2003). In the laboratory, sleep during the day following the night shift, was approximately 35 minutes shorter than that overnight, and on average over six successive shifts led to a cumulative sleep debt of 3.5 hours. In this investigation (Lamond et al, 2003), the participants were young individuals and the sleeping conditions were favourable, with no competing social factors which would have affected the adaptation to the night shift. This could therefore be a conservative estimate of the impact of night work on sleep loss.

In a study of aircrew working night cargo operations, sleep after the first night was also reduced by approximately 30 minutes compared to subsequent nights (Spencer et al, 2004). Thereafter, there was no difference in sleep duration or sleep quality. Over four successive night duties, there was no evidence of an accumulation of fatigue. The nature of the operation with a relatively low workload and an element of self-selection (predominantly night-based duty periods) by the aircrew may account for the lack of a cumulative effect.

Other studies of consecutive night shifts have indicated that performance errors increase and alertness decreases over four consecutive night shifts (Walsh et al, 2004). When rest periods between shifts are nine hours or less, there is some evidence to suggest that subjective fatigue accumulates over a 35-day period, even with time off (two nights) after every three days on shift (Åhsberg et al, 2000). In a study of train drivers, there was a tendency for fatigue to reduce over consecutive early starts (McGuffog et al, 2004).

These studies, in particular the sleep dose-response investigations (Belenky et al, 2003; Van Dongen et al, 2003) suggest that where sleep is restricted to seven hours or less, there are cumulative effects on cognitive performance over successive days. Other field-based investigations lend further support to indicate that the cumulative effect can be related directly to sleep loss.

A.4 BREAKS WITHIN A SHIFT

Whereas a number of papers have been published relating to breaks during a duty period (e.g. Dababneh et al, 2001; Rogers et al, 2004; Galinsky et al, 2000), few papers were identified as being able to contribute directly to the revision of the HSE Fatigue Index. The two studies outlined below provide the most useful information.

In a flight simulator, Neri et al (2002) investigated the effectiveness of five seven-minute breaks during the course of a six-hour night time flight which commenced at 02:00. During the cruise phase the breaks were scheduled at one-hourly intervals and pilots were able to leave the flight simulator and talk to researchers. The flights were described as ‘uneventful’ and involved the ‘heavy use of automation’. A control group was allowed one seven-minute break in the middle of the cruise. Analysis of eye movement data indicated that during the 15 minutes following breaks there was a reduction in slow eye movements (characteristic of sleepiness) Subjective ratings of sleepiness also indicated that those individuals taking regular breaks were less sleepy (for up to 25 minutes after the break) than those who only had one rest opportunity. The reported improvements following the break had disappeared 40 minutes later.

In a review of the impact of breaks on fatigue and performance (Tucker, 2003), the overall conclusion was that rest breaks can be effective in maintaining performance although direct epidemiological evidence indicating a reduced risk of accidents was lacking. Frequent short breaks were associated with benefits and when the timing of rest was at the discretion of the individual it resulted in better fatigue management. However, there are many situations where this may not be feasible. When trying to determine the optimum rest duration, the evidence was conflicting. Tucker (2003) pointed out that the benefits of a rest will be affected by the nature of the work.

More recently, in a field study of train drivers (McGuffog et al, 2004) the duration of breaks was found to be associated with a reduction in fatigue. However, the improvement was only associated with breaks of more than two hours.

Whilst breaks within a duty period are generally seen as beneficial, information is still lacking on their optimum timing and duration.

A.5 REST PERIOD BETWEEN TWO CONSECUTIVE DUTIES

In the previous review of the literature, the importance of sufficient recovery time between shifts was emphasised. The interval between two successive shifts should allow sufficient time to obtain adequate sleep before the start of the next duty period. Problems tend to be associated with obtaining sufficient sleep during the day i.e. following night time duties. The previous review suggested an interval of at least 16 hours between consecutive night shifts is required to obtain adequate sleep. No relevant new information on this topic has been identified in the current review.

A.6 RECOVERY AFTER A LONG SEQUENCE OF DUTIES

The previous literature review revealed little quantitative information on the requirement for rest days between consecutive shifts. Most data related to reports of worker satisfaction.

More recently, a study by Tucker and co-workers (1999) compared fatigue during 12-hour shifts with and without a two-day break between blocks of day and night shifts. Towards the end of the shift there was a tendency for the pattern without rest days to be more fatiguing, although the effects were minor in comparison with those of shift duration.

Åkerstedt and co workers (2000) reviewed the time required to recover from a sequence of consecutive shifts. Their analysis was limited to studies undertaken by the Karolinska Institute (KI) and their measure of recovery was the Karolinska Sleepiness scale (KSS). Whilst overall, the time taken to recover from shift working varied between one and four days, in the abstract it was stated that one day of recovery was 'never sufficient'. The baseline group comprised individuals working 08:00 to 17:00 five days a week with two days off. In this situation recovery was complete during the first day. Similarly, train drivers operating irregular work patterns were deemed to have recovered during the first day off. In this case the first day off was always preceded by a normal nights sleep. Other studies were also cited where recovery was complete during the first day off and in general they were preceded by a normal night's sleep.

In most of the KI studies three to four days of recovery were needed after working 12 hours a day for 12 consecutive days. However, in a study of oil rig workers, five days were insufficient to recover from 14 consecutive 12-hour nights. In this situation the workers are likely to have adapted to the night shift, and the return to diurnal patterns of sleep and wake are likely to have resulted in circadian disruption. The authors concluded that in general two days provide sufficient recovery, although, in situations where the circadian rhythm is severely disrupted, four days may be required.

One of the individual studies (Åhsberg et al, 2000) included in the previous paper (Åkerstedt et al, 2000) examined the recovery from a triad of shifts in paper mill workers. A 55-hour break (including two nights) followed each shift sequence (night, afternoon & morning shift) and this was repeated seven times. It was suggested that the two nights off between shifts sequences was sufficient to prevent fatigue accumulating. However, after a 35-day period following this pattern, there was some evidence of cumulative fatigue.

The study by Belenky et al (2003) discussed above (Section A3), also looked at the recovery process following seven days of sleep restriction. Three recovery nights were insufficient to allow performance to return to baseline levels. During the recovery nights, the time in bed was restricted to eight hours and this restriction may have accounted for the incomplete recovery.

Construction workers operating 15.5 hour shifts, and therefore only having 8.5 hours available for sleep, on average managed to obtain 5.5 hours sleep (Kecklund et al, 2001). The highest levels of fatigue were recorded during the first of the two days off. This increase in fatigue could be related to the sleep loss. Similarly, backward rotating schedules have been reported to require more time for recovery than forward rotating schedules (van Amelsvoort et al, 2004). This may be due to the short periods between successive shifts and the associated disruption to sleep. Forward rotating schedules were associated with better sleep quality and less work-family conflict.

When comparing a six and a seven-week schedule, involving an 84 hour working week, the main difference in terms of recovery was that workers on the seven-week schedule were sleepier during the first recovery day. Overall, recovery from the 84-hour working week was estimated to take around three days (Nordin et al, 2001).

In summary, there is some evidence to suggest that the duration of the period required to recover from a sequence of consecutive shifts is related to the extent of the disruption of sleep during the preceding period.

A.7 TIME OF DAY

The previous review (Rogers et al, 1999) highlighted that the lowest levels of performance tend to occur during the period 03:00 – 06:00 and that many fatigue-related accidents had occurred during the early morning. Since this review a number of studies have been completed that refer to time of day, and in particular to early starts.

In a study of train drivers (McGuffog et al, 2004), time of day was identified as the most important factor contributing to fatigue at the start of a shift, with the highest levels occurring in the early morning. The most tiring shifts were the night shift, closely followed by the early shift. Duty data collected during the study covered start times that encompassed most of the 24-hour day (duties commencing between 04:00 and 23:00). Drivers reported that fatigue reduced as the start time was delayed between 04:00 and 10:00. Associated with this delay was an increase in the amount of sleep obtained before the duty started. Overall, there was a reduction in total sleep time associated with early starts commencing between 04:00 and 04:30. During this period, sleep length was estimated to be 4.8 hours, whereas for duties starting in the late morning, sleep duration was over seven hours.

A number of studies of civil aircrew have been completed which have investigated the effect of time of day on sleep and alertness (Robertson & Spencer, 2003; Spencer & Robertson, 2000; Spencer & Robertson, 2002; Spencer et al, 2004). These diary-based studies have confirmed previous findings that sleep prior to an early shift is truncated (Spencer & Robertson, 2000; Spencer & Robertson, 2002) and that night duties are also associated with shorter sleep periods following the shift (Robertson & Spencer, 2003). Summarising the information from these studies, the early starts led to a reduction in total sleep time which was due to crews advancing their wake-up times but not their sleep onset times. The reduction in sleep time was almost an hour for duties starting between 07:00 and 08:00 and nearly two hours for duties commencing between 05:00 and 06:00. For duties starting before 09:00 there was also an associated increase in fatigue that persisted throughout the duty period.

Night duties were associated with shorter sleep episodes during the following rest period. This meant that, for duties ending between 13:00 and midnight, the average sleep time was 7.4 hours; for those ending between 00:00 and 02:00, the average sleep was 6.4 hours, and this reduced to 5.3 hours for those ending between 03:00 and 05:00 and to 4.4 hours for those ending between 06:00 and 08:00.

Reid and Dawson (2001) carried out a laboratory simulation of a 12-hour rotating shift pattern (2D/2N) and investigated the effect on two different age groups. A young group (mean age 21.2 years) and an older group (mean age 43.9 years) were asked to complete a tracking task at hourly intervals during each shift. The pattern of performance across each shift differed for the two groups. For the older individuals, performance changed across both the day and night shift, whereas the performance of the younger individuals remained fairly constant apart from some difference across the first night shift.

The change from an 8-hour backward rotating to a 10-hour forward rotating shift pattern was investigated at an underground mine (Hossain et al, 2004). The new shift pattern meant that there were only two shifts (day: 07:00 – 17:00 and night: 17:00 – 03:00) instead of the previous three, and the new night shift did not encompass the whole night (previously 23:00-07:00). Performance was subjectively reported to be worse on the 10-hour day compared to the 8-hour day at both one month and after a follow up one year later. Objective measures of performance were only completed by those individuals operating the 10-hour shift system. Among these individuals there was some evidence that performance was better during the 10-hour night shift (e.g. faster reaction times, fewer false responses) compared to the 10-hour day shift, but there was an increase in the number of missed responses on the night shift. There were also fewer subjective reports of near misses and accidents during the drive home after the 10-hour night shift. However, in this situation, individuals would be on the road at 03:00 instead of 07:00 following the 8-hour shift and the exposure to risk would be much reduced.

Early start times frequently cause sleepiness and fatigue, especially where shifts are monotonous and irregular. Four studies (Harma et al, 2002; Ingre et al, 2004; Matuzaki et al, 2003; McGuffog et al, 2004;) have investigated the impact of early morning shifts on sleep and sleepiness. In a study of train drivers, early morning shifts were associated with high levels of fatigue (McGuffog et al, 2004), resulting in more mistakes on the early morning shifts and these were more frequent the earlier the shift. The highest levels of fatigue at the end of the shift were reported for duties ending between 05:00 and 11:00. Factors influencing the duration of sleep prior to an early start were the start time itself and the sequence number of the early start. There was a linear increase in sleep duration as the start time moved from 04:00 to 07:30. There was also an increase in sleep duration during a sequence of up to four consecutive early starts

Harma et al (2002) looked at the impact of rotating shift patterns on the alertness of train drivers and railway traffic controllers. The shifts were described as being morning (starting before 07:00), day, evening or overnight. They investigated the occurrence of a score of greater than or equal to 7 on the KSS. A score of 7 or more has been equated with increased sleepiness and physiological signs of sleepiness, such as microsleeps. This score was more prevalent on the night shift (50%) than on the morning (15-20%) or the day/evening shifts (4-11%). The risk of severe sleepiness was 6-14 times higher in the night shift and about twice as high in the morning shift compared to the day shift.

From the study of train drivers outlined above, there was an impact of age on sleepiness (Harma et al, 2002). Increased age was associated with an additional 8% reduction of risk of severe sleepiness associated with early morning shifts for each year of age, whereas controllers showed no age dependency.

In a separate study of train drivers, sleep length was reduced by 1-2h by the early shift compared to the day and evening shifts (Ingre et al, 2004). The prevalence of severe sleepiness was high, especially during the early shift where 82% of subjects reported at least one event of sleepiness during the drive. The data indicated that there was increased risk for severe sleepiness during the early shift that increased further with the time of the drive between stops. The prevalence of severe sleepiness had an odds ratio of 4.9 compared with the day shift. However, in the study outlined above (Harma et al, 2002), the odds ratio for the early shifts was estimated to be 2.3. Both studies showed increased sleepiness associated with the early shift, but the severity of the increase was greater in the Ingre et al study (2004).

In summary, studies investigating time of day have clearly established the trend in alertness and sleep and have supplemented the information previously reported (Rogers et al, 1999). In particular, the average impact of time of day on sleep duration can now be reliably estimated.

A.8 TIME ON TASK

Few recent studies have looked at the impact of time on task on alertness. The three most relevant papers are outlined below (Gillberg et al, 2003; Haga et al, 2002; McGuffog et al, 2004).

In a simulation study, subjects undertook two shifts in the control room of a thermal power plant trainer (Gillberg et al, 2003). During both the 8-hour day and night shifts, three 20-minute breaks were incorporated. Whereas the performance-type measures were not particularly useful because of the day-night differences, the trend in sleepiness through the shifts showed a clear time-on-task effect and the benefit of a 20-minute break.

Using a dual tracking and memory task of varying difficulty, the impact of time-on-task was assessed during three 30-minute sessions (Haga et al, 2002). The results showed that mean reaction time, workload rating and fatigue rating, all increased as a function of time on task. However, the maximum duration of the task was only 30 minutes, so the information is of limited use for the development of the Fatigue Index.

The duration of continuous duty without a break was shown to contribute to fatigue (McGuffog et al, 2004). This effect was supported by information from an analysis of data from signals passed at danger (SPADs), suggesting that there may be a doubling of risk after six hours on duty. The effect on fatigue of the longest period of continuous driving was fairly constant during the first four hours on task, after which fatigue increased more rapidly (McGuffog et al, 2004).

In summary, long periods on duty without a break contribute to fatigue and sleepiness and to the risk of incidents. The inclusion of short breaks within a duty period has been shown to ameliorate these effects (see section A.4).

A.9 DURATION OF A DUTY PERIOD

The previous review (Rogers et al, 1999) summarised the implications of differences in shift length, with most studies comparing the difference between 8 and 12-hour shifts. The results were equivocal. Whereas the longer shifts are attractive to the workforce, as they maximise leisure time and minimise trips to and from work, there have been reports of greater fatigue and performance decrements. Other concerns associated with longer shifts are the effects on safety, particularly when overtime is added. The popularity of such systems with staff may influence the results and lead to seemingly conflicting findings. Shift changes are also complicated by alterations in the direction of shift change, and by different start and end times.

The effect of shift length on fatigue and well-being can be due to two factors; the direct effects of working longer (time on task effects) or the effect of working long hours on the time available for sleep. A number of papers have studied the influence of shift length on measures of fatigue or performance related to these two factors.

Sallinen et al (2003) studied the effect of the shift system, including shift length, on the associated sleep wake rhythm. Levels of fatigue showed that the risk of falling asleep during the shift was related to the shift duration. It increased by 17% for each hour of the morning shift and by 35% for each hour worked on the night shift.

In a study of very long shifts (Kecklund et al, 2001), there was a clear effect of 15.5-hour shifts on sleep, fatigue and health. This was an unusual group with on-site sleeping in vans and there were the obvious effects on sleep length of having less time available for sleep. The subjects were sleepier compared with individuals working 8-hour shifts and this sleepiness built up over the three days when double shifts were worked.

Hossain and co workers (2004) compared the effects of an 8-hour backward rotating shift system with a 10-hour forward rotating system. Any effects of changing the duration of the shift were complicated by the different direction of the rotation. This study emphasises the difficulty of measuring the effect of a change in shift systems on any one factor.

There was no effect on absenteeism and incident rates when miners moved from an 8-hour pattern to a 12-hour pattern (Baker et al, 2003). However, when uncapped and unregulated overtime was introduced at the weekends, absenteeism increased among maintenance workers. Unfortunately this study did not control for the risk associated with the different schedules and the lack of consultation in introducing such schedules also make the results difficult to interpret.

In summary, new data on the effect of shift length is limited and only three of the papers are likely to be useful in the context of the new index. However, information from these studies is reinforced by information from other studies (McGuffog et al, 2004; Robertson & Spencer, 2003; Spencer et al, 2004; Spencer & Robertson, 2000; Spencer & Robertson, 2002) where duty length has been correlated with fatigue. Shift length should also be considered alongside time on task and breaks, both of which contribute to the development of fatigue and can make a difference to the acceptability of long duty periods.

A.10 DIRECTION AND SPEED OF ROTATION

The benefits of forward-rotating over backward-rotating schedules were reviewed previously (Rogers et al, 1999). In particular, issues such as the avoidance of short 8-hour breaks between shifts, known as quick returns, were highlighted. These short breaks provide insufficient time for sleep between shifts. As far as speed of rotation was concerned, the review reflected the on-going debate in this area. Whereas performance is likely to be better on a permanent night pattern rather than a rotating system, practical issues make it difficult for workers to maintain their orientation to the night due, for example, to social and domestic issues. In addition, the sequence would need to contain sufficient time for adaptation to occur. Therefore, in most circumstances it was suggested that a rapidly rotating system was preferable.

In two papers by Cruz and co-workers that were published together (Cruz et al, 2003a; Cruz et al, 2003b), the differences between forward and backward rotating shifts in air traffic controllers were studied. They were unable to show differences in sleep or various measures of performance. However, both systems showed the problems of early morning shifts with the associated sleep deprivation and of working at night. The same group (Nesthus et al, 2001) also measured circadian temperature rhythms in the subjects described above. Differences between the two groups were reported, with backward rotating shifts showing reduced circadian amplitude and phase delay. The backward rotation was therefore associated with more circadian disruption.

In another study (Hakola & Harma, 2001), the effect of changing the direction of rotation was complicated by an accompanying change in the speed of rotation. The fast forward-rotating system improved sleep quality particularly in older workers. Alertness was improved during the morning shifts in both older and younger workers.

In a study of train operators (Groeger et al, 2004), operators working rotating shift patterns had more difficulty falling asleep than those individuals working fixed shifts. There were no consistent differences between the two groups of workers in performance at a reaction time task.

Finally, Pilcher et al (2000) carried out a meta-analysis of 36 studies of shift workers operating a number of patterns. Slowly rotating shifts had the least detrimental effects on sleep length.

In summary, there is little evidence that provides additional confirmation for the preference for a fast rapidly-rotating, suggested by the previous review.

A.11 WORKLOAD

The relationship between workload and performance has been described by an inverted ‘U’ which suggests that during periods of both high and low workload performance may be impaired. In addition, due to circadian influences the levels of workload that can be maintained during the day are unlikely to be sustained for the same periods overnight.

Since the previous review only one paper has been identified which specifically addressed workload. Macdonald and Bendack (2000) carried out a laboratory and field investigation of 8- and 12-hour shifts. From the field study, the alertness of individuals working 12-hour shifts decreased with higher workload levels and measures of performance were associated with an increasing number of errors.

A.12 VARIABILITY IN THE PATTERN OF WORK

Few new papers were found which addressed the issue of variability in the pattern of work, i.e. the impact of changing the timing of consecutive shifts.

A.13 REFERENCES

Åhsberg E, Kecklund G, Åkerstedt T, Gamberale F (2000). Shiftwork and different dimensions of fatigue. Int J Ind Ergonomics; 26:457-465.

Åkerstedt T, Kecklund G, Gillberg M, Lowden A, Axelsson J (2000). Sleepiness and days of recovery. Transportation Research Part F, 3:251-261.

Baker A, Heiler K, Ferguson SA (2003). The impact of roster changes on absenteeism and incident frequency in an Australian coal mine. Occup Environ Med 60:43-49.

Belenky G, Wesensten NJ, Thorne DR, Thomas ML, Sing HC, Redmond DP, Russo MB, Balkin TJ (2003). Patterns of performance degradation and restoration during sleep restriction and subsequent recovery: a sleep dose-response study. J Sleep Res 12:1-12.

Cruz C, Boquet A, Detwiler C, Nesthus T (2003b). Clockwise and counter-clockwise rotating shifts: effects on vigilance and performance. Aviat Space Environ Med 74:606-614.

Cruz C, Detwiler C, Nesthus T, Boquet A (2003a). Clockwise and counter-clockwise rotating shifts: effects on sleep duration, timing, and quality. Aviat Space Environ Med 74:597-605.

Dababneh AJ, Swanson N, Shell RL (2001). Impact of added rest breaks on the productivity and well being of workers. Ergonomics 44(2):164-174.

Drake CL, Roehrs TA, Burduvali E, Bonahoom A, Rosekind M, Roth T (2001). Effects of rapid versus slow accumulation of eight hours of sleep loss. Psychophysiol 38:979-987.

Galinsky TL, Swanson NG, Sauter SL, Hurrell JJ, Schleifer LM (2000). A field study of supplementary rest breaks for data-entry operators. Ergonomics 43(5):622-638.

Gillberg M, Kecklund G, Goransson B, Akerstedt T (2003). Operator performance and signs of sleepiness during day and night work in a simulated thermal power plant. Int J Industrial Ergonomics 31:101-109.

Groeger J, Banks A, Schiotz T (2004). Shift patterns and work-life balance. Surrey Sleep Research Centre Report.

Haga S, Shinoda H, Kokubun M (2002). Effects of task difficulty and time-on-task on mental workload. Japanese Psychol Res 44(3):134-43.

Hakola T, Harma M (2001). Evaluation of a fast forward rotating shift schedule in the steel industry with a special focus on ageing and sleep. J Human Ergol 30:315-319.

Harma M, Sallinen M, Ranta R, Mutanen P, Muller K (2002). The effect of an irregular shift system on sleepiness at work in train drivers and railway traffic controllers. J Sleep Res 11:141-151.

Hossain JL, Reinish LW, Heslegrave RJ, Hall GW, Kayumov L, Chung SA, Bhuija P, Jovanovic D, Huterer N, Volkov J, Shapiro CM (2004). Subjective and objective evaluation of sleep and performance in daytime versus nighttime sleep in extended-hours shift-workers at an underground mine. J Occup Environ Med 46:212-226.

Ingre M, Kecklund G, Åkerstedt T, Kecklund L (2004). Variation in sleepiness during early morning shifts: A mixed model approach to an experimental field study of train drivers. Chronobiol Int 21(6):973-990.

Kecklund G, Ekstedt M, Åkerstedt T, Dahlgren A, Samuelson B (2001). The effects of double-shifts (15.5 hours) on sleep, fatigue and health. J Human Ergol 30:53-58.

Lamond N, Dorrian J, Burgess HJ, Holmes AL, Roach GD, McCulloch K, Fletcher A, Dawson D (2004). Adaptation of performance during a week of simulated night work. Ergonomics 47(2):154-165.

Lamond N, Dorrian J, Roach GD, McCulloch K, Holmes AL, Burgess HJ, Fletcher A, Dawson F (2003). The impact of a week of simulated night work on sleep, circadian phase, and performance. Occup Environ Med 60(11): e13.

Macdonald W, Bendak S (2000). Effects of workload level and 8- versus 12-h workday duration on test battery performance. Int J Indust Ergon 26: 399-416.

Matuzaki LA, Pasqua IC, Moreno CR (2003). Sleep deprivation and shiftwork: The importance of the morning shift. Sleep 26: A192.

McGuffog A, Spencer M, Turner C, Stone B (2004). Working patterns of train drivers: implications for fatigue and safety. QinetiQ Document Identifier Number QINETIQ/KI/CHS/CR043098. RSSB Reference Number T059.

Neri DF, Oyung RL, Colletti LM, Mallis MM, Tam PY, Dinges DF (2002). Controlled breaks as a fatigue countermeasure on the flight deck. Aviat Space Environ Med 73:654-664.

Nesthus T, Cruz C, Boquet A, Detwiler C, Holcomb K, Della Rocco P (2001). Circadian temperature rhythms in clockwise and counter-clockwise rapidly rotating shift schedules. J Human Ergol 30:245-249.

Nordin M, Knutsson A (2001). Sleepiness and recovery in schedule change and the eighty-four hour workweek. J Human Ergol 30:143-47.

Persson R, Orbaek P, Ursin H, Kecklund G, Osterberg K, Åkerstedt T (2003). Effects of the implementation of an 84-hour workweek on neurobehavioral test performance and cortisol responsiveness during testing. Scand J Work Environ Health 29(4):261-269.

Pilcher JJ, Lambert BJ, Huffcutt AI (2000). Differential effects of permanent and rotating shifts on self-report sleep length: a meta-analytic review. Sleep 23(2):155-163.

Reid K, Dawson D (2001). Comparing performance on a simulated 12 hour shift rotation in young and older subjects. Occup Environ Med 58:58-62.

Robertson KA, Spencer MB (2003). Aircrew alertness on night operations: an interim report. QinetiQ Report Number QINETIQ/KI/CHS/CR021911/1.0.

Rogers AE, Hwang WT, Scott LD (2004). The effects of work breaks on staff nurse performance. JONA 34(11):512-19.

Rogers AS, Spencer MB, Stone BM (1999). Validation and development of a method for assessing the risks arising from mental fatigue. HSE Contract Research Report 254/1999.

Sallinen M, Harma M, Mutanen P, Ranta R, Virkkala J, Muller K (2003). Sleep-wake rhythm in an irregular shift system. J Sleep Res 12:103-12.

Spencer MB, Robertson KA (2000). A diary study of aircrew fatigue in short-haul multi-sector operations. DERA Report Number DERA/CHS/PPD/CR000394.

Spencer MB, Robertson KA (2002). Aircrew alertness during short-haul operations, including the impact of early starts. QinetiQ Report Number QINETIQ/CHS/PPD/CR010406/1.0.

Spencer MB, Robertson KA, Foster SP (2004). A fatigue study of consecutive nights and split-night duties during air cargo operations. QinetiQ Report Number QINETIQ/KI/CHS/CR040976/1.1.

Tucker P (2003). The impact of rest breaks upon accident risk, fatigue and performance: a review. Work and Stress 17(2):123-137.

Tucker P, Smith L, Macdonald I, Folkard S (1999). Distribution of rest days in 12 hour shift systems: impacts on health, wellbeing, and on shift alertness. Occup Environ Med 56:206-214.

van Amelsvoort LGPM, Jansen NWH, Swaen GMH, van den Brandt PA, Kant I (2004). Direction of shift rotation among three-shift workers in relation to psychological health and work-family conflict. Scand J Work Environ Health 30(2):149-156.

Van Dongen HPA, Maislin G, Mullington JM, Dinges DF (2003). The cumulative cost of additional wakefulness: Dose-response effects on neurobehavioral functions and sleep physiology from chronic sleep restriction and total sleep deprivation. Sleep 26(2):117-126.

Walsh JK, Randazzo AC, Stone KL, Schweitzer PK (2004). Modafinil improves alertness, vigilance and executive function during simulated night shifts. Sleep 27(3):434-439.

B REVIEW OF THE LITERATURE ON THE RISK OF INJURIES AND ACCIDENTS RELATING TO SHIFT WORK

B.1 INTRODUCTION

In most shiftworking situations safety is one of the primary concerns of both the employees and their employers. This is particularly true in situations such as transport or the nuclear power industry where there may be a high "public health" or "environmental" risk. Indeed, a number of authors have noted that many of the "headline hitting" disasters of the last few decades, including Three Mile island, Chernobyl, Bhopal, Exxon Valdez, and the Estonia ferry, have all occurred in the early hours of the morning. Accident investigations of these disasters have concluded that in each case they were, at least partially, attributable to human fatigue and/or error.

B.2 LITERATURE

This review was based on (a) the substantial collection of reprints and papers held by the author, and (b) literature searches conducted in December 2004 and January 2005 using standard databases and the Web. The review will concentrate on the those studies that allow the relative risk of accidents or injuries associated with specific features of shift systems to be calculated. The databases used were PsycINFO and SIGLE.

PsycINFO is a database produced by the American Psychological Society. It contains citations and summaries of journal articles, book chapters, books, and technical reports, as well as citations to dissertations, all in the field of psychology and psychological aspects of related disciplines, such as medicine, psychiatry, nursing, sociology, education, pharmacology, physiology, linguistics, anthropology, business, and law. Journal coverage, spanning 1887-present, includes international material selected from more than 1,300 periodicals written in over 25 languages. Current chapter and book coverage includes worldwide English-language material published from 1987-present. Over 55,000 references are added annually through regular updates.

SIGLE (System for Information on Grey Literature in Europe) accesses reports and other "grey" literature produced in Europe. Grey literature is best defined as literature which cannot readily be acquired through normal bookselling channels and which is therefore difficult to identify and obtain. Examples of grey literature include technical or research reports, doctoral dissertations, some conference papers and pre-prints, some official publications, discussion and policy papers. SIGLE covers pure and applied science and technology, economics, other social sciences and humanities. It combines the resources of major European information and document supply centres who have joined together in an association known as EAGLE (European Association for Grey Literature Exploitation). Each centre is responsible for collecting grey literature produced in its own country and for providing details of it.

Literature searches were conducted on these two databases using the terms: "work hours", "shift work", "shiftwork", "time of day" or "work schedule" combined with "accident", "injury", "safety" or "risk". These searches resulted in a total of 274 hits, 263 from PsycINFO and 11 from SIGLE. An initial examination of the titles of the articles in this list of 274 references indicated that a large number of them were of little or no relevance. For example, the "hits" included articles with the titles: "Alcohol use and sexual risk taking among hazardously drinking drug injectors who attend needle exchange", "Psychological Traits and Emotion-Triggering of ICD Shock-Terminated Arrhythmias", and "Body mass, ambient temperature, time of day, and vigilance in Tufted Titmice"!

Table B-1 The main weaknesses or findings of the 18 articles

No.	***Main Weakness or Findings***	***Relevant***
1	Based on perceived risk/safety. No attempt to measure objective risk.	No
45	Time of day analysis took no account of exposure, .i.e. traffic density.	No
60	Accidents and lost-time injuries were associated with length of time at work in forestry workers, but insufficient details given for inclusion.	No
79	Not really relevant. Job stress predicted accident rates.	No
80	Concerned with how accident investigators report sleep in their reports.	No
86	Supplementary 5m breaks per hour reduced discomfort and eye strain.	No
88	Examined accident and absence rates following change from 8h to 12h system, numbers of individuals involved were 15 (before change) and 12 (after change)!	No
109	Primarily concerned with safety climate. No injury/accident rates given.	No
151	Insurance claims for night-time vehicle crashes higher than daytime ones.	No
163	Changing to a 12h shift system improved health, no injury or accident data.	No
174	Nurses on a rotating schedule that included nights reported twice as many accidents and errors as those on a schedule that did not include nights. The reported results do not allow an estimation of any trend.	No
190	Shiftworkers, and especially females, had higher injury rates than non shiftworkers.	No
241	Slower (7d) rotation associated with different pattern of “events” to faster (2d) rotation	?
257	Minima in landing accidents occurred 1-2 hours after breaks, suggesting breaks reduce risk.	No
262	Historic (1928) document of unknown relevance, but difficult to trace.	No
263	Another historic (1928) document of unknown relevance, but difficult to trace.	No
268	Overanalyses 30 accidents, insufficient for any real conclusions to be drawn	No
270	Old German (1969) study of unknown relevance, but difficult to trace.	No

From the 274 articles listed, only 18 were deemed to be worth pursuing. The remainder were either already known to the author (see below) or appeared to be irrelevant. The list of 18 numbered publications is in section B.17. These 18 publications were examined in greater detail. A summary of their main findings or weaknesses is shown in Table B-1. It can be seen from this table that, with a single possible exception, none of the new papers found were deemed to be relevant. While this result could be viewed as disappointing, it could also be viewed as reflecting on the fact that the author already knew about the relevant papers.

Google searches of the entire Web were also performed using similar terms to those used above. These yielded a total of over 1450 hits, but most of those that appeared to be relevant and were examined were general “review” or “advice” documents, often supplied by commercial consultancies or by governmental organisations. The major exceptions were a number of articles of which the author was aware, and an excellent paper by Fortson (2004) describing a 24-hour trend in work-related injuries (see below).

B.3 PROBLEMS WITH THE *A PRIORI* RISK OF ACCIDENTS AND INJURIES

There are few published studies that allow for an unbiased calculation of relative risk estimates of accidents and/or injuries associated with specific features of shift systems due to non-homogeneous *a priori* risk. This means that in many organisations the number of individuals at work is not constant over the 24-hour day while the level of supervision, etc., may also vary substantially. Further, in most shiftworking situations the nature of the job and associated tasks being performed may vary considerably across the 24-hour day. For example, longer, and hence safer, production runs are kept for the night shift. This practice may be official policy within a company, or may simply be condoned or ignored by management. Either way, it means that it is not valid to compare accident rates across work shifts since fewer accidents would be expected on the night shift (or the one with fewer employees at risk).

One example of this type of bias, and that in drawing valid conclusions is the study by Adams et al (1981). In that study, they report the absolute numbers of accidents on the day, afternoon and night shift but then comment that "precise information about the numbers employed on afternoon and night shift is simply not available" (p77). However, the authors continue by pointing out that "the personnel department suggests that a fairly good guide to numbers employed on the various shifts would be the ratio evening (night):1; afternoon:2; day:4". These ratios are then used to estimate that injuries on the night shift were about 30% less than expected. This clearly begs two major questions. Firstly the ratio 1:2:4 is insufficient to accurately form the basis for such a calculation. Secondly, it clearly implies that the factory concerned had far fewer people around at night. This may not only reduce the frequency of injuries, but also suggests that the whole work environment may have been totally different at night.

A further problem stems from the fact that many of the studies reporting accident or injury rates on the different shifts refer to what appear to be increasingly uncommon permanent shift systems, at least in Europe. This means that any comparison across shifts not only confounds potential differences in the numbers working on each shift, but also potential differences in worker-related factors for those shifts. For example, in the USA many permanent shift systems operate on a "seniority" basis whereby newly hired employees to a company typically join the night shift (or the least desirable shift) and eventually progress to the afternoon shift or the morning shift, when they have been with the company for a number of years. Thus both the average age and the level of experience of the workers may likely be different among the three shifts. These factors may account for the fact that a number of authors have reported either fewer injuries on the night shift than on the morning or day shift, or similar rates across the three shifts (e.g. Andlauer, 1960; Adams et al, 1981; Baker et al, 2003; Olowokure et al, 2004; and Ong et al, 1987).

B.4 PROBLEMS WITH THE PROBABILITY OF REPORTING ACCIDENTS AND INJURIES

Even in the few studies of industrial situations where the *a priori* risk of incidents[2] appears to be constant across the 24-hour day, the problem remains that the probability of actually reporting an injury or accident may vary by shift. For example, in a recent unpublished 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 were being reported on the day shift. Further investigation revealed that when members of the predominantly male workforce were injured during the day they were treated by a female nurse at the on-site occupational health clinic. However, this clinic was closed at night and first-aid was provided by the male security guards at the entrance gatehouse to the works. It seems highly probable that this dissuaded many members of the workforce from reporting or seeking treatment for less serious injuries on the night shift. Indeed, the nursing sister at the

[2] *For simplicity, the term' incidents' is used from hereon to refer to injuries and/or accidents .It should be noted that while the majority of studies have reported injury rates, where the information is available the trends in accidents are indistinguishable from those in injuries.*

occupational health clinic also commented that the number of injuries reported during the day varied substantially depending on which nurse was on duty!

In this context, there are published studies that have reported fewer injuries occurring at night, however these studies have suggested that night injuries tended to be more serious than those occurring during the day (e.g. Andlauer, 1960; Oginski et al, 2000). Why more serious accidents occur on the night shift relative to the day is difficult to understand. A reasonable explanation may be that night shift workers are less inclined to report injuries of minor severity, thus resulting in their reported injuries at night being, on average, more serious. Some evidence in support of this interpretation can be gleaned from the results of Oginski et al (2000). On average, the number of days off work was higher following an injury reported on the night shift than following one reported on the morning shift. These results were not stratified by body part of nature of injury, however, it seems probable that this difference reflected largely on the fact that the number of minor injuries reported that resulted in zero days off work was more than twice as high on the morning shift than it was on the night shift.

B.5 TRENDS ASSOCIATED WITH FEATURES OF SHIFT SYSTEMS

There appears to be six reasonably consistent trends in incidents associated with features of shift systems when the *a priori* risk and probability of reporting an injury are taken into account. Two forms of analyses were used to examine most of the trends considered in this review. First, a repeated-measures analysis of variance based on the relative risk values was calculated for all the data sets. 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 (Folkard 1997). The main disadvantage with this first form of analysis is that 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, on the data sets where the frequency values did not have to be corrected for exposure. This second form of analysis essentially weights the studies according to the number of incidents reported, but suffers from the disadvantages (i) of using chi-squares with large data sets and (ii) 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 review both forms of analyses were used in an attempt to overcome the shortcomings associated with each form by itself. Thus, if the results of both analyses resulted in similar conclusions, the conclusions are likely independent of the assumptions underlying each analysis.

B.6 THE TREND ACROSS THE THREE SHIFTS

The first trend relates to the relative risk of incidents on the morning, afternoon and night shifts on 8-hour shift systems. There are five studies (see Table B-2) that are based on relatively large numbers of incidents that appear to have overcome these potential confounders and incident rates are reported separately for the morning (M), afternoon (A) and night (N) 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. They also likely differed in terms of the criteria used in determining whether an incident was recorded. Direct comparisons between studies are therefore biased, but valid comparisons can be made within each study.

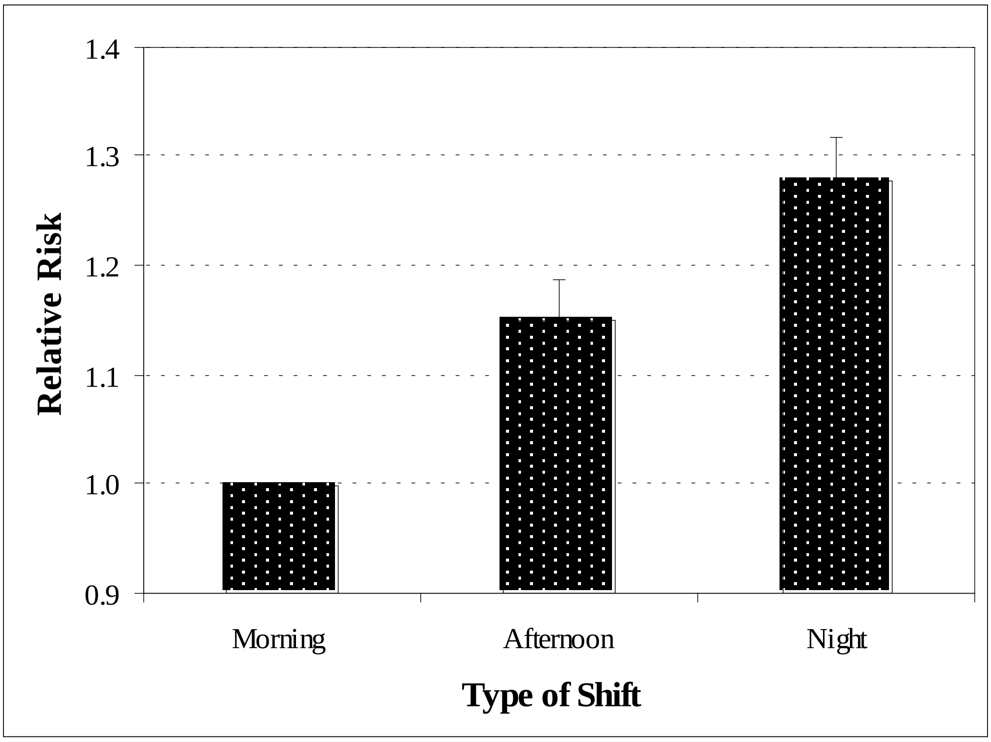
Table B-2 Summary of the studies across three shifts

Author(s)	*Industry*	*Location*	*Measure*	*Total Number (over 3 shifts)*	*Relative Risk Values*		
					M	***A***	***N***
Wanat (1962)	Coal Mining	Underground	Injuries	3699	1.00	1.23	1.36
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

It should be noted that while in some of these studies there were equal numbers of shiftworkers on each shift (Quaas & Tunsch, 1972; Smith, Folkard & Poole, 1994), the authors had to correct the data in the others to take account of inequalities in the number of workers (Levin et al, 1985; Wanat, 1962; Wharf, 1995). In addition, two of the studies report two separate sets of data, for different areas or types of incident, giving a total of seven 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 four days on each shift before a span of rest days (e.g. Quaas & Tunsch, 1972; Smith et al, 1994).

With respect to the trend across the three shifts (Table B-2), the repeated-measures analysis of variance of the relative risk values for each dataset yielded a highly significant main effect of shift [$F(2,12)=42.191$, $p<0.001$]. The chi-square test based on the summed frequencies across the seven data sets for the three shifts also yielded a highly significant effect of shift [$\chi^2=124.08$, df=2, $p<0.001$]. Based on these pooled frequencies, risk increased in an approximately linear fashion, with an increased risk of 15.2% on the afternoon shift, and of 27.9% on the night shift, relative to that on the morning shift (Figure B-1).

Figure B-1 The Relative Risk across three shifts (Error bars are 95% Confidence Intervals (CIs))



In a related recent paper Horwitz & McCall (2004) analysed the 7717 injuries occurring to hospital employees in Oregon from 1990 to 1997, and corrected for exposure using data from the US's Current Population Survey. They report that injury rates (per 10,000 employees) were lowest on the day shift (176) than on either the evening shift (324) or night shift (279). These values translate into relative risk estimates of Day (Morning) = 1.00, Evening (Afternoon) = 1.81 and Night 1.59. These values are not only substantially larger than those shown in Figure B-1, but also suggest that the risk may be higher on the afternoon shift than on the night shift. However, the authors also point out that the average number of days off following an injury on the night shift was higher (46) than that for the day (38) or evening (39) shifts, which may have reflected on a reporting bias (see above). Finally, they also point to the fact that the injury rates they report may reflect on differences in staffing levels, or on the type of jobs undertaken, across the different shifts. Thus it seems unlikely that the *a priori* risk of injuries was constant across the three shifts.

B.7 THE TREND 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 (e.g. Folkard et al, 1995; Tucker et al, 1999). 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. Vernon (1923) reported one of the earlier studies in this area. He examined trends over 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. 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 simply in terms of fatigue.

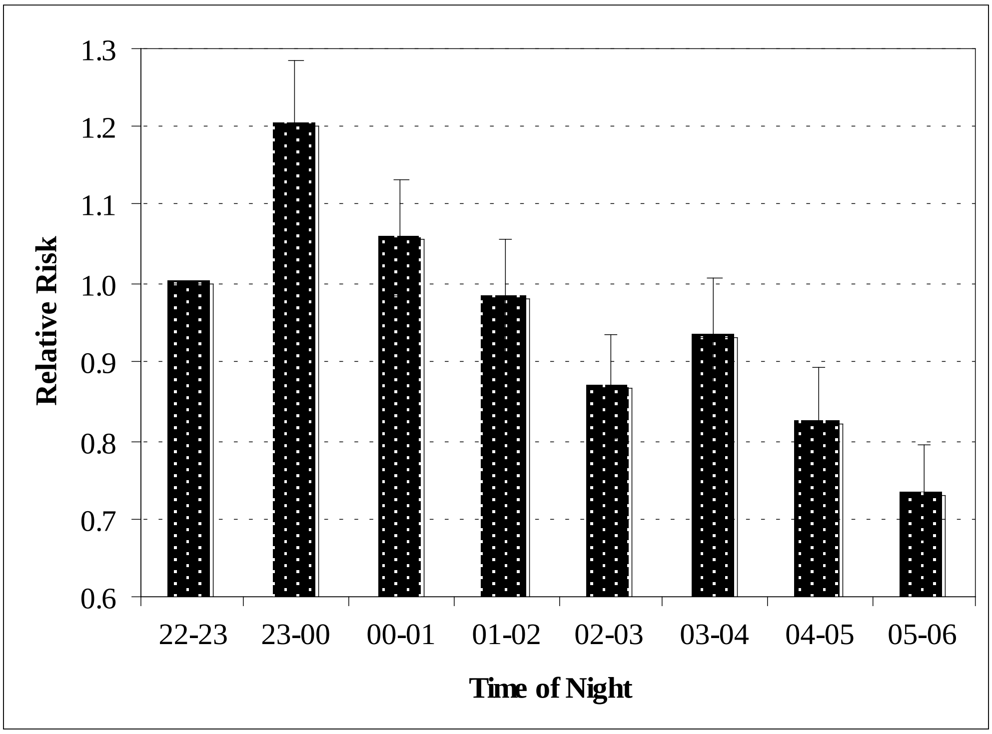
Table B-3 Summary of the studies across the course of the night shift

Author(s)	***Industry***	***Measure***	***Total No. (over 8 hours)***	***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
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

More recent studies have also provided hourly incident rates over the course of the night shift and these, together with that of Vernon (1923), are summarised in Table B-3. 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 nine data sets yielded a significant main effect of hour on shift [$F(7,56)=2.815$, $p=0.014$], indicating some consistency across the data sets. A chi-square test was then based on the summed frequencies across the nine data sets for each hour of the shift and this yielded a highly significant effect of hour on shift ($\chi2=120.516$, df=7, $p<0.001$).

Using these summed values, risk rose by about 20% from the first to second hour, but then fell by a total of about 50%, and in an approximately linear fashion, to reach a minimum at the end of the shift, and this is shown in Figure B-2. 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 to the substantial decrease in risk over most of the night. This trend in risk over the night shift is clearly inconsistent with predictions from fatigue or performance measures which would suggest that the maximum risk should occur in the early hours of the morning.

Figure B-2 The Relative Risk across the course of the night shift (Error bars are 95% CIs)



B.8 THE TREND ACROSS THE 24-HOUR DAY

The third reasonably consistent trend is the trend in occupational injuries over the 24-hour day once exposure has been corrected for. The first study of this type would appear to be that of Åkerstedt (1995) who corrected the Swedish national occupational injury data for exposure on the basis of a time budget study of a representative sample of 1200 members of the population under consideration. More recently there have been similar American studies by Fathallah & Brogmus (1999), Fortson (2004), and Lombardi & Folkard (in prep) that have corrected for exposure using data from the US's Bureau of Labor Statistics. Between them, these four studies report hourly data across the 24-hour day in six different measures[3] (see Table B-4 and Table B-5).

Table B-4 Summary of the studies across the 24-hour day

Author(s)	*Data Source*	*Measure*	*Total Number*
Akerstedt (1995)	Sweden (1990/1)	Lost time Injuries (1+ days)	≈ 160,000
Fathallah & Brogmus (1999)	US Worker compensation claims	All claims	600,000+
		Low Back Disorder claims	≈ 72,000
Fortson (2004)	US Worker compensation claims	Lacerations & fractures	42,902
		Falls	29,074
Lombardi & Folkard (In prep)	US Worker compensation claims	Hand injuries	68,544

[3] *It should be noted that Fathallah & Brogmus (1999) also reported the 24-hour trend for cumulative trauma disorders (CTD), but these data have been omitted in view of their chronic nature.*

Figure B-3 The Relative Risk across the course of the 24-hour day (double-plotted)

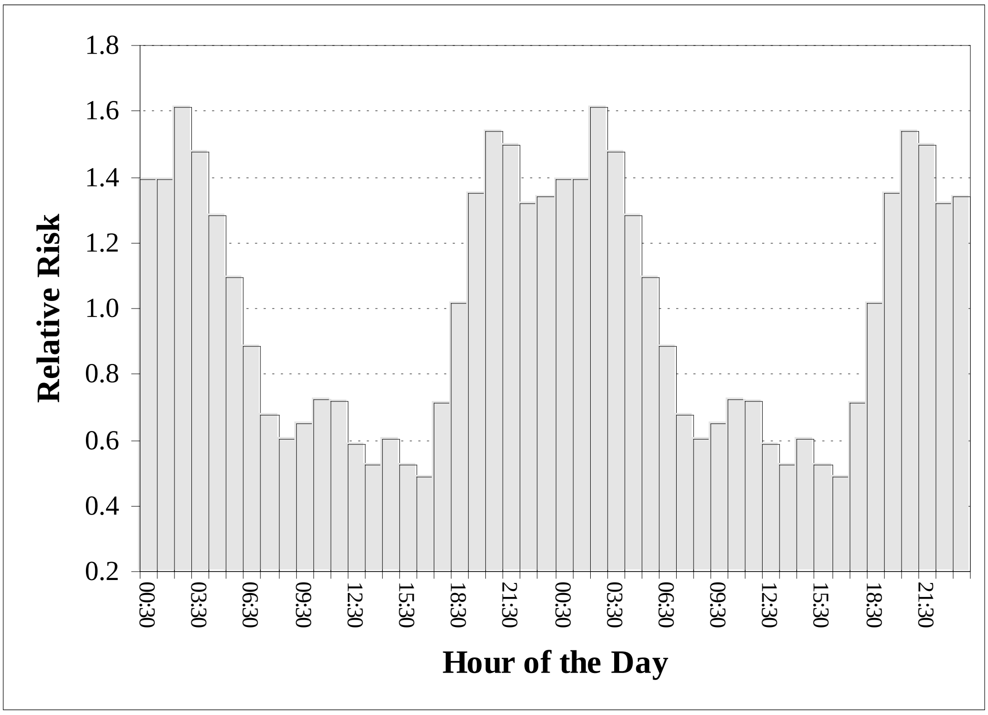


Table B-5 The relative risk values across the 24-hour day

	Akerstedt (1995)	*Fattallah & Brogmus (1999)*		*Fortson (2004)*		*Lombardi & Folkard*
Hour	*All*	*All*	*LBD*	*Lacs & Fracs.*	*Falls*	*Hand*
24:01 to 1:00	1.24	1.44	1.45	1.29	1.25	1.70
1:01 to 2:00	1.48	1.11	1.01	1.76	1.70	1.30
2:01 to 3:00	1.38	2.06	2.03	1.56	1.56	1.10
3:01 to 4:00	1.34	1.94	1.87	1.47	1.33	0.92
4:01 to 5:00	1.13	1.40	1.45	1.27	1.32	1.12
5:01 to 6:00	0.60	1.24	1.46	1.00	0.94	1.34
6:01 to 7:00	0.30	0.90	1.14	0.90	0.93	1.14
7:01 to 8:00	0.60	0.48	0.61	0.76	0.70	0.90
8:01 to 9:00	0.79	0.43	0.48	0.64	0.64	0.62
9:01 to 10:00	0.67	0.58	0.64	0.68	0.67	0.65
10:01 to 11:00	0.84	0.58	0.68	0.80	0.80	0.63
11:01 to 12:00	0.94	0.64	0.69	0.68	0.69	0.68
12:01 to 13:00	0.60	0.59	0.57	0.59	0.60	0.58
13:01 to 14:00	0.71	0.44	0.40	0.53	0.53	0.54
14:01 to 15:00	0.96	0.50	0.43	0.61	0.62	0.50
15:01 to 16:00	0.73	0.48	0.41	0.57	0.53	0.42
16:01 to 17:00	0.63	0.45	0.38	0.56	0.50	0.41
17:01 to 18:00	0.82	0.48	0.43	0.90	0.83	0.79
18:01 to 19:00	1.22	0.78	0.72	1.10	1.00	1.28
19:01 to 20:00	1.47	1.30	1.27	1.11	1.28	1.67
20:01 to 21:00	1.47	1.73	1.71	1.26	1.35	1.70
21:01 to 22:00	1.20	1.81	1.83	1.27	1.43	1.45
22:01 to 23:00	1.28	1.57	1.41	1.21	1.29	1.17
23:01 to 24:00	1.61	1.08	0.93	1.48	1.51	1.41

In order to compare across these six data sets the frequency of incidents for each hour of the day was expressed relative to the 24-hour mean. A repeated-measures analysis of variance based on these relative risk values (see Table B-5) for the six data sets yielded a highly significant main effect of hour of the day [F(23,115)=19.629, p<0.001], indicating considerable consistency across the data sets. Note that in this case it was not possible to base a chi-square test on the summed frequencies since each of the trends had to correct for exposure and thus combining raw frequency scores would be biased.

The average trend across the six data sets is double-plotted in Figure B-3 to emphasise its rhythmic nature. Clearly the mean relative risk values varied substantially over the 24-hour day, being highest at night and lowest during the day. However, as Fortson (2004) recognises, this 24-hour pattern reflects not only on variations in the likelihood of individuals making the sort of mistakes that result in injuries, but also on the nature of the jobs that are performed at different times of day. Thus dangerous jobs, such as industrial production, are far more likely to be worked at night than safer jobs such as clerical work. This might help to explain why the trend between 22:00 and 06:00 is rather different in this figure to that shown in Figure B-2.

B.9 THE TREND ACROSS SUCCESSIVE NIGHT SHIFTS

The fourth consistent trend in incidents is that over successive night shifts. The author is aware of a total of seven published studies[4] that have reported accident or injury (i.e., incidents) frequencies separately for each night over a span of at least four successive night shifts, namely those of Quaas & Tunsch 1972, Vinogradova et al. 1975, Wagner 1988, Smith et al. 1994, Smith et al. 1997, Oginski et al. 2000, and Tucker et al. 2001. In most of the studies these shifts were eight hours long. 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 repeated-measures analysis of variance based on these relative risk values (see Table B-6) for the seven data sets yielded a highly significant main effect of successive shifts [F(3,18)=8.211, p<0.001], indicating a moderately strong effect of shift span across the data sets.

Table B-6 Summary of the studies across successive night shifts

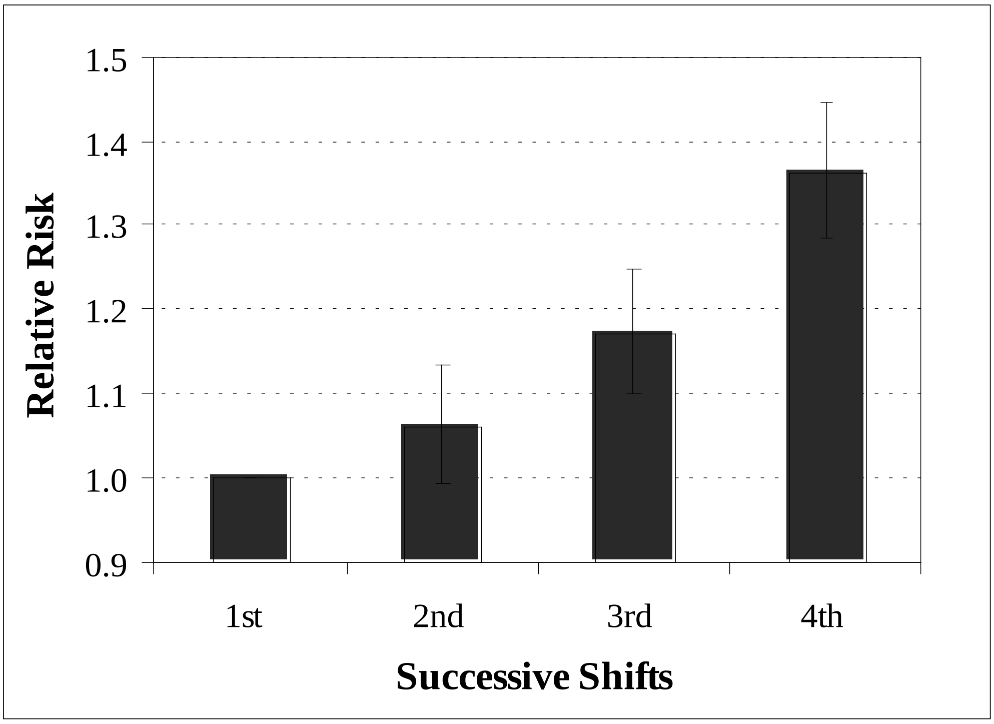
Author(s)	*Industry*	*Measure*	*Total Number (over 1st 4 nights)*	*Relative Risk Values (by successive nights)*			
				1st	*2nd*	*3rd*	*4th*
Quaas & Tunsch (1972)	Metallurgic Plant	Accidents	261	1.00	1.38	1.79	1.71
Vinogradova et al. (1975)	Dockers	Accidents	272	1.00	1.24	1.11	1.60
Wagner (1988)	Iron 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

[4] *Note that the study reported by Monk & Wagner, 1989, was not included since the data reported in that paper were a subset of those reported by Wagner, 1988.*

A chi-square 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 Figure B-4. On average, risk was about 6% higher on the second night, 17% higher on the third night, and 36% higher on the fourth night.

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? There is a paucity of data relating to this and only two of these studies reported incidence rates for a span of more than four night shifts. Both of these studies were based on relatively small numbers of incidents, nevertheless, it is noteworthy that each study (Vinogradova et al, 1975; Wagner, 1988) reported a decrease in risk from the fourth to the fifth night shift which was maintained until the seventh, and final, night shift in Wagner's, 1988 study.

Figure B-4 The Relative Risk over four successive night shifts (Error bars are 95% CIs)



Two studies (Quaas & Tunsch, 1972; Tucker et al, 2001) also 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 studies with the largest sample size (Smith et al, 1994; Smith et al, 1997) showed a progressive increase in risk over all four successive night shifts, potentially reflecting their precision. Thus while it remains a possibility that over longer spans of night shifts risk may actually start to decrease after the fourth night, there is no current evidence to indicate that this is actually the case.

B.10 THE TREND ACROSS SUCCESSIVE DAY SHIFTS

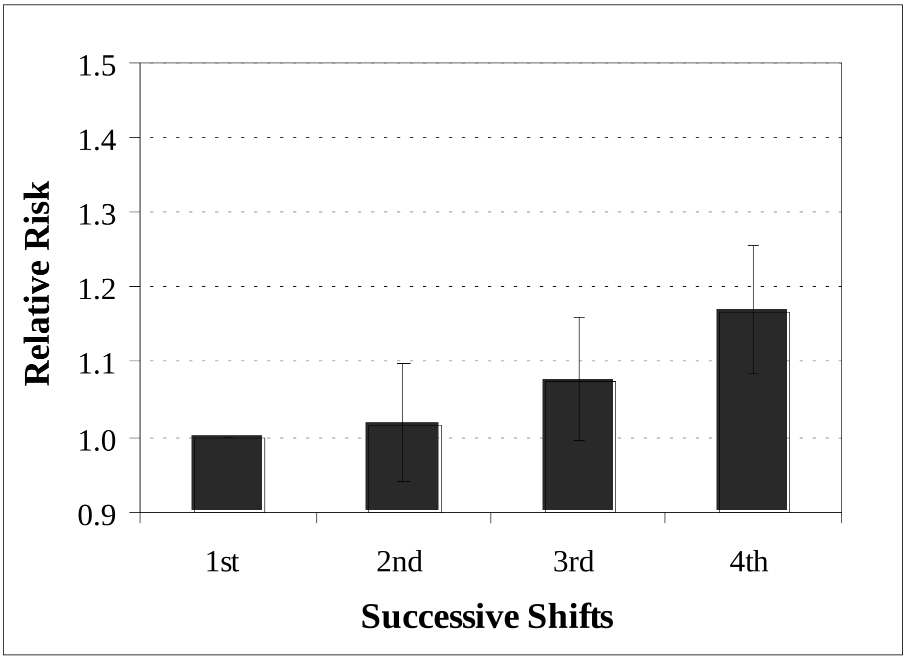
The second important question is whether the increase in risk over successive shifts is confined to the night shift, or whether it might be general to all shifts and represent an accumulation of fatigue over successive workdays. Of the seven studies listed above, five reported the risk over successive morning or day shifts, namely those of Quaas & Tunsch 1972, Smith et al. 1994, Smith et al. 1997, Oginski et al 2000, and Tucker et al. 2001. In most of these studies these shifts were eight hours long.

Table B-7 Summary of the studies across successive day shifts

Author(s)	*Industry*	*Measure*	*Total Number (over 1st 4 days)*	*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

Similar to the previous analyses, 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 of the relative risk values for the five data sets indicated that there was no evidence of a main effect of successive shifts [$F(3,12)=0.789$, $p=0.523$] However, this may reflect the relatively small number of incidents in some of these studies (Table B-7).

Figure B-5 The Relative Risk over four successive morning/day shifts (Error bars are 95% CIs)



A chi-square test based on the summed frequencies across the five studies for the four successive shifts yielded a significant effect of successive shifts ($\chi2=10.092$, df=3, $p=0.018$). These summed values were used to estimate the risk on the successive morning/day shifts relative to the first such shift and the results are shown in Figure B-3. Note that the same scale has been used for this figure as that used in Figure B-2 for direct comparisons. 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.

Clearly there was some evidence, albeit relatively inconsistent compared to the other trends reported in this review, that risk increased over successive morning/day shifts. However, it is important to note that this increase was substantially smaller than that over successive night shifts (compare Figure B-4 and Figure B-5). Thus, there is 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.

B.11 THE TREND ACROSS HOURS ON DUTY AND THE LENGTH OF SHIFTS

The fourth trend considers the impact of different lengths of shift on risk. Studies that have examined this trend have faced the same sort of problems as those previously discussed. However, studies that have interpolated performance measures have typically found a deterioration in performance and alertness on 12-hour shifts compared to that on 8-hour ones (e.g. Rosa 1991). In contrast, Laundry and Lees (1991) found a slight reduction in the occurrence of industrial accidents in a company that changed from an 8-hour system to a 12-hour one, but the authors did not provide any details of the shift systems involved, such as the number of successive work-days. Nevertheless, they report a significant reduction in minor, but not more serious, injuries on the 12-hour system. The question arises as to whether this might reflect a differential reporting bias across shifts.

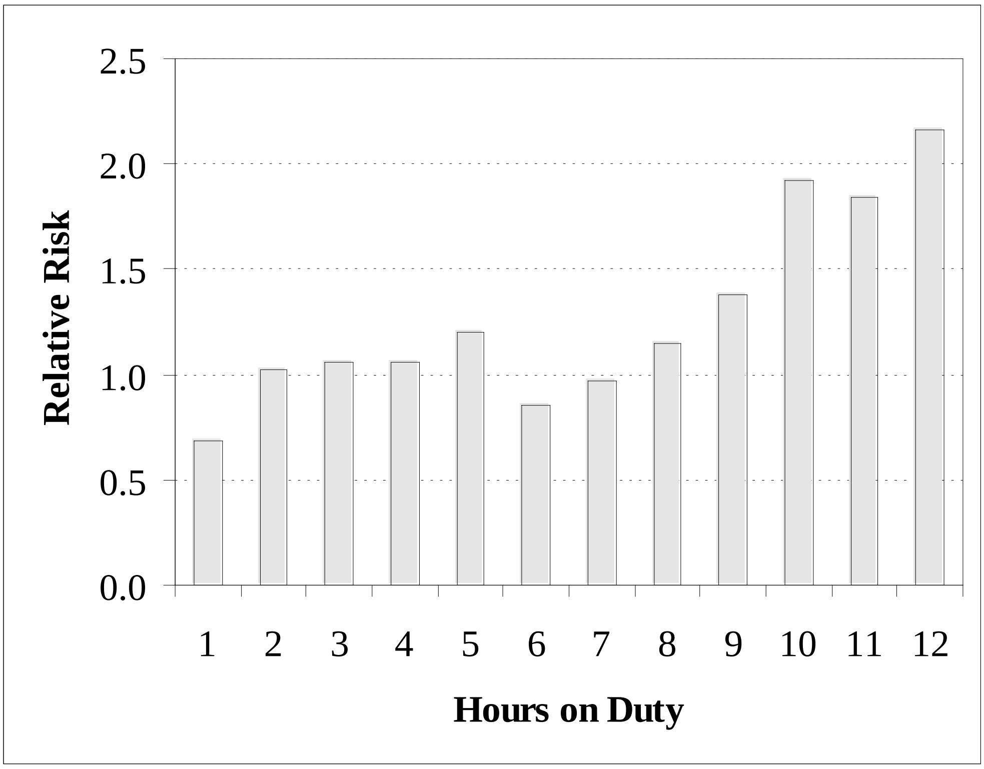
Table B-8 Summary of the studies across hours on duty

Author(s)	***Data***	***Measure***	***Total Number***
Akerstedt (1995)	Sweden (1990/1)	Lost time Injuries (1+ days)	160,000
Folkard (1997)	Various Transport Operations	Accidents or SPADs	N/A
Haenecke et al (1998)	Germany (1994)	Lost time Injuries (>3 days)	1,200,000+
Nachreiner et al (2000)	Germany (1994-7)	Fatal Injuries	2,000+

Four studies have reported the trend in risk over successive hours on duty and have managed to correct for exposure in some manner (Table B-8). These studies were reviewed in detail by Nachreiner (2000), and are those of Akerstedt (1995), Folkard (1997), Haenecke et al (1998) and Nachreiner et al (2000). The study of Folkard (1997) statistically combined several relatively small studies and made various assumptions in deriving an overall trend. However, the remaining three studies were based on substantial numbers of injuries/accidents and report fairly similar trends to that derived by Folkard (1997). These three studies examined trends in national accident statistics and corrected for “exposure” in some way.

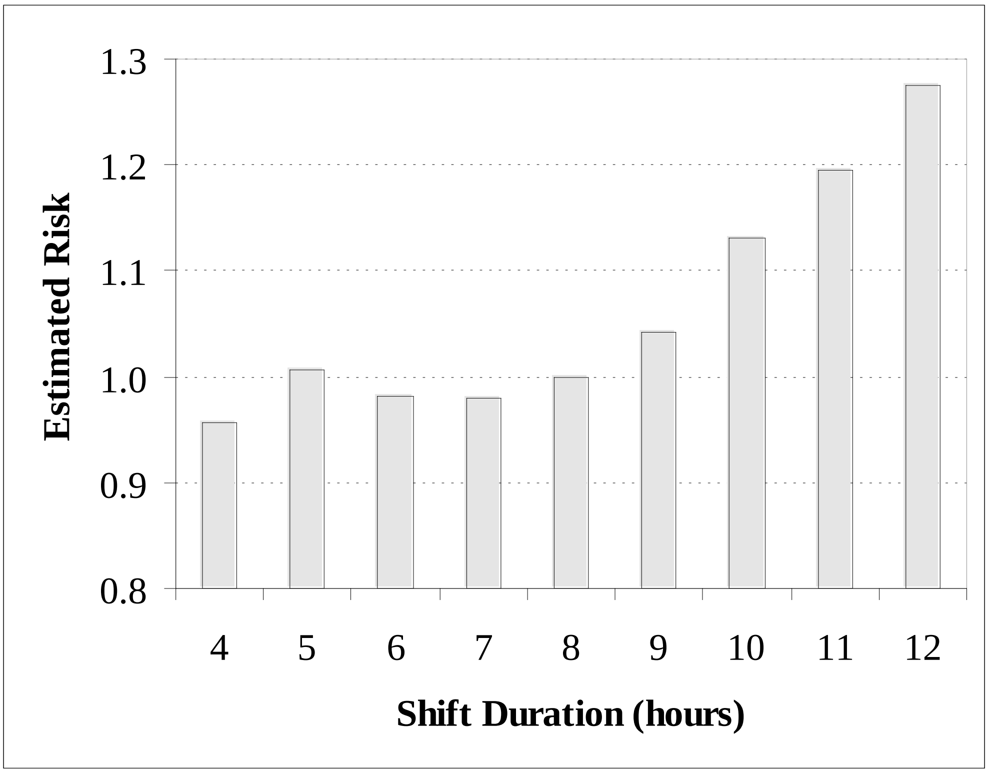
By setting the mean risk in each study for the first eight hours at one, hourly relative risk value were calculated for each study. A repeated-measures analysis of variance based on the relative risk values for the four data sets yielded a highly significant main effect of time on shift [$F(11,33)=14.324$, $p<0.001$], indicating considerable consistency across the data sets. Note that in this case it was not possible to base a chi-square test on the summed frequencies since each of the published trends had to correct for exposure in some way and thus combining raw frequency scores would be biased. The average trend across the four studies is shown in Figure B-6. It is clear from this figure that, apart from a slightly heightened risk from the second to fifth hour, risk increased in an approximately exponential fashion with time on shift. The increased risk during the second to fifth hour is considered in more detail by Folkard (1997) and Tucker et al (2000).

Figure B-6 The mean relative risk over hours on duty



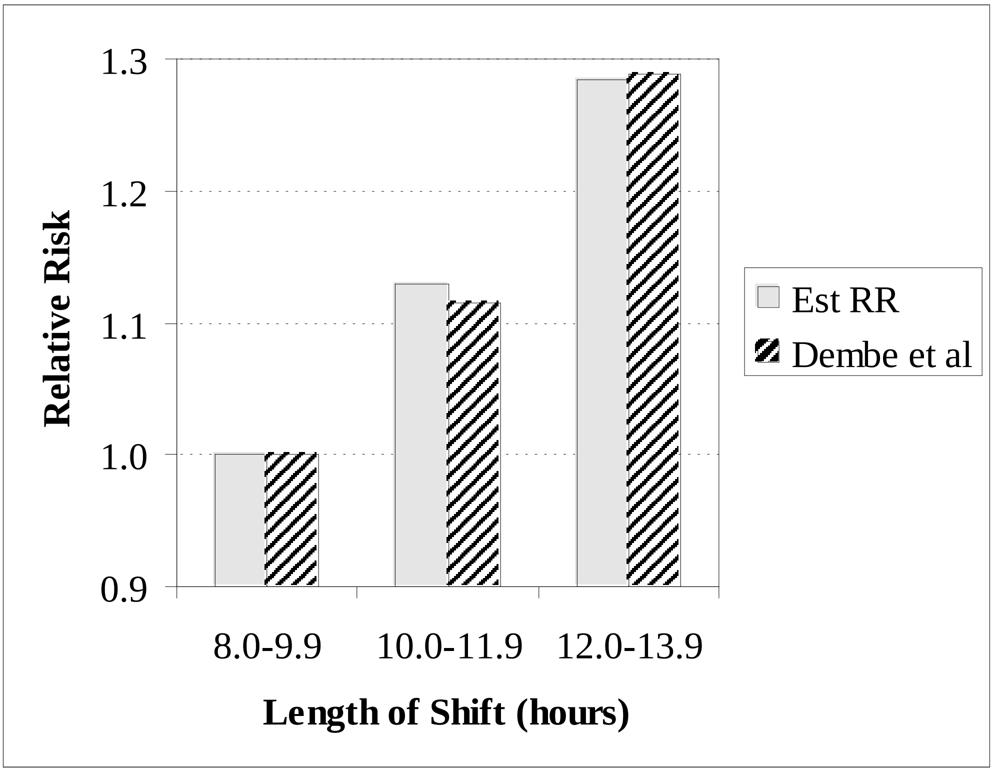
It is possible to estimate the relative risk of shifts of different lengths by calculating the average risk associated with each given length of shift, and the result is shown in Figure B-7. Note that the risk of an eight-hour shift has been set at one based on the procedure described above. From Figure B-7 it is clear that variations in shift length from about 4 to 9 hours will have relatively little impact on overall safety because of (i) the exponential nature of the time on shift trend and (ii) the increased risk from the second to fifth hours. However, the most important point from the present perspective is that we can now estimate the change in risk associated with shorter or longer shifts. Thus, for example, we can estimate that relative to eight hour shifts, ten hour shifts are associated with a 13.0% increased risk and twelve hour shifts with a 27.5% increased risk.

Figure B-7 The estimated relative risk on different lengths of shift



The values shown in Figure B-7 are, of course, estimates of the effect of shift length based on studies of the trend in the frequency of injuries over hours on duty. However, Dembe et al (2004) report a longitudinal study of over 12,000 males who between them reported a total of over 5000 work-related injuries or illnesses (the vast majority of which were injuries, Dembe, pers. com.). They found a clear “dose response” curve for the impact of the number of hours worked per day on the frequency of these incidents. As a check on the accuracy of the estimates shown in Figure B-7, the values reported by Dembe et al were compared with those derived from Figure B-7. Note that the relative risk of injuries for shift durations between 8.0 and 9.9 hours was set at 1.0 in both data sets. The results are shown in Figure B-8 from which it is clear that, when expressed relative to the risk on 8.0 to 9.9 hour work days, there was very close agreement between the estimates derived from Figure B-7, and the values reported by Dembe et al for longer lengths of work day.

Figure B-8 Comparison of the estimated relative risk with that reported by Dembe et al (2004)



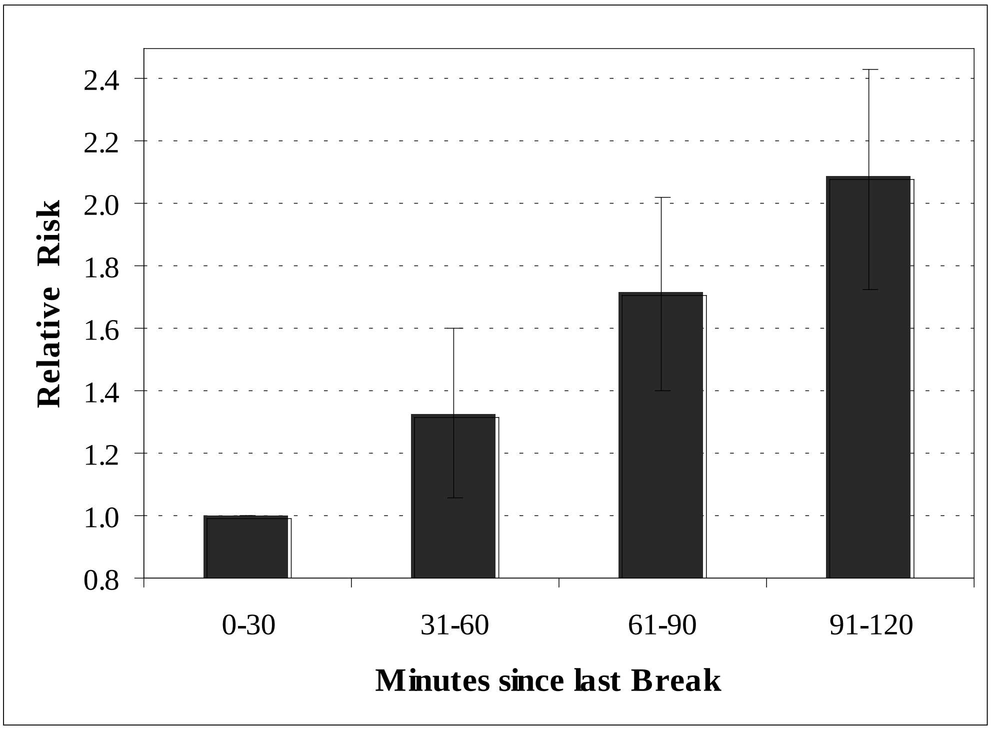
In a recent paper Barger et al (2005) demonstrate that the risks associated with longer shifts are not confined to industrial accidents. They studied 2737 interns using a web-based survey and obtained information about work hours, extended work shifts, and documented vehicle crashes and near-miss incidents. Using a case-control crossover design they were able to demonstrate that, compared to non-extended shifts, extended shifts (greater than 24 hours) were associated with an odds ratio of 2.3 for vehicle crashes and of 5.9 for near-misses following the shift. While industrial shifts are seldom of this duration, a number of authors have warned of the dangers of driving home after a night shift, and the results of Barger et al add weight to this view.

What is unclear about the results from the study of Barger et al (2005) however is quite why the risk of a near miss should be increased so much more than that of an actual crash following an extended shift. One possibility is yet another form of potential reporting bias, namely that a tired individual may perceive a given situation as rather more dangerous than an alert one, simply because they feel less able to cope with it. However, the fact that the increase in actual crashes is rather less than that in near-misses suggests that tired individuals may actually underestimate their ability to cope with potentially dangerous situations.

B.12 THE EFFECTS OF REST BREAKS

It should be noted that the trend for hours on duty shown in Figure B-6 does not control for the influence of breaks during a duty period, and indeed one possible explanation for the decrease in risk after the fifth hour may be that it reflects the influence of rest breaks. A number of laboratory studies on the effects of breaks have been conducted (see, the review by Tucker 2003, and, for example, Kopadekar & Mital, 1994; Galinsky et al, 2000; Dababneh et al, 2001), but there appears to be only a single, recent study that has examined the impact of rest breaks on the risk of incidents (Tucker et al, 2003).

Figure B-9 The trend in relative risk between 2-hourly breaks (Error bars are 95% CIs)



The study of Tucker et al (2003) examined industrial injuries in an engineering plant in which breaks of 15, 45 and 10 minutes, respectively, were given after each period of two hours of continuous work. The number of injuries within each of the four 30-minute periods between breaks was calculated, and the risk in each 30-minute period was expressed relative to that in the first 30-minute period immediately following the break. The results are shown in Figure B-9 from which it is clear that risk rose substantially, and approximately linearly, between successive breaks such that risk had doubled by the last 30-minute period before the next break. It is also noteworthy that there was no evidence that this trend differed for the day and night shifts, or for the three successive periods of two hours of continuous work within a shift.

B.13 THE EFFECTS OF OTHER FACTORS

A number of other factors have been identified in the literature that may influence the rate of objectively measured accidents and/or injuries, namely:

Prophylactic Naps. First, Garbariono (2004) reports an interesting and potentially very important study in which the use of prophylactic naps reduced the risk of car accidents during night work in professional drivers. He further suggests, that the risk of accidents was more influenced by the time since the last sleep than by the internal body clock, and that prophylactic naps may reduce the frequency of accidents by between 38 and 48%. It seems likely, although unproven, that a similar effect might be found for the risk of industrial accidents.

Weekly Work Hours. Dembe et al (2004) report a "dose response" curve for the impact of the number of hours worked per week on the frequency of incidents from their longitudinal study of over 12,000 males. Thus the authors report that the risk of incidents was approximately doubled in individuals who worked 65 hours or more per week relative to those who worked less than 40 hours per week. There are, however, two problems in drawing meaningful conclusions from these findings. First, those working longer hours clearly have a greater exposure than those working shorter hours. Secondly, when the work week is extended beyond about 40 hours individuals will almost certainly be exposed to longer shifts, longer spans of shifts, and quite probably riskier times of day. It is thus difficult to isolate the effects of prolonged weekly hours from the trends associated with these factors discussed above.

In this context it is worth pointing out that in a recent presentation (Folkard & Lombardi 2004a) we used a prototypic "Risk Index" (Folkard & Lombardi 2004b) based on some of the trends presented above to model the effects of long working hours per week. We were able to demonstrate that considering the weekly work hours in isolation from other factors is fairly meaningless since, depending on their composition, long weekly work hours can prove less risky than short weekly work hours. Thus, for example, relative to a "standard" work week of 40 hours comprising 5 successive eight hour day shifts, a 40 hour week comprising 5 successive eight hour night shifts is associated with a 34% increased risk while a 60 hour week comprising 5 successive twelve hour day shifts is associated with only a 28% increased risk . Clearly the length of the working week cannot sensibly be considered in isolation from the precise work schedule. Likewise limits on the length of the working week are likely to be of little use in restricting risk unless they form part of a more comprehensive set of limits.

B.14 REST DAYS AND SHIFT PATTERN

There appears to be no published research on the effects of rest days on the risk of incidents. However, given that risk increases over a span of successive work days, it seems logical that some "recovery" must take place over spans of rest days, otherwise the risk would continue to rise ad infinitum. It also seems logical that the longer the span of work days, i.e. the more risk has increased, the longer the span of rest days necessary for complete recovery. Indeed in one of the very few published studies in this area, Totterdell et al (1995) showed alertness and performance to be impaired on the first three days back at work following a single rest day as compared to a span of two or three rest days. Thus it may be the ratio of rest to work days that is important with respect to allowing full recovery. This latter point brings us to the overall shift pattern. Clearly spans of successive work days need to be limited to avoid an undue build up in risk, and equally the subsequent span of rest days needs to be sufficient to allow complete recovery. As a general "rule of thumb" it would seem prudent under normal circumstances to limit spans of successive work days to not more than six, and to require a minimum of two successive rest days.

Quick Returns. Finally, Macdonald et al (1997) examined the impact of "quick returns", i.e. a period of less than 11 hours off between two successive shifts, on injury rates. They compared two sites within a heavy industry that had similar shift systems that differed in one important respect, namely whether or not they included a quick return. Both sites used identically-timed, 8-hour, morning afternoon and night shifts, in a "2-2-3" sequence, such that seven successive shifts were worked before a span of two or three days off. One site rotated the shifts in the classic delaying sequence of MAN, while the other used the advancing sequence MNA with a quick return of 8-hours between the night and afternoon shifts. Using a hierarchical loglinear analysis Macdonald et al found a site by shift interaction ($p=0.0150$) which they interpreted as reflecting on the impact of the quick return. Thus they showed that, relative to the risk on the morning shift, the biggest difference between the two sites occurred on the afternoon shift, with the risk at the site whose shift system included a quick return being rather higher.

This analysis by Macdonald et al (1997) appeared reasonable at the time, but failed to take account of the fact that risk is likely to increase over a span of successive shifts (see Figure B-4 and Figure B-5 above). Thus it is hardly surprising that risk on the afternoon shift was higher on the MNA sequence than on the MAN one. For the purpose of this review the author thus compared the data reported by Macdonald et al (1997) with predictions derived from the Risk Index developed by Folkard & Lombardi (2004). The afternoon shift relative risk levels reported by Macdonald et al (1997) differed by only 8.5% from those predicted by the Risk Index. In contrast, relative risk on the night shift on the MNA sequence was 34% higher than predicted. However, it should be noted that this comparison fails to take account of the varying intervals between successive shift at the change from one type to another.

Nevertheless, this finding clearly questions the interpretation of the results in terms of the quick return. Rather is suggests that the main difference between the sites was an increase in risk on the night shift on the MNA sequence. This increase may have reflected on the advance in the timing of sleep required when moving from the morning to the night shift, or on the fact that on this sequence the night shift is likely to have followed shortened sleeps on the morning shifts (rather than the longer sleeps associated with afternoon shifts).

B.15 CONCLUSIONS

Perhaps the major conclusion that should be drawn from this review is that there is a shortage of good epidemiological studies of accident and injury rates in occupational settings that have controlled for the *a priori* risk and for biases in reporting. Nor are more recent studies any better than older ones in controlling for these contaminating factors. Studies such as those of Baker et al (2003) and Olowokure et al (2004) make no attempt to ensure that the *a priori* risk is constant and report incident rates that almost certainly reflect variations in activity rather than on the state of the individuals concerned.

However, those studies that have managed to control for confounding factors or to correct for them in some manner have yielded results that show a reasonable degree of consistency with one another. For this reason we would disagree with Frank (2000, p34) who after reviewing the literature concluded that “there is little definitive information available of sufficient quality to make meaningful recommendations”. Rather, there appear to be consistent trends in the literature with respect to the relative risk across: (i) the three shifts, (ii) the course of the night shift, (iii) the 24-hour day, (iv) successive night shifts, (v) successive day shifts, and (vi) successive hours on duty. In addition, there is some evidence to suggest the importance of rest breaks, prophylactic naps, and the direction of rotation of shift systems with respect to the relative risk.

Finally, it would appear that the trends in risk identified in this review are of sufficient consistency and magnitude to warrant their inclusion in any index or model developed to assess shift systems or work schedules, such as a revised version of the HSE’s Fatigue Index (FI). Indeed, a prototypic “Risk Index” (RI) based on some of these trends has already been successfully developed and shown to produce results that are not entirely dissimilar to those derived from the FI (Folkard & Lombardi 2004b).

B.16 REFERENCES

Adams NL, Barlow A, Hiddlestone J (1981). Obtaining ergonomics information about industrial injuries: A five-year analysis. Applied Ergonomics. 12, 71-81.

Åkerstedt T (1995). Work injuries and time of day – national data. Shiftwork International Newsletter 12(1) 2.

Andlauer P (1960). The effects of shift working on workers’ health. European Productivity Agency. TU Information Bulletin 29.

Baker A, Heiler K, Ferguson SA (2003). The impact of roster changes on absenteeism and incident frequency in an Australian coal mine. Occup Environ Med. 60, 43-49.

Barger LK, Cade BE, Ayas NT, Cronin JW, Rosner B, Seizer FE, Czeisler CA (2005). Extended work shifts and the risk of motor vehicle crashes among interns. New England Journal of Medicine. 352, 125-134.

Dababneh AJ, Swanson N, Shell RL. (2001). Impact of added rest breaks on the productivity and well-being of workers. Ergonomics, 44, 164-174.

Dembe, AE, Erickson JB, Delbos R, Banks S, Reville, R (2004). The Impact of Overtime and Extended Work Hours on Occupational Injuries and Illnesses: New Evidence from the United States. Ms submitted for publication.

Fathallah FA & Brogmus GE (1999). Hourly trends in workers' compensation claims. Ergonomics. 42, 196-207.

Folkard S (1997). Black times: temporal determinants of transport safety. Accident Analyses and Prevention, 29, 417-430.

Folkard S & Lombardi DA (2004a). Modelling the impact of the components of long work hours on injuries and "accidents". Paper presented at the national conference on "Long working hours, safety and health: towards a national research agenda", Balitmore, Maryland, April 29-30th, 2004.

Folkard S & Lombardi DA (2004b). Towards a "Risk Index" to assess work schedules. Chronobiology International. 21, 1063-1072.

Folkard S, Spelten E, Totterdell P, Barton J, Smith L (1995). The use of survey measures to assess circadian variations in alertness. Sleep. 18, 355-61.

Fortson KN (2004). The diurnal pattern of on-the-job injuries. Monthly Labor Review. September 2004, 18-25.

Frank AL (2000). Injuries related to shiftwork. American J Preventive Medicine. 18, 33-36.

Galinsky TL, Swanson NG, Sauter SL, Hurrell JJ, Schleifer LM. (2000). A field study of supplementary rest breaks for data-entry operators. Ergonomics, 43, 622-638.

Garbarino S, (2004). Professional shift-work drivers who adopt prophylactic naps can reduce the risk of car accidents during night work. Sleep. 27, 1295-1302.

Haenecke K, Tiedemann S, Nachreiner F, Grzech-Sukalo H (1998). Accident risk as a function of hours at work and time of day as determined from accident data and exposure models for the German working population. Scand J Work Environ Health 24 (suppl 3), 43-48.

Horwitz IB, McCall BP, 2004. The impact of shift work on the risk and severity of injuries for hospital employees: an analysis using Oregon workers' compensation data. Occup Med. 54, 556-563.

Kopadekar P, Mital A. (1994). The effect of different work-rest schedules on fatigue and performance of a simulated directory assistance operator's task. Ergonomics, 37, 1697-1707.

Laundry BR, Lees REM (1991). Industrial accident experience of one company on 8- and 12-hour shift systems. J. Occupational Medicine, 33, 903-906.

Levin L, Oler J, Whiteside JR (1985). Injury incidence rates in a paint company on rotating production shifts. Accident Analysis and Prevention, 17, 67-73.

Lombardi DA & Folkard S (In prep). The time of day effect in occupational hand injuries.

Macdonald I, Smith L, Lowe SL, Folkard S (1997). Effects on accidents of time into shift and of short breaks between shifts. International Journal of Occupational and Environmental Health. 3, S40-S45.

Monk TH, Wagner JA (1989). Social factors can outweigh biological ones in determining night shift safety. Human Factors, 31, 721-724.

Nachreiner F. (2000). Extended work hours and accident risk. In Marek T, Oginska H, Pokorski J, Costa G, Folkard S, eds. Shiftwork 2000 - implications for science, practice and business. Kraków: Institute of Management, Jagiellonian University, pp 29-44.

Nachreiner F, Akkermann S, Haenecke K. (2000). Fatal accident risk as a function of hours into work. In: Hornberger S, Knauth P, Costa G, Folkard S, eds. Shiftwork in the 21st Century. Frankfurt am Main: Peter Lang, pp 19-24.

Oginski A, Oginska H, Pokorski J, Kmita W, Gozdziela R (2000). Internal and external factors influencing time-related injury risk in continuous shift work. Int J Occup Safety and Ergonomics. 6, 405-421.

Olowokure B, Saunders PJ, Dyer JA, Kibble AJ (2004). Temporal and seasonal variation in the occurrence of chemical incidents. Occupational and environmental Medicine. 61, 177-179.

Ong CN, Phoon WO, Iskandar N, Chia KS (1987). Shiftwork and work injuries in an iron and steel mill. Applied Ergonomics. 18, 51-56.

Quaas M, Tunsch R (1972). Problems of disablement and accident frequency in shift- and night work. Studia Laboris et Salutis. 11, 52-57.

Rosa, R. (1991). Performance, alertness and sleep after 3.5 years of 12h shifts: a follow-up study. Work and Stress, 5, 107-116.

Samel A, Vejvoda M, Maaß H & Wenzel J (1999). Stress and fatigue in 2-pilot crew long-haul operations. Proceedings of CEAS/AAAF Forum “Research for Safety in Civil Aviation”, Paris, Oct. 21-22, 1999, Chapter 8.1, 9 p.

Smith L, Folkard S, Poole CJM (1994). Increased injuries on night shift. Lancet 344, 1137-1139.

Smith L, Folkard S, Poole CJM (1997). Injuries and worktime: Evidence for reduced safety on-shift. Journal of Health and Safety, 12, 5-16.

Totterdell P, Spelten E, Smith L, Barton J, Folkard S (1995). Recovery from work shifts: how long does it take? Journal of Applied Psychology. 80, 43-57.

Tucker P. (2003). The impact of rest breaks upon accident risk, fatigue and performance: a review. Work & Stress, 17, 123-137.

Tucker P, Folkard S, Macdonald I (2003). Rest breaks and accident risk. Lancet, 361, 680.

Tucker P, Folkard S, Macdonald I, Charyszyn S (2001). Temporal determinants in accident risk in a large engineering assembly plant. Paper presented at the 15th International Symposium on Night and Shift Work, Hayama, Japan, 10th-13th September, 2001.

Tucker P, Smith L, Macdonald I, Folkard S (1999). The distribution of rest days in 12 hour shift systems: impacts upon health, well-being and on-shift alertness. Occupational and Environmental Medicine 56, 206-214.

Tucker P, Sytnik N, Macdonald I, Folkard S (2000). Temporal determinants of accident risk: the "2-4 hour shift phenomenon". In Hornberger S., Knauth P., Costa G. & Folkard S. (Eds) Shiftwork in the 21st Century. pp 99-105. Peter Lang, Frankfurt, Berlin, Bern, Bruxelles, New York, Oxford & Wien.

Vernon HM (1923). The causation of industrial accidents. J Industrial Hygiene, 5, 14-18.

Vinogradova OV, Sorokin GA, Kharkin NN (1975). A complex study into the strenuousness of night work done by dockers (in Russian). Gig. Truda prof. Zabol. 19, 5-8.

Wagner JA (1988). Shiftwork and safety: A review of the literature and recent research findings. In F. Aghazadeh (Ed) Trends in Ergonomics/Human factors V: Proceedings of the third industrial ergonomics and safety conference. LSU, New Orleans, June 8-10th, 1988.

Wanat J (1962). Nasilenie wypadkow w roznych okresach czasu pracy e kopalniach wegla kamiennego. Prcae Glownego Instytutu Gornictwa, Seria A, Kom 285.

Wharf HL (1995). Shift length and safety. Report to British Coal.

B.17 DETAILS OF THE 18 ARTICLES FOUND IN THE LITERATURE SEARCHES THAT WERE DEEMED WORTHY OF PURSUIT

Record 1 of 274 in PsycINFO Weekly 2004/12 Week 4
AN: 2004-99016-192
DT: Dissertation-Abstract
AU: Seo,-Dong-Chul
TI: Development and testing of a model that explains contributing factors to unsafe work behavior.
SO: Dissertation-Abstracts-International:-Section-B:-The-Sciences-and-Engineering. 2004; Vol 65 (2-B): 691
UM: AAI3122737

Record 45 of 274 in PsycINFO 2003 Part B
AN: 2003-04707-002
DT: Peer-Reviewed-Journal
AU: Jones,-Andrew-P; Jorgensen,-Stig-H
TI: The use of multilevel models for the prediction of road accident outcomes.
SO: Accident-Analysis-and-Prevention. Jan 2003; Vol 35 (1): 59-69

Record 60 of 274 in PsycINFO 2002 Part B
AN: 2002-02811-003
DT: Peer-Reviewed-Journal
AU: Lilley,-Rebbecca; Feyer,-Anne-Marie; Kirk,-Patrick; Gander,-Philippa

TI: A survey of forest workers in New Zealand: Do hours of work, rest, and recovery play a role in accidents and injury?
SO: Journal-of-Safety-Research. Spr 2002; Vol 33 (1): 53-71

Record 79 of 274 in PsycINFO 2000
AN: 2001-16002-006
DT: Peer-Reviewed-Journal
AU: Trimpop,-Ruediger; Kirkcaldy,-Bruce; Athanasou,-James; Cooper,-Cary
TI: Individual differences in working hours, work perceptions and accident rates in veterinary surgeries.
SO: Work-and-Stress. Apr-Jun 2000; Vol 14 (2): 181-188

Record 80 of 274 in PsycINFO 2000
AN: 2001-07176-005
DT: Peer-Reviewed-Journal
AU: Phillips,-Richard
TI: Sleep, watchkeeping and accidents: A content analysis of incident at sea reports.
SO: Transportation-Research-Part-F:-Traffic-Psychology-and-Behaviour. Dec 2000; Vol 3 (4): 229-240

Record 86 of 274 in PsycINFO 2000
AN: 2000-15928-003
DT: Peer-Reviewed-Journal
AU: Galinsky,-Traci-L; Swanson,-Naomi-G; Sauter,-Steven-L; Hurrell,-Joseph-J; Schleifer,-Lawrence-M
TI: A field study of supplementary rest breaks for data-entry operators.
SO: Ergonomics-. May 2000; Vol 43 (5): 622-638

Record 88 of 274 in PsycINFO 2000
AN: 2000-13299-006
DT: Peer-Reviewed-Journal
AU: Mitchell,-Rebecca-J; Williamson,-Ann-M
TI: Evaluation of an 8 hour versus a 12 hour shift roster on employees at a power station.
SO: Applied-Ergonomics. Feb 2000; Vol 31 (1): 83-93

Record 109 of 274 in PsycINFO 1998-1999
AN: 1998-11144-001
DT: Peer-Reviewed-Journal
AU: Lluis-Melia,-Josep
TI: A psychosocial causal model of work accidents / Un modelo causal psicosocial de los accidentes laborales.
SO: Anuario-de-Psicologia. Sep 1998; Vol 29 (3): 25-43

Record 151 of 274 in PsycINFO 1995-1997
AN: 1996-00203-009
DT: Peer-Reviewed-Journal
AU: Sorock,-Gary-S; Ranney,-Thomas-A; Lehto,-Mark-R
TI: Motor vehicle crashes in roadway construction workzones: An analysis using narrative text from insurance claims.
SO: Accident-Analysis-and-Prevention. Jan 1996; Vol 28 (1): 131-138

Record 163 of 274 in PsycINFO 1992-1994
AN: 1994-27721-001
DT: Peer-Reviewed-Journal
AU: Williamson,-Ann-M; Gower,-CGI; Clarke,-BC

TI: Changing the hours of shiftwork: A comparison of 8- and 12-hour shift rosters in a group of computer operators.
SO: Ergonomics-. Feb 1994; Vol 37 (2): 287-298

Record 174 of 274 in PsycINFO 1992-1994
AN: 1993-15286-001
DT: Peer-Reviewed-Journal
AU: Gold,-Diane-R; Rogacz,-Suzanne; Bock,-Naomi; Tosteson,-Tor-D; et-al
TI: Rotating shift work, sleep, and accidents related to sleepiness in hospital nurses.
SO: American-Journal-of-Public-Health. Jul 1992; Vol 82 (7): 1011-1014

Record 190 of 274 in PsycINFO 1989-1991
AN: 1991-08625-001
DT: Journal
AU: Novak,-RD; Smolensky,-Michael-H; Fairchild,-EJ; Reves,-RR
TI: Shiftwork and industrial injuries at a chemical plant in southeast Texas.
SO: Chronobiology-International. 1990; Vol 7 (2): 155-164

Record 241 of 274 in PsycINFO 1872-1971
AN: 1981-02234-001
DT: Peer-Reviewed-Journal
AU: Bell,-CR; Telman,-Nursel
TI: Errors, accidents, and injuries on rotating shift-work: A field study.
SO: International-Review-of-Applied-Psychology. Jul 1980; Vol 29 (3): 271-291

Record 257 of 274 in PsycINFO 1872-1971
AN: 1959-07130-001
DT: Journal
AU: Smiley,-JR
TI: Relation between time of day and aircraft landing accidents.
SO: Journal-of-Aviation-Medicine. 1958; 29: 33-36

Record 262 of 274 in PsycINFO 1872-1971
AN: 1930-05017-001
DT: Journal
AU: Reid,-HL
TI: Time of day accidents occur.
SO: Industrial-Hygiene-Bulletin. 1928; 5

Record 263 of 274 in PsycINFO 1872-1971
AN: 1929-04588-001
DT: Journal
AU: Haide,-C
TI: Fatigue and working hours as causes of accidents / Ermuedung und Arbeitszeit als Unfallveranlassung.
SO: Reichsarbeitsblatt-. 1928; 8: 157-158

Record 268 of 274 in SIGLE 1980-2004/06
TI: Shift patterns/time of day/year and drill floor accidents.
AU: Wilson,-J.
CS: Health and Safety Executive, London (GB).
DP: Jun 2000.
SE: Offshore technology report. no. OTO 2000 044.
DT: R-Report

Record 270 of 274 in SIGLE 1980-2004/06
TI: Studies regarding the effect of shift work on the sick-rate and accident frequency in an automobile plant.
OT: Untersuchungen ueber den Einfluss der Schichtarbeit auf den Krankenstand und die Unfallhaeufigkeit in einem Automobilwerk.
AU: Ponsold,-Rosemarie.
CS: Universitaet Leipzig, Leipzig.
DP: 1969.
DT: N-Numerical-data; U-Dissertation

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C THE DERIVATION OF THE FATIGUE INDEX

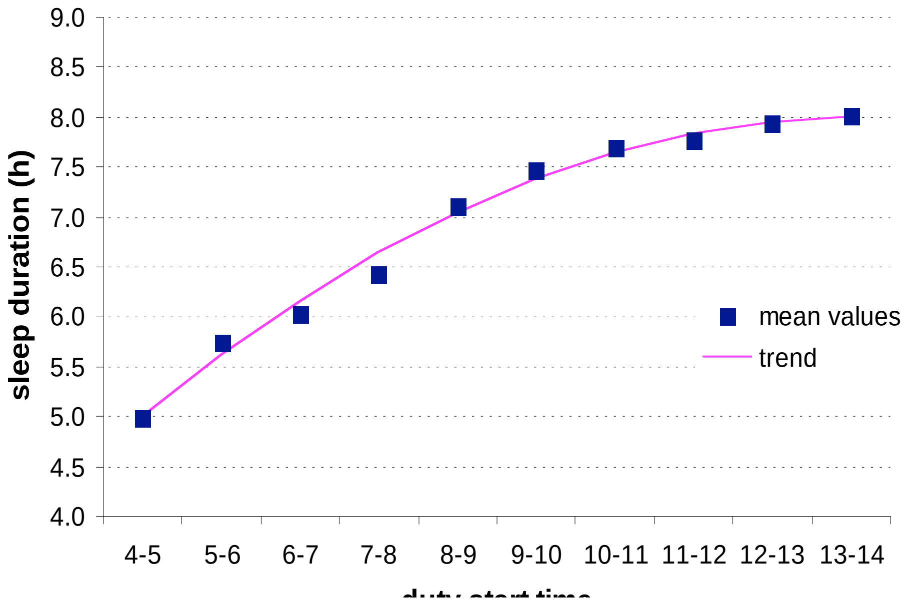
C.1 CUMULATIVE EFFECTS

The derivation of the component associated with cumulative fatigue is related to the amount of sleep loss that is likely to be associated with the pattern of work and rest (see Figure C-1). It was therefore necessary to establish two relationships in order to derive this component: firstly the relationship between the pattern of duty and sleep, and secondly, the impact of any loss of sleep on levels of fatigue. Finally, the predictions of cumulative fatigue, derived in this way, were compared with the increase in fatigue over consecutive duty periods from aircrew studies (Spencer & Robertson, 2000).

Figure C-1: Derivation of the cumulative fatigue component

The loss of sleep associated with the pattern of duty was derived from the CHS studies of aircrew (Spencer & Robertson, 2000; Spencer & Robertson, 2002; Robertson & Spencer, 2003) and train drivers (McGuffog et al, 2004). Two main cases were addressed, the impact of early start times and of late finishes / overnight work. The effect of an early start time is illustrated in Figure C-2, where a trend line in the form of a quadratic function has been fitted to the mean values. This function has been used to estimate the reduction in sleep associated with a given start time. There is no reduction for start times between 13:00 and 14:00, where an eight-hour sleep is predicted, but as the start time advances into the morning, so the duration of sleep is progressively reduced.

Figure C-2: Sleep duration prior to early start times

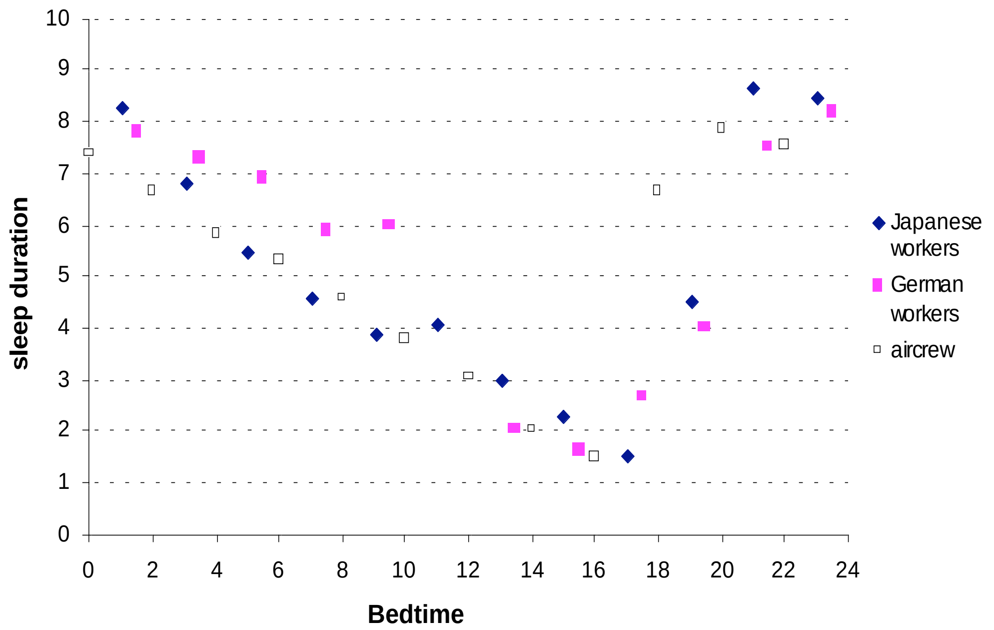


The estimated loss of sleep following a late finish or overnight duty was somewhat more complicated and relied on data from two different sources:

- the reported sleep times of Britannia crews on duties ending at various times from the early evening through to mid-morning (Robertson & Spencer, 2003);
- the duration of sleep as a function of time of sleep onset for German and Japanese workers based on diary records, summarized by Kogi (1985).

These data are plotted in Figure C-3.

Figure C-3: The duration of sleep related to bedtime



The fitted estimate of sleep duration was based on the mean of the aircrew data and the averaged shiftwork data. This was then expressed as a function of duty end time, using the relationship between sleep onset and duty end time from the aircrew data. The resultant predictions for the duration of sleep varied between eight hours (no sleep loss) for duties ending at 18:00 to three hours (five hours sleep loss) for duties continuing through to 12:00.

The only other adjustments to sleep duration based on the pattern of duty were made to accommodate quick returns. This was achieved by constraining the duration of sleep to be no greater than the length of the rest period less commuting time and less a further hour to allow for personal needs.

The second stage was to relate the predicted loss of sleep to fatigue levels. This relied on information from the two laboratory studies by Belenky et al (2003) and Van Dongen et al (2003). From the Belenky data, it was possible to derive exponential fits to the deterioration in performance in the PVT[5] task over seven consecutive days with restricted overnight sleep. From the Van Dongen study, this deterioration in performance was proportional to the amount of sleep loss on each successive night.

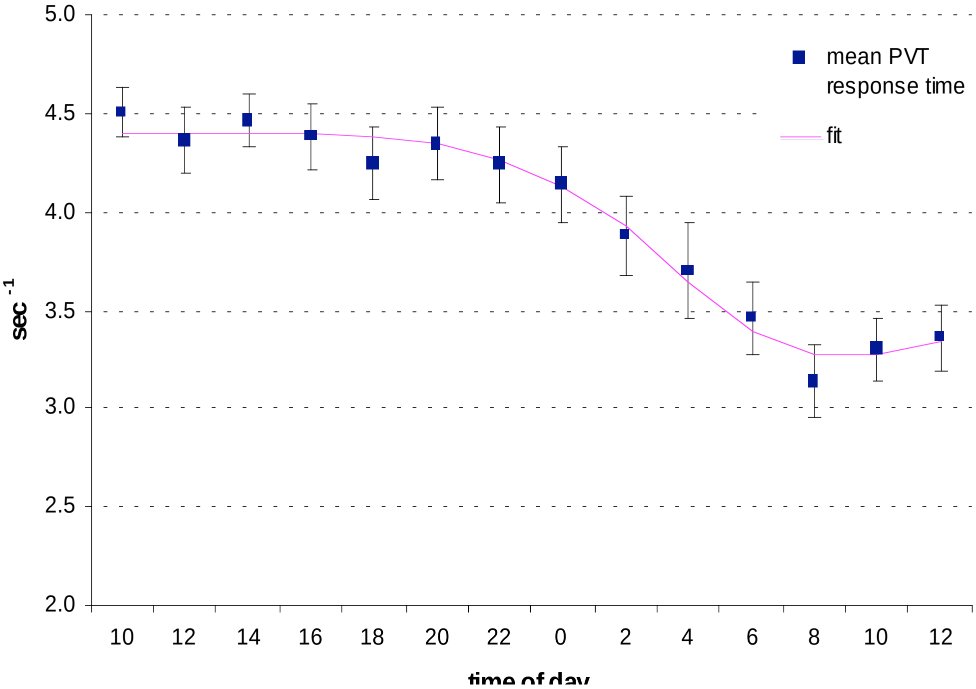
The exponential fit therefore included two parameters, the exponential parameter, representing the time course of the deterioration, and a parameter representing the asymptote, i.e. the steady state that performance would eventually reach if the same amount of sleep were lost every night. This exponential fit was applied on each successive night, using the amount of sleep lost according to the calculations described above.

[5] *The Psychomotor Vigilance Task (PVT) is a sustained-attention reaction time task.*

The Belenky study reported the recovery in PVT performance over three days following the period of sleep restriction, and a separate exponential function was fitted to these data. It transpired that the exponential parameter for this fit was approximately five times larger than for the fit with restricted sleep. This indicates that the process of recovery is considerably more rapid than the process of deterioration.

Finally, the output from the PVT was converted to the output scale used for the Fatigue Index, namely the KSS. The conversion was carried out using information on the time course of changes in the PVT over a 28-hour period without sleep as reported by Lamond et al (2005). This was compared with the prediction of sleepiness based on the timing of wakefulness, as used for the derivation of the second component of the index (see below). The fit to the PVT data based on this prediction is shown in Figure C-4.

Figure C-4: Fit to PVT data based on transformed KSS score



This procedure therefore enabled an estimate of cumulative fatigue to be obtained for any shift pattern, and the output to be expressed on the same scale as the other components of the index.

C.2 DUTY TIMING

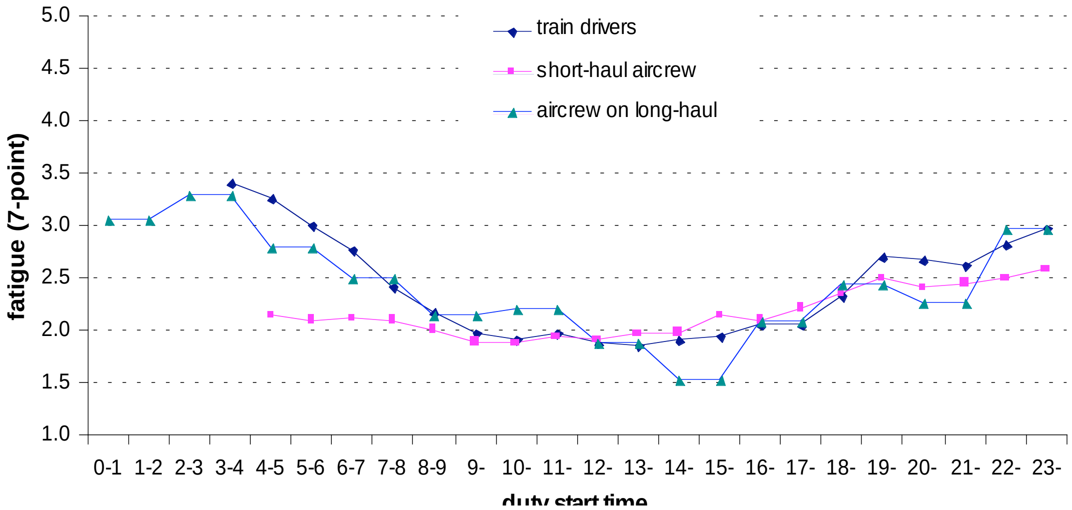
The three factors that contribute to this component of the index are:

- the start time of the duty;
- the time of day throughout the duty period;
- the length of the duty period.

They have been derived from several studies of aircrew and train drivers. In many of these studies, fatigue assessments have been obtained, not only at the start and end of duty, but at various points in between. The statistical models that have been fitted to the data have enabled the separate influence of these three factors to be estimated. It has also been possible to establish that the effect of these factors is approximately additive.

The effect of start time is illustrated in Figure C-5, where the scale on the y-axis is the seven-point Samn-Perelli (SP) scale which varies between one (fully alert, wide awake) and seven (completely exhausted, unable to function effectively). This figure illustrates that there are considerable differences between the results of the different studies. It is particularly noticeable, for example, that the increased fatigue associated with start times between 04:00 and 08:00 is less marked for the short-haul aircrew than for either the long-haul crews or the train drivers, and it is unclear how this difference has arisen.

Figure C-5: Fatigue levels at the start of duty

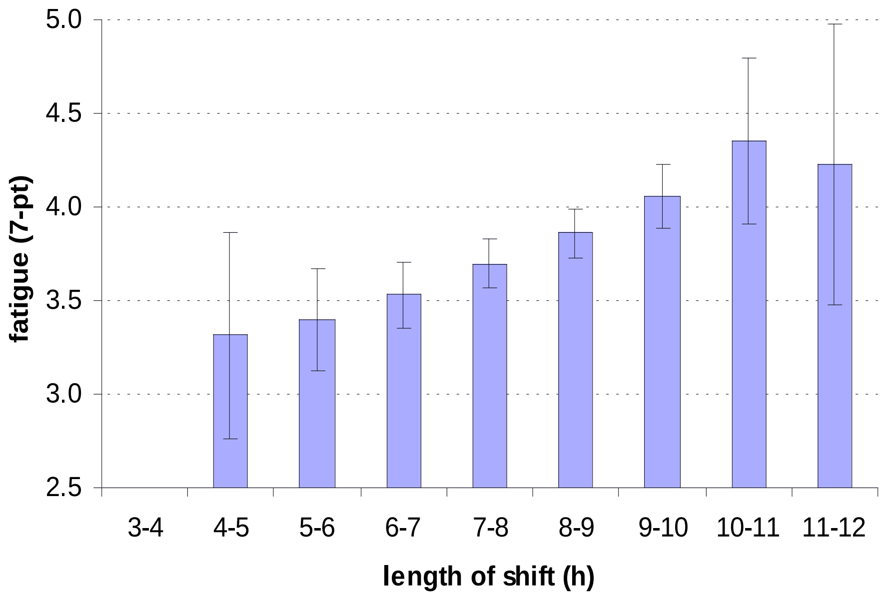


The estimation of the effect of start time has been based on the average of the two groups, the long-haul crews and the train drivers, that are in close agreement. From these, a fit was obtained in the form of a circadian rhythm with an amplitude of 0.49 and an acrophase, corresponding to the highest levels of fatigue, of 01:15. In the statistical model, this rhythm represents the sum of two components, one of which corresponds to an initial state, presumably related to sleep, whose effect persists throughout the duty period.

The other component is the underlying circadian rhythm which varies throughout the duty period. The estimates of this rhythm from the various studies suggest that its acrophase is several hours later than for the start time, and this is consistent with the results of laboratory studies. For the calculation of this component, an acrophase of 05:15 has been used, and an amplitude, on the SP scale, of 0.74.

The analysis of the various studies has indicated that the component associated with the duration of a duty period is very close, at least on the SP-scale, to a linear function of duty length. An example, showing the effect of duty length on the fatigue levels reported by train drivers at the end of a shift, is given in Figure C-6. The average increase in fatigue is 0.14 per hour.

Figure C-6: The effect of length of shift (train drivers)



However, this represents the effect of shift length after correcting for the amount of time spent driving. If the time spent driving is included, the slope of the trend line increases, depending on the amount of driving undertaken during a particular shift. With an average amount of driving, the overall rate of increase in this particular study was 0.23 per hour. This suggests that the effect of shift length should take into account the nature and intensity of the work being carried out. For this reason, job type, together with breaks, has been included as a separate component, and is discussed below. For the duty timing component, an increase of 0.14 per hour has been assumed.

Finally, a transformation has been applied to convert these results from the seven-point SP scale to the scale of the Fatigue Index, namely the percentage of high values on the KSS. This transformation has been based on a large study of aircrew in which data were collected on both scales simultaneously (Robertson et al, 2002). The value for the whole shift is then obtained as the mean level over all times within the shift.

The aircrew studies on which the duty timing component has been based involve typical commuting times of approximately 30 minutes, as opposed to that typically reported for shiftworkers which is approximately 40 minutes. Suitable adjustments are made when the user of the index specifies either a longer or a shorter commuting time.

C.3 JOB TYPE / BREAKS

While it is clear that the intensity of the work being carried out and the provision of breaks within a shift have a significant influence on fatigue, there is relatively little information on which to base reliable estimates. On the one hand, there are laboratory studies and simulations which have shown that alertness is reduced during continuous periods of activity and recovers after a break. On the other hand, there are data collected in the work place which have shown that subjective levels of sleepiness and fatigue are strongly influenced by the levels of workload.

For the construction of this component, considerable use has been made of the results of the laboratory simulations carried out by Gillberg et al (2003), in which periods of 100 minutes of continuous activity, both during the day and overnight, were separated by breaks of 20 minutes. Of the field studies, much emphasis has been placed on the increase in fatigue experienced by train drivers (McGuffog et al, 2004) and aircrew (Robertson & Spencer, 2003; Spencer & Robertson, 2000; Spencer & Robertson, 2002) during duty periods involving different levels of workload. The derivation of the formulae for this component will not be described here in detail. However, the principles which have been used for their construction are the following:

1) There is a baseline level of fatigue that increases slowly throughout a shift (assuming that no naps are taken). It corresponds to the effect of continuous wakefulness, together with a minimal level of activity that is unaffected by breaks. This is represented in the Duty Timing component of the Index.

2) There is an increase in fatigue associated with a period of continuous activity, and the more intense the activity the greater the increase. If there are no breaks of any sort, the increase in fatigue can be represented by a negative exponential function of time.

3) The effect of a break is to initiate a recovery process. If the break is very short (e.g. two minutes), the effect is to halt, rather than reverse, the accumulation of fatigue. If it is long (e.g. 30 minutes), fatigue recovers to its baseline level, with 50% recovery achieved after approximately 15 minutes.

The new version of the Fatigue Index requests information on the nature of the workload, the requirement for continuous attention and on the length and frequency of breaks. This information is used to construct the parameters for the job type / breaks component, using the methodology outlined above.

C.4 THE FORM OF THE FINAL INDEX

The final form of the Fatigue Index is given by

$$FI = 100 \{ 1 – (1-C) (1-J-T) \}$$

where C is the cumulative fatigue component,

T is the duty timing component,

and J is the job type / breaks component.

In this formula, C, J and T correspond to probabilities and therefore take values between 0 and 1. In the final spreadsheet, they have been converted to percentages, like the FI itself, by multiplying by 100.

C.5 REFERENCES

Belenky G, Wesensten NJ, Thorne DR, Thomas ML, Sing HC, Redmond DP, Russo MB, Balkin TJ (2003). Patterns of performance degradation and restoration during sleep restriction and subsequent recovery: a sleep dose-response study. J Sleep Res 12:1-12.

Gillberg M, Kecklund G, Goransson B, Akerstedt T (2003). Operator performance and signs of sleepiness during day and night work in a simulated thermal power plant. Int J Industrial Ergonomics; 31:101-09.

Kogi K (1985). Introduction to the problems of shiftwork. In: Hours of work. Temporal factors in work-scheduling. Eds S Folkard & TH Monk. John Wiley, Chichester 165-184.

Lamond N, Dawson D, Roach GD (2005). Fatigue assessment in the field: validation of a hand-held electronic psychomotor vigilance task. Aviat Space Environ Med 76; 486-489.

McGuffog A, Spencer M, Turner C, Stone B (2004). Working patterns of train drivers: implications for fatigue and safety. QinetiQ Document Identifier Number QINETIQ/KI/CHS/CR043098. RSSB Reference Number T059.

Robertson KA et al (2002). Predicting alertness in future long-range operations: a validation study by ECASS. QinetiQ Report Number QINETIQ/KI/CHS/CR021119/2.0.

Robertson KA, Spencer MB (2003). Aircrew alertness on night operations: an interim report. QinetiQ Report Number QINETIQ/KI/CHS/CR021911/1.0.

Spencer MB, Robertson KA (2000). A diary study of aircrew fatigue in short-haul multi-sector operations. DERA Report Number DERA/CHS/PPD/CR000394.

Spencer MB, Robertson KA (2002). Aircrew alertness during short-haul operations, including the impact of early starts. QinetiQ Report Number QINETIQ/CHS/PPD/CR010406/1.0.

Van Dongen HPA, Maislin G, Mullington JM, Dinges DF (2003). The cumulative cost of additional wakefulness: Dose-response effects on neurobehavioral functions and sleep physiology from chronic sleep restriction and total sleep deprivation. Sleep 26(2):117-26.

D THE DERIVATION OF THE RISK INDEX

D.1 CUMULATIVE EFFECTS

The estimation of the increase in risk on consecutive shifts has been based on the relative risk data over four successive night (Figure B-4) and day (Figure B-5) shifts. The increase is reasonably approximated by a linear trend, representing an increase of 0.0562 over each consecutive day shift and of 0.1207 over each consecutive night shift. To estimate the risk for a shift starting at any time of day, a cosine fit has been applied to these linear trends, resulting in an acrophase at midnight (corresponding to the mid-point of the shift), an average increase of 0.0886 and an amplitude of 0.0359. The increase associated with each successive shift therefore varies between 0.0886 + 0.0359 = 0.1245 for shifts centred on midnight and 0.0886 – 0.0359 = 0.0527 for shifts centred on midday. When two consecutive shifts occur at two different times of day, the average of the values corresponding to the two different shifts has been taken.

There is no information on the time course of the recovery in risk after a sequence of consecutive shifts. Accordingly, the pattern of recovery used in Risk Index has been designed to follow, as closely as possible, that of the Fatigue Index.

There is also no information on the effect of quick returns on risk, and estimates have again been based on comparisons with the Fatigue Index. A simple formula has been adopted, whereby the increase in risk is linearly related to the amount by which the rest period is less than nine hours. Each additional hour of lost rest is assumed to be associated with a 6% increase in risk.

D.2 DUTY TIMING

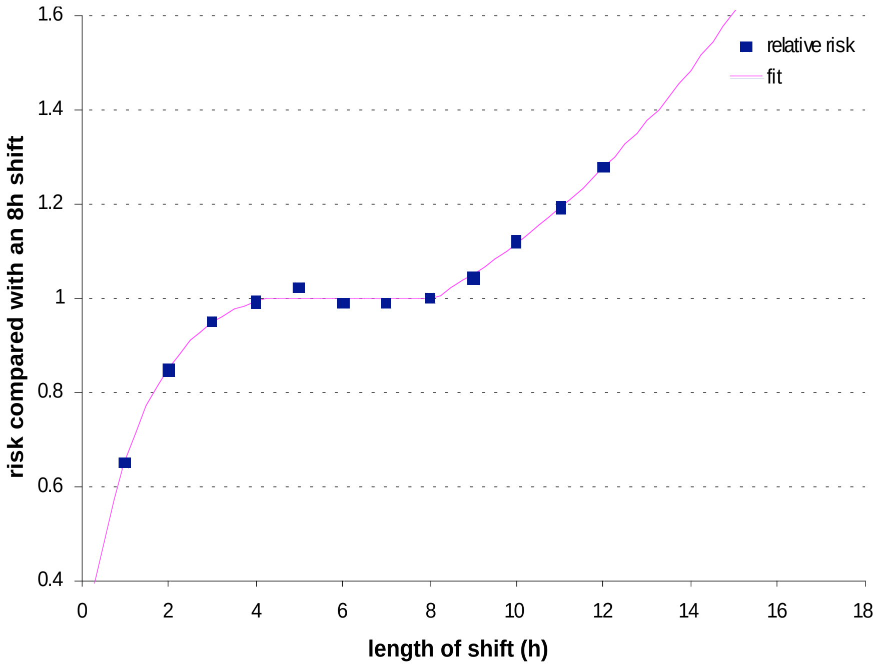
This component is calculated by multiplying the risks associated with two individual factors, namely the time of day and the length of the shift.

The risk associated with the time of day was derived from the relative risk on the afternoon (1.1519) and night shifts (1.2788), compared with the morning shift (1.0000) (Figure B-1). However, these values were based on the average risk over a sequence of shifts, not the risk on the first shift. They have therefore been recalculated, using the sequence effect (see above under 'Cumulative effects') to obtain an estimate of the risk associated with the first shift. The cosine fit to this risk has an amplitude of 0.1057 and an acrophase, corresponding to the maximum risk, close to midnight, and this fit was used in the calculation of the index.

The factor related to shift length was derived from the relative risk on different lengths of shift (Figure B-7). The fit that was used for the calculation of the index is shown in Figure B-7, where the risk is expressed relative to the average risk on an 8h shift, which was set equal to one. As there is very little change in the level of risk during shifts lasting between four and eight hours, the relative risk for these shifts was also set to one. A negative exponential function was used to estimate the lower levels of risk on shifts shorter than four hours, and an exponential function with a positive exponent was used for shifts longer than eight hours. For shifts longer than 12h, this has involved extrapolation beyond the range of the available data.

It was assumed that the shifts that contributed to the estimation of incident risk involved average commuting times of approximately 40 minutes, as this is typical of time spent travelling to or from work. If the user of the index specifies a commuting time either longer or shorter than 40 minutes, the estimation of the risk associated with duty timing is adjusted appropriately.

Figure D-1: Relative risk of shifts of different duration



D.3 JOB TYPE / BREAKS

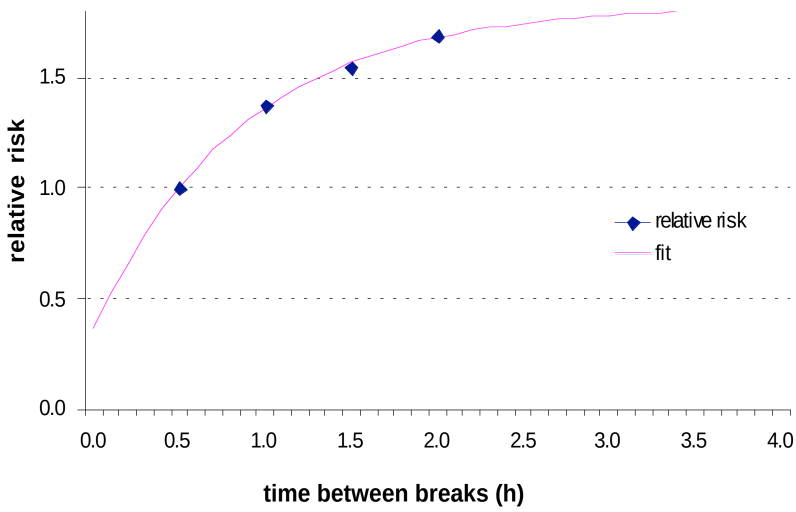
Figure B-9 shows the increase in risk as a function of the time since the last break, derived from the studies of Tucker et al (2003). At a recent international shiftwork meeting, held in Amsterdam, new information on the impact of breaks on risk was reported (Tucker et al 2005). The relative risk over four consecutive 30-minute periods from these two studies is given in Table D-1, together with the average values.

Table D-1: The increase in relative risk between breaks

30-min periods	***Relative risk***		
	Tucker et al 2003	***Tucker et al 2005***	***Mean***
1	1.0000	1.0000	1.0000
2	1.3256	1.4207	1.3731
3	1.7093	1.3810	1.5452
4	2.0814	1.2927	1.6870

An exponential fit to these average values is shown in Figure D-2, where the risk is relative to a value of 1.0 over the first 30 minutes. This function has been used to estimate the changes in risk associated with continuous periods of work, as specified by the user of the index on the defaults screen. As there is no information on the reduction in risk associated with breaks of different duration, the recovery function used for the Fatigue Index has been adopted. Similarly, there is no information of the impact of workload on risk, and the Fatigue Index has again been used to derive the values for risk.

Figure D-2: Relative risk of continuous periods between breaks



D.4 THE FORM OF THE FINAL INDEX

The final form of the Risk Index is given by:

RI = C * J * T

where C is the cumulative fatigue component,

T is the duty timing component,

and J is the job type / breaks component.

The index has been normalised with respect to a typical two-day, two-night, four-off schedule, where the following conditions apply:

- the shift changes occur at 07:00 and 19:00;
- typical commuting time is 40 minutes;
- the work is moderately demanding, requiring continuous attention some of the time;
- a break of 15 minutes is typically taken every two hours;
- the longest period without a break is typically four hours, followed by a break of 30 minutes.

The normalization ensures that, if this schedule is repeated over 21 consecutive cycles, covering a period of 24 weeks, the average value of the index is 1.00. The average values of C and T (but not J) are also normalized to 1.00 over the same period.

D.5 REFERENCES

Tucker P, Folkard S, MacDonald I (2003). Rest breaks and accident risk. Lancet, 361, 680.

Tucker P, Smith L, Folkard S (2005). Rest break schedules and accident risk. Shiftwork Int Newsletter 22(2); 149.

E REVIEW OF THE LITERATURE ON THE ADJUSTMENT TO PERMANENT NIGHT SHIFTS

E.1 INTRODUCTION

"Permanent" or "fixed" night shifts offer a potential benefit over rotating shift systems in that they may serve to maximise the adjustment of the body clock, and hence minimise the various health and safety problems associated with night work. Various authors have argued in favour of permanent shift systems (e.g. Wilkinson 1992), but their arguments assume at least substantial, if not complete, adjustment of the body clock. It is also noteworthy that permanent night shifts appear to be popular in North America where a "seniority" system is often operated. New, usually younger, employees are put onto a fixed night shift, and only after a number of years on this system are they moved onto a fixed evening shift, and finally onto a fixed morning shift. It is perhaps no coincidence that this progression with age accords well with anecdotal evidence that younger workers find it easier to cope with the night shift and that older workers find it easier to cope with the morning shift.

E.2 BACKGROUND

There has been considerable debate as to whether the detrimental effects of shiftwork on health and safety could be minimised by the judicious choice of shift system. Thus, for example, Wilkinson (1992) reviewed the literature relating to sleep duration, circadian adjustment, performance, and health and personal satisfaction on rapidly rotating, slowly rotating and permanent shift systems. While conceding that rapidly rotating systems were the most popular, he concluded that permanent shift systems were certainly better with respect to sleep duration, and marginally so with respect to the other measures. However, there were only a limited number of studies available at the time that allowed a comparison in terms of health or performance. Nevertheless, Wilkinson (1992) found a reasonable number of studies that reported subjective day sleep duration between successive night shifts on rapidly and weekly rotating shift systems, and on permanent night shifts. Having excluded the results from one, highly atypical, study the mean day sleep durations between successive night shifts were:

Rapidly rotating	- 5.79 hours
Weekly rotating	- 6.30 hours
Permanent nights	- 6.72 hours

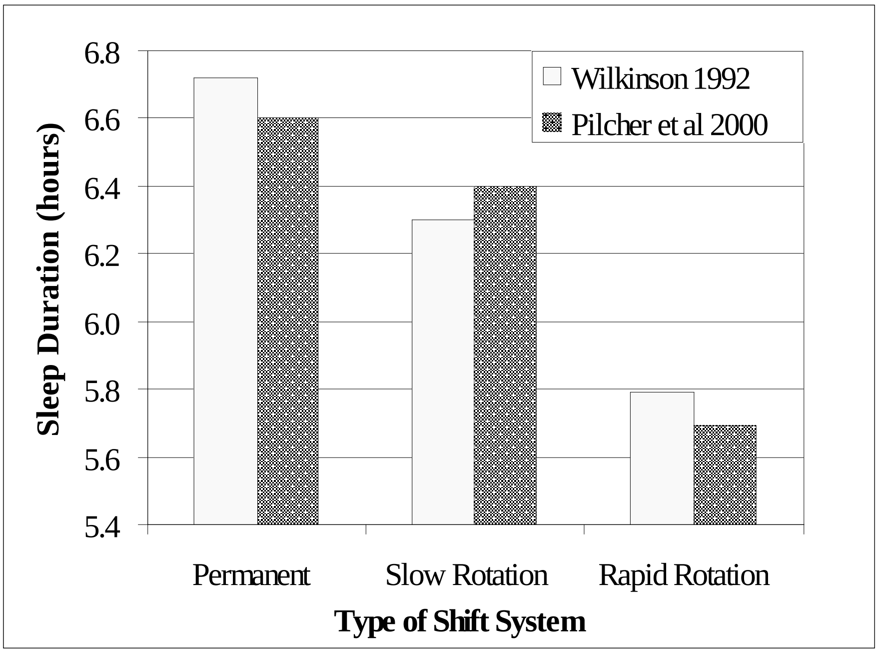
Wilkinson analysed these differences by performing independent t-tests based on the mean values reported in the studies that he reviewed and concluded that the day sleep durations between night shifts were reliably longer on permanent nights than on either weekly ($p=0.048$) or rapidly ($p=0.002$) rotating shift systems, and also that those on weekly rotating systems were marginally longer ($p=0.053$) than those on rapidly rotating systems. Although Wilkinson (1992) conceded that "perfect adaptation is very rare on the permanent night shift" (p 1440) he argued on the basis of these sleep duration results that "…permanent or slowly rotating night shift systems emerge superior to rapidly rotating ones…" (p 1441). This conclusion was questioned for a range of reasons by both Folkard (1992) and Wedderburn (1992) in rejoinders to Wilkinson's original article.

More recently Pilcher, Lambert & Huffcutt (2000) reported a meta-analytic review of the differential effects of permanent and rotating shift systems on the day sleep duration between successive night shifts. They performed formal literature searches on a range of databases and also followed up papers cited in a number of review articles. They found a total of 168 primary studies of shiftwork that included data on sleep duration, of which 36 gave sufficient information to be included in their meta-analysis. They compared permanent night shifts with rapidly rotating (<4 days on each shift) and slowly rotating (≥ 4 days on each shift) shift systems. The mean day sleep durations between successive night shifts were:

Rapidly rotating	- 5.69 hours
Slowly rotating	- 6.40 hours
Permanent nights	- 6.60 hours

These mean values clearly compare favourably with those reported by Wilkinson (1992) and this is illustrated in Figure E-1. The mean values reported in these two reviews differed by a maximum of 0.12 hours, and this was rather less than the average differences between the types of shift systems. On the face of it, this finding of Pilcher at al (2000) would appear to lend considerable support to Wilkinson's (1992) conclusion. However, in discussing their findings, Pilcher et al (2000) point out that the apparent advantage of the permanent night workers "…may simply be due to the individuals being required to work numerous night shifts in a row, thus increasing their physiological need for sleep" (p 160). In other words, it is impossible to judge the extent to which an individual's body clock has adjusted to night work based on day sleep duration alone since longer spans of successive short day sleep will result in an increased pressure for sleep, and hence in lengthened day sleeps.

Figure E-1 The mean day sleep durations reported by Wilkinson (1992) and Pilcher et al (2000)



In fairness, Wilkinson (1992) appears to have recognised this problem since he also considers the adjustment of various physiological rhythms, and especially body temperature, to night work. He points out that "the matter of circadian adaptation has been examined most systematically in laboratory studies" (p 1443) and concludes that "the circadian rhythm in body temperature can adjust almost completely to continuous night work *when there are no days off to disrupt the adaptation*" (p 1434). This conclusion is based largely on the laboratory studies by Colquhoun et al (1968a, 1968b, 1969) and Knauth et al (1978). However, these early studies failed to take account of the fact that measured rhythm in body temperature reflects both an endogenous body clock component and an exogenous "masking" component. Folkard (1988) estimated that these two components each accounted for about 50% of the measured rhythm. On this basis Folkard (1989) went on to model the results of Colquhoun et al and showed that the apparent adjustment of the body temperature rhythm that they described was probably entirely due to "masking" by the changed sleep timing.

In the light of these problems in assessing the degree of adjustment to permanent night work based on either day sleep duration or physiological rhythms such as body temperature that comprise both endogenous and exogenous components, this review concentrates on the adjustment of the circadian rhythm in melatonin. Melatonin is secreted by the pineal and the circadian rhythm in it appears to be largely unaffected by the timing of sleep, activity, and food ingestion. It is thus considered to be the best known indicator of the state of the endogenous body clock, although it should be noted that melatonin secretion can be inhibited by exposure to bright light.

E.3 LITERATURE SEARCHES

This review was based on (a) the substantial collection of reprints and papers held by the author, and (b) literature searches conducted in July 2005 using standard databases and the Web. The review will concentrate on those "real life" studies that allow an assessment of the degree to which the circadian rhythm in melatonin adjusted to permanent night work in "normal" shiftworking environments. "Abnormal" shiftworking environments such as offshore oil rigs and "fly in –fly out" mining operations have been excluded from this review in view of the lack of family and social contact while on the rig or at the mine. This, and various other factors, may account for the considerably greater than average adjustment found in these abnormal environments. Likewise, laboratory studies were excluded since the participants in these are typically required to sleep in a laboratory rather than return home during the off-duty periods between shifts.

The databases used were PsycINFO and SIGLE. PsycINFO is a database produced by the American Psychological Society. It contains citations and summaries of journal articles, book chapters, books, and technical reports, as well as citations to dissertations, all in the field of psychology and psychological aspects of related disciplines, such as medicine, psychiatry, nursing, sociology, education, pharmacology, physiology, linguistics, anthropology, business, and law. Journal coverage, spanning 1887-present, includes international material selected from more than 1,300 periodicals written in over 25 languages. Current chapter and book coverage includes worldwide English-language material published from 1987-present. Over 55,000 references are added annually through regular updates.

SIGLE (System for Information on Grey Literature in Europe) accesses reports and other "grey" literature produced in Europe. Grey literature is best defined as literature which cannot readily be acquired through normal bookselling channels and which is therefore difficult to identify and obtain. Examples of grey literature include technical or research reports, doctoral dissertations, some conference papers and pre-prints, some official publications, discussion and policy papers. SIGLE covers pure and applied science and technology, economics, other social sciences and humanities. It combines the resources of major European information and document supply centres who have joined together in an association known as EAGLE (European Association for Grey Literature Exploitation). Each centre is responsible for collecting grey literature produced in its own country and for providing details of it.

Literature searches were conducted on these two databases using the terms: "night work or "night shift" or "shiftwork" combined with "melatonin" and "adjustment", or "phase" or "entrainment". These searches resulted in several hundred hits, most of which were totally irrelevant. A refined search was conducted using the term: ((melatonin) and ((adjustment) or (phase) or (entrainment))) and ((night work) or (night shift) or (shiftwork) or (shift work)) which resulted in a total of 20 hits. These 20 hits are detailed in section E.7 and their main characteristic(s) summarised in Table E-1.

Table E-1 The main characteristic(s) of the 20 "hit" articles

No.	***Main Characteristic(s)***	***Relevant***
1	General review of circadian rhythms.	No
2	Use of melatonin as a marker of phase position.	No
3	Use of melatonin, light & dark to adjust phase.	No
4	Use of light and dark to adjust phase to night work.	No
5	Use of melatonin and vitamin B12 to attenuate alcohol induced phase shifts.	No
6	Use of melatonin administration to adjust phase to night work.	No
7	Use of melatonin as a marker of adjustment to night work.	Yes
8	Review of sleep disorders.	No
9	Use of light with SAD & other patients	No
10	Review of circadian phase in sleep & mood disorders.	No
11	Book on melatonin in psychiatric & neoplastic patients	No
12	Use of melatonin administration in jet-lag, shiftwork & blindness.	No
13	Use of melatonin administration as a chronobiotic.	No
14	Circadian adjustment on mean and women to night work.	No
15	Use of melatonin administration in circadian rhythm disorders & phase shifts.	No
16	Use of melatonin administration to phase shift the body clock.	No
17	Circadian rhythms in the human pupil and eyelid.	No
18	The prediction of circadian adaptation to time-zone transitions.	No
19	Phase response curve for melatonin administration.	No
20	Biological rhythms linked to sleep and psychological adaptation.	No

E.4 ADJUSTMENT OF THE MELATONIN RHYTHM TO PERMANENT NIGHT WORK.

The literature search identified only a single relevant study that the author was unaware of. This summary is thus based on a total of only six studies reported in seven published journal articles.

The earliest study appears to be that of Waldhauser et al (1986) who studied two male permanent night (19:00-04:00) bakers. On average, they showed a substantially reduced amplitude and a considerably earlier phase of their melatonin rhythm than five control (day working) participants. However, both night workers showed a peak in their melatonin rhythm outside (after) their day sleep period and one had elevated melatonin during the work period i.e. only 1 of them showed "good" adjustment of their melatonin rhythm.

Sack et al (1992) studied eight female and two male permanent night workers from health care and industrial organisations. Only one out of nine participants who completed the study showed the normal phase relationship between their melatonin rhythm and their day sleep. Six out of nine had elevated melatonin levels during their night work periods. However, all but one showed some phase shift of their rhythm i.e. on a strict criterion, only one out of nine showed "good" adjustment of their melatonin rhythms.

Roden et al (1993) studied nine young, male permanent night workers (night guards with high work satisfaction) at the end of a week of night work. Only one out of nine showed a clear phase shift (advance) of their melatonin rhythm with the onset occurring at about 12:00 (instead of about 22:00). The remaining eight night workers showed melatonin onset, acrophase and offset values that were indistinguishable from day working controls. They conclude that "even during permanent night work the setting of the endogenous clock does not normally lose its diurnal orientation" (p R266).

Koller et al (1994) studied 14 permanent male night watchmen. Only two of them had phases outside the timing of normal nights sleeps, i.e. they showed a "complete" phase reversal, although five showed a phase shift of six hours or more. I.e. there was evidence of some adjustment in five of the 14 watchmen, although in only two of them was this of sufficient magnitude to be of any real benefit.

Quera-Salva et al (1996 &1997) report a (single) study of 20 permanent night working nurses and 20 permanent day working nurses on both work and rest days, with 16 females and 4 males in each group. On rest days the melatonin of night workers peaked about two hours later (at about 07:00) than that of day workers. The melatonin rhythm of day workers peaked at about the same time on work days as on rest days, whereas that of night workers showed a "random distribution" on work days. The authors distinguished two sub-groups of night workers. The larger group had a similarly timed melatonin peak on work days as on rest days. The smaller group (N=6) had a peak that was delayed by an average of five hours (i.e. to about 12:00), although the large standard deviation ($\pm$ 40 mins) suggests considerable variation across individuals. Unfortunately, estimates of the "peak" time were based on cosinor analyses and insufficient details are given of the individual results to assess how many of those who showed a delayed phase could be considered as having shown "good" adjustment.

Finally, in a carefully conducted study Dumont et al (2001) studied 30 permanent night nurses (27 women and 3 men) who worked shifts from 00:00 to 08:00 on a schedule that involved at least three successive night shifts. Melatonin was measured every two hours under dim light conditions in a laboratory for a 24-hour period following the third night shift. The authors report both the timing of the episode of melatonin secretion and the estimated acrophase for each of the 30 individuals. Only a single participant showed a melatonin secretion episode (from 08:00 to 20:00) that was entirely outside the timing of the night shift, although a further 4 showed an onset at 06:00. The authors refer to these five individuals as the "delayed group", and they also identified an "advanced group" of three participants whose melatonin onset occurred at 16:00 or 18:00, instead of between 22:00 and 02:00.

Interestingly, the "advancers" also showed a significantly later day sleep onset and offset than either the delayed group, or the non-adjusters. They would thus have been awake for significantly less time than the others before starting their night shift, and are likely to have felt less fatigued at the start of their night shifts because of this. Nevertheless, it is clear that only 8 out of 30 individuals showed clear evidence of adjustment of their melatonin rhythm, and only in one of these was the adjustment clearly "good".

In summary, a total of 34 male and 51 female permanent night workers have been examined in a total of six studies published in seven journal articles with respect to the adjustment of their circadian rhythms in melatonin to a permanent night shift. These studies and their main findings are summarised in Table E-2. It is clear from this table that only six out of 85 (i.e. 7%) permanent night workers studied showed evidence of "good" adjustment. However, 25 of the 85 (i.e. 29%) showed evidence of at least some adjustment that may have benefited them in some way.

Table E-2 Summary of the studies of the adjustment of the melatonin rhythm to permanent night work

Study	*No. of Participants*		*No. showing adjustment*	
	Male	*Female*	*Some**	*Good*
Waldhauser et al (1986)	2	0	2	1
Sack et al (1992)	2	8	3	1
Roden et al (1993)	9	0	1	1
Koller et al (1994)	14	0	5	2
Quera-Salva et al (1996 &1997)	4	16	6	?
Dumont et al (2001)	3	27	8	1
Total Numbers	**34**	**51**	**25**	**6**

* This figure includes those showing "good" adjustment.

Although the various studies fail to identify the gender of those that showed some adjustment, it is clear from Table E-2 that three of the studies involved only males (total N= 25), while in the other three studies the vast majority of the participants were female (51 out of a total N of 60). Given this, it is possible to estimate the proportion of participants showing some evidence of adjustment separately for the male and "predominantly female" groups. In the studies in which the females predominated 17 out of 60 (i.e. 28%) showed evidence of some adjustment, while in the studies of males only, 8 out of 25 (i.e. 32%) showed evidence of adjustment.

E.5 CONCLUSIONS AND IMPLICATIONS FOR A "FATIGUE INDEX"

From this review of the adjustment of the circadian rhythm in the secretion of melatonin to permanent night work it seems reasonable to conclude that:

- only a small minority (<10%) of permanent night workers shows evidence of "good" adjustment of their circadian system to night work,
- less than one-third of permanent night workers show evidence of sufficient adjustment to derive any benefit from it, and
- there is no evidence of a gender difference in the adjustment to permanent night work.

These conclusions have a number of implications for the design of a "Fatigue Index" for use with permanent night workers. First, it seems possible that the general (rotating) version of the new fatigue index might work adequately for the majority (about 70%) of permanent night workers. Thus, although there is evidence for an increased average day sleep duration in permanent night workers in comparison to rotating workers, this may reflect on the combined effects of (i) an increased sleep duration in the minority (30%) of permanent night workers who show evidence of adjustment to night work, and (ii) increased pressure for sleep due to a cumulative sleep debt in those who show insufficient adjustment. There is thus some reason to suggest that non-adjusting permanent night workers might be treated in the same manner as rotating shift workers whose shift system involves night work.

Secondly, however, the use of the "normal" Fatigue Index on a group of permanent night workers would almost certainly prove over-restrictive for the significant minority (about 30%) of permanent night workers who are likely to show some adjustment of their circadian rhythms. These individuals would probably be able to work a substantially longer span of successive night shifts without suffering any major ill effects in terms of fatigue and safety.

Indeed, it seems probable that in some situations, such as oil rigs, and some other occupations where the workforce comprises predominantly young, single, individuals, the proportion that shows adjustment of their circadian rhythms to night work might be rather higher. Further, there is suggestive evidence that those who adjust by advancing their rhythms may be at an advantage over those who delay.

In conclusion, based on the available evidence it seems that it would be possible to develop a "Fatigue Index" for permanent night workers, but that this would need to take account of the extent of adjustment, if any, to nightwork. This would require the development of some means of assessing the extent to which any given individual showed adjustment to permanent nights. The simplest way of assessing this would probably be to develop and validate a self-assessment questionnaire of adjustment. This would ideally allow a determination of both the extent and direction of adjustment of an individual's circadian rhythms. Once validated, this could then be used to determine which version of a permanent night "Fatigue Index" was applicable for any given individual. It could also potentially be used to identify those individuals who are best suited to a permanent night shift.

E.6 REFERENCES

Colquhoun WP, Blake MJF, Edwards RS (1968a). Experimental studies of shiftwork I. A comparison of rotating and stabilized 4-hour systems. Ergonomics, 11, 437-453.

Colquhoun WP, Blake MJF, Edwards RS (1968b). Experimental studies of shiftwork II. Stabilized 8-hour shift system. Ergonomics, 11, 527-546.

Colquhoun WP, Blake MJF, Edwards RS (1969). Experimental studies of shiftwork III. Stabilized 12-hour shift system. Ergonomics, 12, 865-882.

Dumont M, Benhaberou-Brun D, Paquet J (2001). Profile of the 24-h light exposure and circadian phase of melatonin secretion in night workers. Journal of Biological Rhythms, 16, 502-511.

Folkard S (1988). Circadian rhythms and shiftwork: adjustment or masking? In W.Th.J.M. Hekkens, G.A. Kierkhof & W.J. Rietveld (Eds.), Trends in Chronobiology, Oxford: Pergamon Press, 173-182.

Folkard S (1989). The pragmatic approach to masking. Chronobiology International, 6, 55-64.

Folkard S (1992). Is there a 'best compromise' shift system? Ergonomics, 35, 1453-1463.

Harma M (2000). Circadian adaptation to shift work: A review. In Hornberger S., Knauth P., Costa G. & Folkard S. (Eds) Shiftwork in the 21st Century. pp 125-130. Peter Lang, Frankfurt, Berlin, Bern, Bruxelles, New York, Oxford & Wien.

Knauth P, Rutenfranz J, Herrmann G, Poppel SJ (1978). Re-entrainment of body temperature in experimental shift work studies. Ergonomics, 21, 775-783.

Koller M, Harma M, Laitinen JT, Pielger B, Haider M (1994). Different patterns of light exposure in relation to melatonin and cortisol rhythms and sleep of night workers. Journal of Pineal Research. 16, 127-135.

Pilcher JJ, Lambert BJ, Huffcutt AI (2000). Differential effects of permanent and rotating shifts on self-report sleep length: a meta-analytic review. Sleep, 23, 155-163.

Quera-Salva MA, Defrance R, Claustrat B, De Lattre J, Guilleminault C (1996). Rapid shift in time and acrophase of melatonin in short shift work schedule. Sleep, 19, 539-543.

Quera-Salva MA, Guilleminault C, Claustrat B, Defrance R, Gajdos P, McCann CC, De Lattre J (1997). Rapid shift in peak melatonin secretion associated with improved performance in short shift work schedule. Sleep, 20, 1145-1150.

Roden M, Koller M, Pirich K, Vierhapper H, Waldhauser F (1993). The circadian melatonin and cortisol secretion pattern in permanent night shift workers. American Journal of Physiology, 34, R261-R267.

Sack RL, Blood ML, Lewy AL (1992). Melatonin rhythms in night shift workers. Sleep, 15, 434-441.

Waldhauser F, Vierhapper H, Pirich K (1986). Abnormal circadian melatonin secretion in night-shift workers. New England Journal of Medicine, 315, 1614.

Wedderburn AA (1992). How fast should the night shift rotate? A rejoinder. Ergonomics 35, 1447-1451.

Wilkinson RT (1992). How fast should the night shift rotate? *Ergonomics*, 35, 1425-1446.

E.7 DETAILS OF THE 20 ARTICLES FOUND IN THE REFINED LITERATURE SEARCHES

Search Term: ((melatonin)and((adjustment)or(phase)or(entrainment)))and((night work)or(night shift)or(shiftwork)or(shift work))

1 AN: 2003-06316-007
DT: Chapter
AU: Waterhouse,-James-M; DeCoursey,-Patricia-J
TI: The relevance of circadian rhythms for human welfare.
BK: (2004). Loros, Jennifer J (Ed), et-al. Dunlap, Jay C (Ed), Chronobiology: Biological timekeeping. (pp.325-356). Sunderland, MA, US: Sinauer Associates, Inc. xix, 406 pp.
In Database: PsycINFO 2004 Part B.

2 AN: 2003-99841-004
DT: Peer-Reviewed-Journal
AU: Roemer,-Hermann-C; Griefahn,-Barbara; Kuenemund,-Christa; Blaszkewicz,-Meinolf; Gerngross,-Colonel-Heinz
TI: The Reliability of Melatonin Synthesis as an Indicator of the Individual Circadian Phase Position.
SO: Military-Medicine. Aug 2003; Vol 168 (8): 674-678
In Database: PsycINFO 2003 Part A.

3 AN: 2003-10238-005
DT: Peer-Reviewed-Journal
AU: Crowley,-Stephanie-J; Lee,-Clara; Tseng,-Christine-Y; Fogg,-Louis-F; Eastman,-Charmane-I
TI: Combinations of Bright Light, Scheduled Dark, Sunglasses, and Melatonin to Facilitate Circadian Entrainment to Night Shift Work.
SO: Journal-of-Biological-Rhythms. Dec 2003; Vol 18 (6): 513-523
In Database: PsycINFO 2003 Part A.

4 AN: 2002-06864-006
DT: Peer-Reviewed-Journal
AU: Boivin,-Diane-B; James,-Francine-O
TI: Circadian adjustment to night-shift work by judicious light and darkness exposure.
SO: Journal-of-Biological-Rhythms. Dec 2002; Vol 17 (6): 556-567
In Database: PsycINFO 2002 Part A.

5 AN: 2001-95022-144
DT: Dissertation-Abstract
AU: Wasielewski,-Jill-Ann
TI: Attenuation of alcohol-induced circadian phase-shifts using melatonin and vitamin B12.
SO: Dissertation-Abstracts-International:-Section-B:-The-Sciences-and-Engineering. Dec 2001; Vol 62 (5-B): 2529
In Database: PsycINFO 2001 Part A.

6 AN: 2001-95008-117
DT: Dissertation-Abstract
AU: Sharkey,-Katherine-Margaret
TI: Melatonin administration to phase shift circadian rhythms and promote sleep in human models of night shift work.
SO: Dissertation-Abstracts-International:-Section-B:-The-Sciences-and-Engineering. May 2001; Vol 61 (10-B): 5178
In Database: PsycINFO 2001 Part A.

7 AN: 2001-05020-004
DT: Peer-Reviewed-Journal
AU: Dumont,-Marie; Benhaberou-Brun,-Dalila; Paquet,-Jean
TI: Profile of 24-h light exposure and circadian phase of melatonin secretion in night workers.
SO: Journal-of-Biological-Rhythms. Oct 2001; Vol 16 (5): 502-511
In Database: PsycINFO 2001 Part A.

8 AN: 2001-06192-005
DT: Peer-Reviewed-Journal
AU: Zisapel,-Nava
TI: Circadian rhythm sleep disorders: Pathophysiology and potential approaches to management.
SO: CNS-Drugs. 2001; Vol 15 (4): 311-328
In Database: PsycINFO 2001 Part B.

9 AN: 1998-07414-000
DT: Edited-Book
AU: Lam,-Raymond-W (Ed)
TI: Seasonal affective disorder and beyond: Light treatment for SAD and non-SAD conditions.
BK: (1998). Washington, DC, US: American Psychiatric Association. xii, 327 pp.
In Database: PsycINFO 1998-1999.

10 AN: 1997-36779-003
DT: Chapter
AU: Lewy,-Alfred-J; Sack,-Robert-L; Cutler,-Neil-L; Bauer,-Vance-K; Hughes,-Rod-J
TI: Melatonin in circadian phase sleep and mood disorders.
SE: Progess in Psychiatry, No. 55.
BK: (1998). Shafii, Sharon Lee (Ed), Shafii, Mohammad (Ed), Melatonin in psychiatric and neoplastic disorders. (pp.81-104). Washington, DC, US: American Psychiatric Association.

xxiii, 314 pp.
In Database: PsycINFO 1998-1999.

11 AN: 1997-36779-000
DT: Edited-Book
AU: Shafii,-Mohammad (Ed); Shafii,-Sharon-Lee (Ed)
TI: Melatonin in psychiatric and neoplastic disorders.
SE: Progess in Psychiatry, No. 55.
BK: (1998). Washington, DC, US: American Psychiatric Association. xxiii, 314 pp.
In Database: PsycINFO 1998-1999.

12 AN: 1998-12090-013
DT: Peer-Reviewed-Journal
AU: Arendt,-Josephine; Skene,-Debra-J; Middleton,-Benita; Lockley,-Steven-W; Deacon,-Stephen
TI: Efficacy of melatonin treatment in jet lag, shift work, and blindness.
SO: Journal-of-Biological-Rhythms. Dec 1997; Vol 12 (6): 604-617
In Database: PsycINFO 1995-1997.

13 AN: 1998-12090-012
DT: Peer-Reviewed-Journal
AU: Sack,-Robert-L; Lewy,-Alfred-J
TI: Melatonin as a chronobiotic: Treatment of circadian desynchrony in night workers and the blind.
SO: Journal-of-Biological-Rhythms. Dec 1997; Vol 12 (6): 595-603
In Database: PsycINFO 1995-1997.

14 AN: 1996-04296-002
DT: Peer-Reviewed-Journal
AU: Hakola,-Tarja; Harma,-Mikko-I; Laitinen,-Jarmo-T
TI: Circadian adjustment of men and women to night work.
SO: Scandinavian-Journal-of-Work,-Environment-and-Health. Apr 1996; Vol 22 (2): 133-138
In Database: PsycINFO 1995-1997.

15 AN: 1996-03952-009
DT: Peer-Reviewed-Journal
AU: Skene,-Debra-J; Deacon,-Stephen; Arendt,-Josephine
TI: Use of melatonin in circadian rhythm disorders and following phase shifts.
SO: Acta-Neurobiologiae-Experimentalis. 1996; Vol 56 (1): 359-362
In Database: PsycINFO 1995-1997.

16 AN: 1996-02195-019
DT: Peer-Reviewed-Journal
AU: Lewy,-Alfred-J; Ahmed,-Saeeduddin; Sack,-Robert-L
TI: Phase shifting the human circadian clock using melatonin.
SO: Behavioural-Brain-Research. Dec 1995; Vol 73 (1-2): 131-134
In Database: PsycINFO 1995-1997.

17 AN: 1995-95009-261
DT: Dissertation-Abstract
AU: Loving,-Richard-Thomas
TI: Circadian rhythms in the human pupil and eyelid.
SO: Dissertation-Abstracts-International:-Section-B:-The-Sciences-and-Engineering. May 1995; Vol 55 (11-B): 4788
In Database: PsycINFO 1995-1997.

18 AN: 1993-24813-001
DT: Peer-Reviewed-Journal
AU: Suvanto,-S; Harma,-Mikko; Laitinen,-JT
TI: The prediction of the adaptation of circadian rhythms to rapid time zone changes.
SO: Ergonomics-. Jan-Mar 1993; Vol 36 (1-3): 111-116
In Database: PsycINFO 1992-1994.

19 AN: 1993-20910-001
DT: Journal
AU: Lewy,-Alfred-J; Ahmed,-Saeeduddin; Jackson,-Jeanne-L; Sack,-Robert-L
TI: Melatonin shifts human circadian rhythms according to a phase-response curve.
SO: Chronobiology-International. Oct 1992; Vol 9 (5): 380-392
In Database: PsycINFO 1992-1994.

20 AN: 1992-85634-001
DT: Peer-Reviewed-Journal
AU: de-Koninck,-Joseph
TI: Biological rhythms linked to sleep and psychological adaptation / Les rythmes biologiques lies au sommeil et l'adaptation psychologique.
SO: Journal-of-Psychiatry-and-Neuroscience. Sep 1991; Vol 16 (3): 115-122
In Database: PsycINFO 1989-1991.

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