Epidemiological Diagnosis of Occupational Fatigue in a Fly-In–Fly-Out Operation of the Mineral Industry

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Objective: A prospective epidemiological study was conducted at a fly-in–fly-out mining operation in Australia to assess the dynamics of occupational fatigue and its potential risk factors.

Methods: Performance and perceived fatigue were measured at the start/finish of each 12-h shift throughout the 28-day roster (10 days day shift work on-site, 5 days rest off-site, 8 days night shift work on-site and 5 days rest off-site) using the Mackworth Clock Vigilance test and the Swedish Occupational Fatigue Inventory, respectively. Additionally, major predisposing/reinforcing factors of fatigue were measured including a detailed sleep diary (length/quality of sleep, wake patterns), a diary on alcohol consumption and a general health/fitness questionnaire.

Results: Of 55 production staff at the site 52 (95%) participated in the study. Significantly increased occupational fatigue was observed at concerning levels at the finish of night shifts 1–3 and from day shift 8 onwards. At the measured level, total hours of sleep (average 6.8 h per night) and number of standard drinks (average 1.5) were not significantly correlated with fatigue measurements.

Conclusions: A disturbed diurnal rhythm at the beginning of night shift and a roster of more than eight consecutive days were identified as the primary contributing factors to occupational fatigue in this setting. The observed magnitude of effects suggests adverse implications for safety as the effects on performance were beyond what would be expected at blood alcohol concentrations of 0.05%. The results of this study have been used to generate highly specific strategies to reduce fatigue in the workplace.

Keywords: epidemiology; mining; occupational fatigue; risk assessment; risk management

INTRODUCTION

Fatigue in the workplace is of concern due to its potential to contribute to incidents that result in injury and fatalities and in causing damage to the environment. Occupational fatigue has been identified as a cause of major incidents such as the Three Mile Island and Chernobyl nuclear reactor meltdowns, the Challenger Space Shuttle disaster, the Bhopal Union Carbide plant explosion and the grounding of the Exxon-Valdez oil tanker (Mitler et al., 1988; Dinges, 1995). The cost of fatigue-related incidents to industry was estimated to be $US16 billion per year in the US and $80 billion per year worldwide in 1993 (Moore-Ede, 1993).

Fatigue is defined as a syndrome of effects resulting in impaired physical or mental performance (Grandjean, 1979). Fatigue is characterized by a range of signs and symptoms such as tiredness and increasing sleep need and may be regarded as a common outcome of a wide variety of potential intrinsic and extrinsic risk and causal factors. Much of occupational fatigue-related research has focused on specific sleep-related risk factors [quality, quantity, circadian rhythm and deprivation of sleep (Parkes, 1994; Pilcher and Huffcutt, 1996; Dawson and McCulloch, 2005; Durmer and Dinges, 2005)]. While these effects are undisputed, the view that ‘It’s all about sleep’ (Dawson and McCulloch, 2005) overlooks a number of other important predisposing, precipitating and perpetuating factors (in the following termed ‘risk factors’) that either cause or influence susceptibility to fatigue. These may include physiological factors such as lack of physical fitness.
(Bultmann et al., 2002), morbidity (Ting and Malhotra, 2005), and alcohol intoxication, hangover and withdrawal (Wiese et al., 2000). Perceived fatigue may also be an outcome of psychological disorders including depression and anxiety (Sharpe and Wilks, 2002). In occupational settings, the workplace environment (heat, noise, vibration) and organizational factors [job demand and control (Finkelman, 1994), work to rest ratios, start time (Smith et al., 1998) and shift and roster duration (Duchon et al., 1994; Pilcher et al., 2000)] have also all been identified as potential causes of fatigue.

The paucity of evidence-based research of the multiple factors influencing occupational fatigue contrasts sharply with the undisputed immense impact of occupational fatigue on industry. Research is needed that looks at the role of individual risk factors on fatigue experiences and effects in the workplace.

Research on occupational fatigue has focused on the effects of irregular hours of work. Fly-in–fly-out (FIFO) operations are a form of irregular working hours that has attracted little research attention despite increasing in popularity in the mining sector. Staff at FIFO operations are flown to the worksite and subsequently stay at the site for the duration of the roster. FIFO is clearly suited to remote operations in the minerals extraction industries throughout the world. FIFO work arrangements have significant potential to cause occupational fatigue as FIFO rosters differ significantly from the standard working week. Rosters generally consists of a large number of consecutive shifts, usually from 8 to 14 days of 12-h duration involving night shifts, followed by an extended block of rest and recreation (R&R) spent off-site. In contrast, however, the results of the few studies of FIFO operations suggest that shift workers in this type of work organization have better circadian adaptation due to the 24-h nature of the living and working conditions in the remote or offshore worksites (Barnes et al., 1998; Bjorvatn et al., 1998). These findings, on the other hand, may simply reflect a self-selection of those with a superior ability to adapt to FIFO rosters.

The lack of unequivocal findings on the effects of FIFO as well as the increasing use of FIFO operations in Australia and elsewhere provided the impetus for the current study to evaluate the effects of FIFO operations on fatigue in the mineral industry in Australia.

The Occupational Health Research Group (OHRG) at James Cook University (JCU) has been conducting extensive epidemiological studies on workplace environment and health since 2000 at different FIFO operations in Australia. In 2005, a specifically designed prospective study of individual risk factors for fatigue, self-reported fatigue and changes in performance in production staff was conducted at one FIFO site. The specific study aims were to:

1. examine the effects of FIFO operations on self-reported fatigue and performance over a whole FIFO production roster and
2. determine attributable fractions for potential individual risk factors for occupational fatigue.

METHODS

Setting

The study was conducted at a minerals extraction and processing operation located in the remote Australian dry tropics where staff are exposed to relatively hot temperatures for much of the year. At 0600 h on day 1 of their 28-day roster, production staff are flown (1.5 h) from their home coastal city to the remote inland worksite where they are accommodated throughout 10 consecutive 12-h day shifts (0600–1800 h daily, the first day shift starts at 0800 h). At the end of day 10, they return home to have five full days R&R. At 2000 h on day 15, staff are again flown to the worksite to start the first of eight consecutive 12-h night shifts (1800–0600 h daily, the first night shift starts at 2000 h). On day 23 at 0600 h, staff are flown home for another 5 days R&R following which the roster starts again. While at the worksite, time off-shift is spent at a camp of self-contained bungalows with ensuite amenities located close to the production site. Facilities at the camp include a dining room, licensed bar, swimming pool and gymnasium. Bungalows are fully darkened for daytime sleep during night shift.

Participants

All staff \((n = 55)\) working in the production roster were invited to participate. Duties range from observation and control of data management screens to routine maintenance tasks. Three staff declined to participate and four staff did not complete either a full day or a night shift period due to leave. Forty-eight staff completed at least 1 day or night shift period. Complete data of a day and night shift period were available for 42 and 41 subjects, respectively. The resulting proportions of participation and compliance were 95 and 87%, respectively. The Human Ethics Sub-committee at JCU granted approval for all parts of this study.

Sample size

The sample size for this study was calculated to detect a change of 10% in response times assuming a baseline mean of 700 ms with a standard deviation of 100 ms. Thirty-five employees were required to detect this difference as statistically significant at an alpha level of 0.05 and a power of 0.8.

Self-reported data. Baseline questionnaire: The baseline questionnaire was specifically designed
and extensively tested prior to employment and comprised the following groups of items: (i) demographics, (ii) general fitness [as measured anthropometrically, especially body mass index (BMI) and waist-to-hip ratio (WHR)], (iii) prior diagnoses of health events with potential associations with fatigue (hypertension, cardiovascular disease, diabetes, sleep-related disorders) and (iv) recent signs and symptoms of fatigue, sleep patterns and problems and work and leisure activity patterns including a diary of self-reported alcohol consumption and the National Sleep Foundation of America Sleep diary.

Sleep diary: The Pittsburgh Sleep Diary (National Sleep Foundation of America sleep diary) (Monk et al., 1994) was used to daily record self-reported work, sleep, leisure and physical activity patterns of participants throughout the entire observation period. This sleep diary has been repeatedly validated, is very well established and generally accepted as the standard for a detailed measurement of different dimensions of sleep including overall and net duration, quality of sleep, wake phases, time to onset of sleep and perceived sleep quality.

Dimensions of fatigue questionnaire: The Swedish Occupational Fatigue Inventory (SOFI), a well-validated and accepted instrument (Ahsberg and Gamberale, 1997; Ahsberg et al., 1997; Ahsberg et al., 2000a,b), was administered to measure the perceived intensity of the following five physical and mental dimensions of fatigue: (i) lack of energy, (ii) physical exertion, (iii) physical discomfort, (iv) lack of motivation and (v) sleepiness. Participants rated their perceived fatigue according to 20 items using a seven-point adjectival scale from ‘not at all’ (0) through to ‘extremely’ (6). Four items relate to each of the above five dimensions of perceived fatigue and are for analytical purposes averaged to produce one robust scale (ranging from 0 to 6) for each dimension.

Performance tests. The Mackworth Clock Vigilance (MCV) task, a validated computer-based performance test, was used to measure concentration and reaction times via response time to visual cues (Williamson et al., 2001). The vigilance task tests were performed on dedicated computers in a quiet room specifically devoted to the data collection process. During this passive vigilance test of 15-min duration, a circle of 24 equally spaced dots is presented on the computer screen. Each dot flashes briefly in a clockwise sequence at a constant interval of 0.5 s. One of the dots is omitted from the flashing sequence on 15 occasions at random intervals throughout the test. Subjects are to respond to the change in flashing sequence as quickly as possible by depressing a designated key on the computer keyboard; response times are recorded. The MCV in contrast to other ‘reaction’ tests also implies a component of cognitive processing.

Methods of participant evaluation

Each participant was measured initially by the baseline questionnaire. The study subsequently collected detailed data of performance tests, perceived fatigue and diaries of self-reported items from staff during both the day and night shift phases of the roster twice daily (within 2 h following commencement and prior to cessation of each shift) for the duration of the 28-day production roster. Two crews started this monitoring process with the day shift phase and another two crews started the process with the night shift phase of their roster. Sleep diaries were also kept during the R&R phases of the roster.

Data analysis

Internal consistency of the five dimensions of the SOFI and the MCV task were evaluated using Cronbach’s alpha.

Numerical variables were described using standard parametric or non-parametric measures of central tendency/dispersion depending on the normality of the underlying distributions. Categorical variables were described as percentages.

Bivariate testing on performance measures and SOFI ratings were carried out by paired and unpaired t-tests and analysis of variance models since no violation of normality assumption was observed. Bonferroni-Holmes adjustments of the P-values were applied for multiple pairwise comparisons. Time trends of SOFI ratings and performance measures are displayed as means (±standard error) together with a fitted spline function.

Possible associations between fatigue ratings, performance measures and potential influencing factors were assessed by standard parametric regression analyses. Multivariate regression analyses are not presented because of the small sample size and the coinciding lack of statistical power.

RESULTS

Demographics and work history

The mean age of the sample was 37 years, all were male. Two-thirds of the sample were either married (45.1%, n = 23) or in a de facto relationship (19.6%, n = 10). Almost half of employees had completed education beyond secondary school. Participants were experienced in working in FIFO operations and shift work with medians (inter-quartile ranges) of continuous employment of 48 (27–60) and 48 months (18–144), respectively.

Baseline physiology

The mean BMI was 28.9 kg m⁻², with 35.3% (n = 18) of staff having a BMI of greater than 30 kg m⁻². The mean WHR of the sample was 0.93.
One-third of the sample (33.3%, n = 17) had a WHR in the excess of 0.95.

**Baseline self-reported data of fatigue-related health**

Previous notification of high blood pressure or heart-related illness by a medical practitioner was reported by 17.6 and 3.9% of the participants, respectively. No subjects reported a previous diagnosis of diabetes, stomach ulcer or sleep apnoea.

More than half of all subjects had experienced tired or strained eyes (80.4%, n = 41), difficulty remembering or concentrating (60.8%, n = 31), difficulty staying asleep (54.9%, n = 28), excessive daytime sleepiness (54.9%, n = 28) and tension, irritability or nervousness (49.0%, n = 26) while on-site in the 4 weeks prior to the baseline survey. The symptoms most frequently experienced every or almost every day were tired or strained eyes (11.8%, n = 6) and excessive drowsiness on waking (7.8%, n = 4).

**Baseline self-reported lifestyle data**

More than a quarter of the sample smoked (27.5%, n = 13) and the same proportion reported being former smokers (27.5%, n = 13) with a median pack-year history of 18.0 and 12.3 pack-years, respectively. No alcohol consumption at all was reported by 15.7% while at-camp and 13.7% while off-site. Of those who drink alcohol, a median of two drinking days per week (inter-quartile range of 1–5) was reported while at-camp and two (1–4) while off-site with a median of four (2–6) standard drinks per session at-camp and six (3–10) drinks off-site. The reported median hours of sleep were 6.5 h (6–7) at-camp and 8 h (7–9) off-site. Physical activity of >30 min of vigorous exercise was reported on 5 days (3–7) per week at-camp and 4 (2–5) days per week off-site.

**Diary on self-reported alcohol consumption**

An average of two standard drinks of alcohol was consumed at-camp during the day shift phase of the roster; the range of median standard drinks the night before the next day shift ranged from 1.7 to 2.8. During the night shift phase of the roster, the average number of drinks consumed was 1.0 with a range of daily medians from 0.6 to 1.4. Alcohol consumption was highest during the first 2 days of the R&R segment of the roster where medians of 3.5 drinks were observed during the first 2 days, followed by 2 days of 2.5 drinks and 1 day of 1.0.

**The Pittsburgh Sleep Diary**

The overall median of durations of ‘net’ sleep (i.e. subtraction of time taken to fall asleep and wake phases during the night) was 6.6 h during the day shift phase of the roster with medians of single nights ranging from 6.4 to 6.8 h. The respective durations of net sleep during the night shift phase were 6.7 h with a range of 6.4–7.2 h observed over the single days. The longest sleeps were observed during the R&R phase with a medium duration of 8.2 h of net sleep during the first four nights. The median hours of net sleep during the nights before the next work phase were 5.8 and 7.0 h for a subsequent day and night shift, respectively.

The frequency of waking during sleep was reported with a median below 1 time during the day shift phase with the exception of a median of 2 for the last night before fly-out. The median frequency during the night shift phase was 1 for all days measured. For the R&R, the frequency of waking during the night was reported at a median of 0.8.

**Subjective fatigue ratings: the SOFI**

**Internal consistency.** Evaluations of the five dimensions of SOFI revealed high internal consistencies for both, the day shift phase and the night shift phase of the roster with Cronbach’s alpha ranging between 0.953 and 0.985.

**Lack of energy.** The general level of perceived lack of energy ranged between 1 and 2 (i.e. between 15 and 33% of the range of the measurement scale) during day shift and between 1.2 and 2.5 (20 and 42% of the scale) during night shift. The peaks were centred around day shifts 9 and 10 and at the end of night shifts 1–3. After shift readings were significantly higher than pre-shift readings across the board. Increasing time trends over the day shift phase were observed for the pre-shift readings (significant from day 5 onwards) and post-shift readings (only day 10) but not over the night shift phase. A perceived lack of energy is therefore seen to play a relevant role at the end of the first night shifts and as an accumulating factor over the length of the day roster.

**Physical exertion.** The general level of perceived physical exertion did not exceed 1.5 (i.e. 25% of the range of the scale) at any measurement point. No significant changes or trends were observed.

**Physical discomfort.** The general level of physical discomfort ranged between 1 and 1.6 during day shift and between 1 and 1.8 during night shift (i.e. at no point in time exceeded 30% of the range of the scale). Post-shift readings were significantly higher than pre-shift measurements for all working days of the night shift phase but not for the day shift phase. The peaks were observed after the last three night shifts but no significant trends were discernible during the day or the night shift phase of the roster.

**Lack of motivation.** Scores on the perceived lack of motivation scale ranged between 1.3 and 1.8 (22–30% of the scale) during day shift and between 1.7 and 2.3 during night shift (28–38% of the scale). There were no statistically significant differences between day and night shift or from pre- to post-shift on this scale. Also no significant peaks or trends
were observed over the duration of either phase of the roster.

Sleepiness. The general level of perceived sleepiness increased (not significantly though) from 1.3 to 1.7 (22–28% of scale) during day shift (see Fig. 1a,b). These readings are comparable to the pre-shift measurements of the night roster (1.3–1.8; 22–30%). The peaks of perceived sleepiness during the night shift phase of the roster occur at the end of the first four night shifts with readings constantly above 40% of the scale with a maximum of 2.8 (47% of the scale) after the second night shift which constitutes the maxima of all readings on any dimension of perceived fatigue. The readings after the first four night shifts are also significantly higher than the corresponding day shift measurements. Perceived sleepiness is therefore seen to play an important role at the end of the first four night shifts.

The main results from the subjective ratings of occupational fatigue dimensions indicate that (i) the pure physical dimensions do not seem to play a major role at the site and (ii) lack of energy and sleepiness are perceived at relevant levels and indicate fatigue issues during the first three to four shifts of the night roster and—as an accumulating effect—over the consecutive day shifts, especially during the second half of the day shift phase of the roster.

Performance measure: the MCV task

Internal consistency. Evaluations revealed high internal consistency of the performance measure with a Cronbach’s alpha of 0.954 for the day shift phase and 0.913 for the night shift phase of the roster, respectively.

Dynamics. During the day shift phase of the roster, pre- and post-shift response times gradually rose until day 8, when a significant increase in pre- and post-shift response times was sustained to the end of the day shift phase of the roster (Fig. 2a).

During the night shift phase of the roster, the worst response times of all readings were measured at the end of the first four night shifts. The pre-shift response times remained constant for the first four nights and then increased gradually until a significant increase at night 7 was reached. The respective post-shift measurements during night shift, albeit significantly higher than the pre-shift readings, do not show any significant change over the nights (Fig. 2b).

These results indicate an issue during the first four as well as the last night of the night roster and—as an accumulating effect—over the consecutive days of the day roster, especially during day shift 9 and 10.

Change over shifts. Figure 3a,b display the observed changes in response times (over day and night shifts, respectively) as a percentage of the response times measured at the start of the roster phase. Studies have established (Lamond and Dawson, 1999; Williamson and Feyer, 2000; Williamson et al., 2001) that a 10 and 20% increase in response time is equivalent to the impairment arising from blood alcohol concentrations of 0.05 and 0.10%, respectively. The equivalent impairments in response times expected by these blood alcohol concentrations are displayed as horizontal reference lines.

Association between potential individual risk factors to occupational fatigue, subjective (SOFI) assessments and performance (MCV)

No significant correlations were observed between BMI, WHR or self-reported physical activity patterns and MCV and SOFI measurements (all $r^2 < 0.1$; all $P > 0.2$). No significant associations between any of the examined prior diagnoses of health events with a potential to impact on fatigue and both MCV and SOFI readings were found (all $P > 0.3$).

Comprehensive analyses correlating MCV measurements and SOFI ratings with the detailed information on net hours of sleep from the diary (examined as net hours of sleep prior to the next shift readings as well as accumulated hours of sleep over the length of the shifts) revealed no significant findings (all $r^2 < 0.13$, typically below 0.05; all $P > 0.1$).

Identical analytical approaches were used to assess the potential relationship between alcohol consumption and MCV and SOFI assessments. No significant correlations were found (all $r^2 < 0.1$, typically below 0.05; all $P > 0.1$) for absolute number of standard drinks or the respective accumulated number over the length of the shift.

Therefore, inadequate sleep, alcohol consumption, physical fitness and prior diagnoses of health events could all be excluded as major contributing factor to occupational fatigue at the assessed site.

DISCUSSION

An evaluation of the effects of FIFO rosters on occupational fatigue is timely given their increasing use in the minerals industry worldwide. This study demonstrated adverse effects on subjective fatigue ratings and performance capacity during blocks of both day and night shifts in a FIFO operation at this Australian minerals operation. The results show that a FIFO working arrangement incorporating 10 consecutive 12-h day shifts is of concern as significant performance decrements appeared after eight consecutive shifts. Even more obvious effects were seen during the consecutive 12-h night shifts. At the end of the first two night shifts, workers showed significantly elevated fatigue ratings and significantly slower response times compared to the beginning of the shift. Notably, the observed magnitude of effects suggests adverse implications for safety as the deteriorations of performance were beyond what would be expected at blood alcohol concentrations of 0.05%, a level...
legally rendering subjects unfit to drive a vehicle in Australia (Williamson and Feyer, 2000).

These results suggest the action of two different mechanisms. The effects of the extended sequence of day shifts are most likely due to the accumulation of fatigue, despite adequate self-reported sleep between shifts (see detailed discussion on sleep below). Current shift scheduling recommendations suggest a maximum of five to seven consecutive working days (Knauth and Hornberger, 2003). The effects of the transition to night shifts clearly indicate a circadian disruption and are a well-recognized consequence of shift work (Drake et al., 2001; Belenky et al., 2003). These findings are also in agreement with other studies of FIFO-related working arrangements (Bjorvatn et al., 1998). Importantly, there was also evidence of circadian adaptation to night work in the FIFO workers in this study since the adverse effects decreased over consecutive night shifts. This adaptation is again consistent with those of previous studies of night shift workers at remote locations which showed decreased night work sleepiness (Barnes et al., 1998; Bjorvatn et al., 1998) and full adaptation of the melatonin rhythm over

Fig. 1. Dynamics of the sleepiness dimension of SOFI during the day shift (a) and night shift (b) phase of the roster.
14 consecutive 12-h night shifts. These findings support the idea that the living conditions of remote and FIFO worksites can be more suitable for staff working shifts due to increased control of their rest period activities and exposure to light during night shift.

This study provided an opportunity to explore the effects of individual risk factors for occupational fatigue including fatigue-related health problems, lifestyle characteristics including alcohol consumption and sleep characteristics. Baseline physiological measures indicated that one-third of participants could be classified as overweight. However, no extreme values were observed, and the number of stated days during a week with moderate physical activity (5 days while on-site and 4 days while off-site) also supports a general fitness for work. It is consequently unsurprising that no significant associations were observed between any anthropometric or physical activity variables and the fatigue or performance measures. The same holds true for prior medical diagnoses of potentially fatigue-related illnesses.

Fig. 2. Dynamics of performance capacity (MCV) during the day shift (a) and night shift (b) phase of the roster.
Dehydration is a potential risk factor for occupational fatigue in this workforce as temperatures in the area are often above 40°C for much of the year. Though not measured during the present study, dehydration can also be safely excluded as a major contributor to occupational fatigue at the site due to extensive prior studies with these workers (Carter et al., 2006). The earlier results showed that although the highest urine specific gravity occurred at the start of shift when one in five workers arrived with a urine specific gravity of 1.025 or above, they improved substantially from 2 h into the shift onwards. Furthermore, none of the workers had a urine specific gravity of 1.030 or more. Therefore, although the long-term effects of dehydration in these workers are unresolved, short-term dehydration could be excluded as a potential contributor to occupational fatigue for this study population.

Self-reported alcohol consumption was moderate so it is not unexpected that there were no significant associations between alcohol use and fatigue ratings or performance. While self-reported alcohol consumption is often regarded as unreliable (Feunekes et al., 1999), the OHRG at JCU has established an

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**Fig. 3.** Percentage change of performance capacity (MCV) during the day shift (a) and night shift (b) phase of the roster. The reference lines indicate impairments expected from blood alcohol concentrations of 0.05 and 0.10%, respectively.
effective relationship with staff at the site over 5 years repeatedly demonstrating strict confidentiality of any individual information. The resulting basis of trust should guarantee at least a reasonable level of validity of self-reported alcohol consumption in this specific study.

Sleep history could also be excluded as a risk factor for fatigue ratings and performance in this study. Laboratory-based studies have consistently reported that humans following a normal circadian rhythm require an average of approximately 8 h of basal sleep to maintain neurobehavioral performance (Van Dongen et al., 2003a). However, there is significant inter-individual variation in both the amount of basal sleep required and the impact of sleep loss on subsequent performance (Van Dongen et al., 2003b; Van Dongen et al., 2005). The present study corroborates previous sleep laboratory-based findings (Drummond et al., 2000; Drake et al., 2001; Belenky et al., 2003) that an average of close to 7 h of net sleep is sufficient to avoid any relevant impact on performances and perception of fatigue over the duration of the roster. The statement that staff had ‘adequate’ sleep during shifts has to be interpreted in the sense of ‘sufficient to avoid impact on performances’ since staff apparently do accumulate a moderate sleep debt as indicated by the increased hours of sleep during the R&R phase of the roster.

In summary, the direct measurement of fatigue at the individual level has excluded the ‘classical risk factors’ as major contributors to occupational fatigue at this FIFO operation. In this context, it seems worth noting that this statement is not based on statistical significance only (P-values may be disputable because of the relatively small sample size) but rather the coefficients of determination that state the percentage of explained variance and therefore deliver a reliable measure of relevance. A residual summary effect of all risk factors taken together, however, cannot be ruled out. However, a quantification of such a possible effect is neither viable (multivariate techniques are impeded by the small size) nor helpful in practical terms as a summary effect would not identify any tangible targets for intervention strategies.

The main factors influencing occupational fatigue in staff at this operation were a disturbed circadian rhythm at the start of the night roster and the overall length of the day roster. Importantly, these organizational factors played a role when individual risk factors were excluded.

It could be argued that due to the multifactorial nature of the fatigue syndrome, the findings of this study may be site specific and may not be readily generalizable to other operations. The results, however, were similar to those of the few previous studies of remote or FIFO working arrangements. Furthermore, this study is also largely free from potential selection bias. The proportions of informed consent and compliance were 95 and 87%, respectively, which is very high for studies in an operational setting.

The comprehensive research approach of this study using direct measurements at the individual level can readily be employed in other operations and industries. This approach has the potential to not only generate highly specific strategies to reduce fatigue in the workplace but also to improve the methodologies used to research occupational fatigue which are currently characterized by general (i.e. non-site or staff subgroup specific) prescriptive fatigue management guidelines issued by the companies and mostly developed from an inconclusive descriptive evidence base that addresses outcomes rather than causal or risk factors.

Evidence of the potential for the presented comprehensive type of research to influence policy and practice can be seen in the follow-up of the current study. In a proactive approach to health and safety, the mine operators have reduced the length of the day roster to 8 days and research on the impact of this change is under way.

Currently, epidemiological studies are being designed to address the identified fatigue issue during night shifts by applying the current findings from the field of chronobiology (Foster and Kreitzman, 2004) where exposures of 10–15 min to artificial illumination of moderate level (250 lux) (Bourgrine et al., 1995; Eastman and Martin, 1999; Boivin and James, 2005) during specific time slots improved adaptation to a change in circadian rhythm during night shift (Iwata et al., 1997; Martin and Eastman, 1998). Short naps have also been demonstrated as effective in reducing fatigue in industry settings (Muzet et al., 1995; Purnell et al., 2002; Bonnefond et al., 2004; Takeyama et al., 2004; Takeyama et al., 2005) and will also be further researched on-site.

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REFERENCES
