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Gemma Maisey
Edith Cowan University

Marcus Cattani
Edith Cowan University

Amanda Devine
Edith Cowan University

Johnny Lo
Edith Cowan University

Shih Ching Fu

See next page for additional authors

Authors

Gemma Maisey, Marcus Cattani, Amanda Devine, Johnny Lo, Shih Ching Fu, and Ian C. Dunican
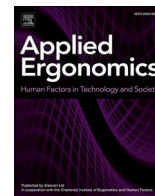
Original Research Paper

Digging for data: How sleep is losing out to roster design, sleep disorders, and lifestyle factors

Gemma Maisey [a,*], Marcus Cattani [a], Amanda Devine [a], Johnny Lo [b], Shih Ching Fu [b], Ian C. Dunican [a]

[a] *School of Medical and Health Science, Edith Cowan University, Perth, W.A., Australia*
[b] *School of Science, Edith Cowan University, Perth, W.A., Australia*

A B S T R A C T

Shift workers employed at a remote mining operation may experience sleep loss, impaired alertness, and consequently negative health and safety outcomes. This study determined the sleep behaviors and prevalence of risk for sleep disorders among shift workers; and quantified alertness for a roster cycle. Sleep duration was significantly less following; night shift by 77 ± 7 min and day shift by 30 ± 7 min. The wake after sleep onset was less by 23 ± 3 min for night shifts and 22 ± 3 min for day shifts ($p < 0.05$ for all). The prevalence of risk for sleep apnea was 31%, insomnia was 8%, and shiftwork disorder was 44%. Average alertness for all working hours was 75%. Shiftwork in remote mining operations is a significant factor that leads to sleep loss and reduced alertness, which is exacerbated by the high prevalence of risk for sleep disorders.

1. Introduction

In the Australian mining industry, the remote location of many mine sites requires individuals to travel long distances by air to work a roster cycle for up to two weeks or more. This is commonly known as a fly-in, fly-out (FIFO) roster (Langdon et al., 2016). It is estimated that there are approximately 60,000 FIFO workers across West Australian mines (Pupazzoni, 2020). Whilst on site they work a roster, such as 14 consecutive shifts of 12 h, starting with seven-day shifts followed by seven-night shifts. This provides a challenge for mining organizations and individuals, to manage fatigue risk and maintain alertness (Chellappa et al., 2019), given the potentially hazardous work and often safety-critical roles (Akerstedt and Wright, 2009; Barger et al., 2009). Of the limited literature on FIFO mining, it is reported that shift workers experience significant sleep loss (<7 h) (Ferguson et al., 2010; Paech et al., 2010). Despite this, very little is known about sleep behaviors and the potential risk of sleep disorders in FIFO shift workers.

Quantifying the problem of sleep loss in terms of risk exposure, hazard, injury, cost and the impact on production is extremely difficult (Felknor et al., 2019). It is anticipated that the costs associated with sleep loss may be due to absenteeism, reduced productivity, and an increase in compensation claims as a result of increased injury rates (Barnes and Watson, 2019). Research in shift work populations reports

that the injury rate of shift workers is over double that of non-shift workers (Safe Work Australia, 2016), and is associated with chronic health conditions such as obesity, diabetes, cancer, cardiovascular disease, and mental health disorders (James et al., 2017).

Shiftwork is a known risk factor for sleep loss (<7 h) due to circadian disruption and extended hours of wakefulness (Kecklund and Axelsson, 2016). Roster design elements such as shift durations over 12 h, early shift start times before 0600, and backward rotating rosters (i.e. individuals starting on night shifts followed by day shifts) can impact the opportunity for sleep (Akerstedt and Wright, 2009). The presence of undiagnosed and untreated sleep disorders is also an important consideration, with higher prevalence and comorbidity rates reported in shift workers compared to non-shift workers (Kerkhof, 2018). There are more than 70 recognized sleep disorders (Sateia, 2014), with reported prevalence rates of 8% for obstructive sleep apnea (OSA), 11% for insomnia (Deloitte Access Economics, 2017) and shiftwork disorder affecting up to 63% of people in shift work populations (Vanttola et al., 2019). Further factors that may contribute to sleep loss are (i) obesity which is a known risk factor for OSA (Dong et al., 2020), and (ii) alcohol consumption as shift workers often consume alcohol to promote sleep onset, however, it may also negatively affect sleep quality and quantity (Tynan et al., 2017).

Despite the important role of sleep in reducing fatigue and the

associated adverse safety and health outcomes, there is a scarcity of research concerning sleep behaviors and the prevalence of risk for sleep disorders in the mining industry. Quantifying the sleep behaviors of shift workers using actigraphy as an objective means has been reported in a range of applied settings including offshore oil and gas, aviation, and healthcare (McCormick et al., 2012; Amann et al., 2014; Riethmeister et al., 2019). This data can be used in biomathematical modeling to estimate alertness for a roster cycle and is a common approach in high-risk shiftwork industries including aviation and rail (Hursh et al., 2006; Roma et al., 2012; Dawson et al., 2017). Currently, there are no published studies reporting biomathematical modeling to estimate alertness for a roster cycle in the mining industry. Furthermore, there is a need to report on the prevalence of risk for sleep disorders using validated sleep-related questionnaires to inform their management (Rajaratnam et al., 2011).

Managing sleep loss associated with a FIFO shiftwork lifestyle is complex, although largely preventable, requiring an enhanced understanding of sleep behaviors, sleep disorders, and lifestyle factors (Caldwell et al., 2019). The collection of data and information on these factors can provide valuable information towards the development of a Fatigue Risk Management System (Lerman et al., 2012), an essential part of an Occupational Health and Safety Management System in shiftwork organizations. Furthermore, data on the risk of sleep disorders can inform occupational medical programs, wellbeing initiatives, and identify individuals who require further medical assessment.

We hypothesize that due to circadian disruption from shiftwork, roster design, risk of sleep disorders, and poor lifestyle factors, that shift workers within a FIFO mining operation will achieve less sleep, thereby adversely affecting their alertness levels.

The present study, therefore, aimed to (i) quantify and describe the sleep behaviors of shift workers on a FIFO mining operation (ii) determine the prevalence of risk for sleep disorders, and (iii) conduct biomathematical modeling to estimate alertness across a roster cycle.

2. Materials and methods

2.1. Participants

Eighty-eight participants from an available workforce of 872 shift workers working for a FIFO mining operation in Australia were self-selected into the study. Recruitment for the study was via information sessions delivered onsite by the researcher, over one week. Interested shift workers were provided with a detailed information sheet and gave their informed consent to participate in the study. The Edith Cowan University Human Research Ethics Committee approved the study protocol (approval number: 2019-00813-MAISEY). The study protocol has been published and is summarized below (Maisey et al., 2021).

2.2. Study protocol

Shift workers from the mobile maintenance and drill and blast teams who worked seven-day shifts, followed by seven-night shifts of a 12 h duration, with seven days off (7 days/7 nights/7 off) were eligible to participate in the study. Shift workers completed an online survey and were assigned a wrist-activity monitor to measure their sleep duration, efficiency, and alertness for the 21-day study period (overall roster cycle) that included day shifts, night shifts, and days off (shift types). The day shift start time was 0530 and the day shift end time was 1730, followed by a 24-h rest period before commencing the night shift. The night shift start time was 1730 and the night shift end time was 0530, followed by 7 days off. Shift workers traveled by air from the state's capital city to the mining operation on day shift one and departed directly following night shift seven, residing in camp accommodation and commuting 25 min by bus daily to work for the duration of their roster cycle. To attain a representative sample of shift workers in a remote mining operation, there were no exclusion criteria. Data were collected over 21 days between 17th February and 16th March 2020 (this included a period of the Covid-19 pandemic).

2.3. Survey instrument

An online survey instrument was administered via Qualtrics™ and included demographic information, anthropometric measurements, a validated alcohol consumption questionnaire, and four validated sleep-related questionnaires. A detailed description of the survey instrument has been published elsewhere (Maisey et al., 2021).

Demographic and general information questions were used to determine age, gender, educational attainment, shiftwork experience, caffeine consumption, and medication use.

Body Mass Index (BMI) was used to determine the prevalence of overweight and obesity. Body Mass Index was calculated from self-reported height and weight measures (kg/m^2).

The Alcohol Use Disorders Identification Test (AUDIT) developed by the World Health Organisation was used to screen for excessive alcohol consumption (Thomas et al., 2001).

The Berlin Questionnaire (BQ) was used to assess the potential risk of obstructive sleep apnea (OSA) (Enciso and Clark, 2011).

The Epworth Scale of Sleepiness (ESS) was used to assess daytime sleepiness (Doneh, 2015).

The Insomnia Severity Index (ISI) was used to assess the potential risk of insomnia (Bastien et al., 2001).

The Shiftwork Disorder Questionnaire was used to assess an individual's risk of shiftwork disorder (Barger et al., 2012).

2.4. Wrist-activity monitors

Measures of sleep were objectively measured using wrist-activity monitors. These devices are unobtrusive, cost-effective, and can be worn continuously to measure sleep across time (Smith et al., 2018).

The Readiband™ version 5 (Readiband™, Fatigue Science Inc., Canada) wrist-activity monitor device contains a tri-axial accelerometer that records movement that is then converted to periods of sleep and wake using the Readiband Sync™ automated proprietary scoring algorithm (Russell et al., 2000). The Readiband™ has produced comparable results with both in-laboratory polysomnography (PSG) for one night and the ActiGraph™ device over seven nights at home (Dunican et al., 2018). Also, this device has been validated in a technical report against in-laboratory PSG with an epoch-to-epoch sleep/wake scoring accuracy of 82%, sensitivity of 88%, and specificity of 55% (Russell et al., 2000), and is approved by the United States Food and Drug Administration as a device to measure sleep and activity (Food and Drug Administration, 2011).

Shift workers were allocated a wrist-activity monitor on day one of the study and instructed to wear the device continuously for 21 days. Derived and direct measures from the wrist-activity monitors were used to determine sleep duration, efficiency, and alertness (Table 1).

2.5. Biomathematical modeling

Measures of estimated alertness across the 21-day roster cycle were calculated using the Sleep, Activity, Fatigue, and Task Effectiveness (SAFTE™) biomathematical model. This three-process biomathematical model incorporates the functions of the homeostatic sleep reservoir, circadian oscillator, and sleep inertia (Hursh et al., 2006). The SAFTE™ model has been validated in the rail transportation industry and the aviation industry and was found to have positive associations between estimated alertness by the model and accident risk, alertness, reaction times, and lapses as measured by psychomotor vigilance tests (Hursh et al., 2006; Roma et al., 2012). The inputs for this model included the average time at sleep onset, sleep duration, wake after sleep onset, and time at wake by shift type (i.e. days, nights, and days off), as recorded by the wrist-activity monitor, in addition to working time and geographical

Table 1

Summary of derived and direct sleep measures from the Readiband™ (Fatigue Science, Canada) device. This table is based upon Dunican et al. Sleep and Biological Rhythms (2018).

Sleep Measures	Units	Measurement	Description
Sleep Onset Latency	Minutes	Derived	The number of minutes from Time at Lights Out to Time at Sleep Onset.
Time at Sleep Onset	Time of day	Directly measured	Time of day when the first epoch of sleep occurs between Time at Lights Out and Time at Wake.
Sleep Duration	Minutes	Derived	The number of minutes from Time at Sleep Onset to Time at Wake, minus the number of minutes awake (WASO).
Wake After Sleep Onset	Minutes	Directly measured	The number of minutes awake after Time at Sleep Onset.
Fragmentation Index	Frequency	Directly measured	The number of awakenings between Time at Sleep Onset and Time at Wake.
Time at Wake	hh:mm	Directly measured	The time that wake occurs with no further sleep duration.
Time in Bed	Minutes	Derived	The total time spent in bed, from Time at Lights Out to Time at Wake.
Sleep Efficiency	Percentage	Derived	Sleep Duration divided by Time in Bed multiplied by 100.
Mid-sleep	hh:mm	Derived	The mid-time point between Time at Sleep Onset and Time at Wake.
Alertness	Percentage	SAFTE™	The measure of alertness calculated using the biomathematical model known as SAFTE™ (Sleep, Activity, Fatigue, and Task Effectiveness) algorithm.

Notes: This table provides a summary of the ten derived and direct sleep measures from the Readiband™ for analysis. A measure is classified as derived if it is a calculation of measures that are directly extracted from the Readiband™.

location (longitude and latitude) (Hursh et al., 2004). The model output graphically displays estimated alertness across the 21-day roster cycle on a scale of 0–100%. An alertness score of <90% has been associated with an increased accident risk due to human error, with risk increasing further when levels fall below 70% (Hursh et al., 2006) (Supplementary Fig. 1).

2.6. Statistical analysis

Statistical analysis was performed using SPSS v26 (IBM Corp, 2019). The potential prevalence of sleep disorders and sleep measures amongst the sample was reported using descriptive statistics including frequencies, percentages, means, and standard deviations (SD). A random intercept linear mixed model was used to compare the sleep measures between shift types (day shift, night shift, and days off) and shifts (e.g. day shifts 1–7). All measures of sleep were adjusted for age and gender, in addition to BMI score, AUDIT score, shiftwork disorder outcome, OSA outcome, and ISI score for specific sleep measures based on the current sleep science literature. Adjusted means, standard errors (SE), and their 95% CIs are reported. A forward stepwise logistic regression model was performed to explore the relationship between OSA and shiftwork disorder outcomes, and adjusting for age, gender, BMI score, AUDIT score, caffeine consumption, smoking, non-prescribed, and prescribed medication use. The subsequent result is summarized by odds ratios (ORs) and the associated 95% confidence intervals (CIs). For all tests, p ≤ 0.05 was considered statistically significant.

3. Results

The final data set analyzed consisted of 75 shift workers. Thirteen

shift workers were excluded from the study due to failure to adhere to the protocol.

3.1. Demographic characteristics

Of all shift workers (n = 75), 72 (96%) were male and 3 (4%) were female. Shift worker's mean (±SD) age was 37 ± 11 years and body mass index was 27 ± 5 kg/m^2. Twenty-seven (36%) shift workers consumed alcohol at hazardous and/or harmful levels or were at risk of alcohol dependence (Supplementary Table 1).

3.2. Potential prevalence of risk for sleep disorders

Forty-five (60%) shift workers screened positive for risk of one or more sleep disorders, with the risk for shiftwork disorder being the most prevalent (Table 2). Supplementary Fig. 2 depicts the comorbidity of the prevalence of risk for sleep disorders.

3.3. Objective sleep measures

3.3.1. Overall roster cycle

When analyzing the entire 21-day roster cycle; sleep onset latency (time to fall asleep) was 22 ± 1 min (CI = 21–23 min), sleep duration was 386 ± 3 min (CI = 380–393 min), wake after sleep onset (WASO) (time spent waking up) was 48 ± 1 min (CI = 45–51 min), fragmentation index (number of awakenings) was 4 ± 0 events (CI = 4-4 events), with a total time in bed of 456 ± 4 min (CI = 449–464 min). This resulted in overall sleep efficiency of $85 \pm 0\%$ (CI = 85–86%), and alertness of $81 \pm 0\%$ (CI = 80–81%) (Fig. 1).

3.3.2. Comparison by shift type

Significant differences were found when comparing day shift and night shift versus days off for the following (Table 3):

Day shifts compared to days off resulted in a mean decrease for sleep duration by 30 ± 7 min (CI = 14–46 min), WASO by 22 ± 3 min (CI = 15–30 min), fragmentation index by 1 ± 0 event (CI = 1–2 events), and time in bed by 51 ± 8 min (CI = 31–70 min). A $3 \pm 1\%$ (CI = 2–4%) increase in sleep efficiency was observed. Time at sleep onset was earlier by 82 min and time at wake earlier by 133 min, resulting in earlier mid-sleep by 110 min (all p < 0.05). Sleep onset latency and alertness were not found to be significant.

Night shifts compared to days off resulted in decreased sleep duration by an average of 77 ± 7 min (CI = 60–94 min), WASO by 23 ± 3 min (CI = 15–31 min), fragmentation index by 1 ± 0 event (CI = 1–2 events), time in bed by 101 ± 8 min (CI = 80–121 min), and alertness by $2 \pm 1\%$ (CI = 1–4%). Time at sleep onset was later by 595 min and wake time

Table 2

Sleep-related questionnaire data for all participants.

Measure	Count and %
	(n = 75)
Berlin Questionnaire for Obstructive Sleep Apnea	
Low risk	52 (69%)
High risk	23 (31%)
Shiftwork Disorder Questionnaire	
Low risk	42 (56%)
High risk	33 (44%)
Insomnia Severity Index	
No clinically significant insomnia	40 (53%)
Subthreshold insomnia	29 (39%)
Clinical insomnia (moderate severity)	6 (8%)
Epworth Sleepiness Scale	
Lower normal daytime sleepiness	36 (48%)
Higher normal daytime sleepiness	30 (40%)
Mild excessive daytime sleepiness	6 (8%)
Moderate excessive daytime sleepiness	3 (4%)

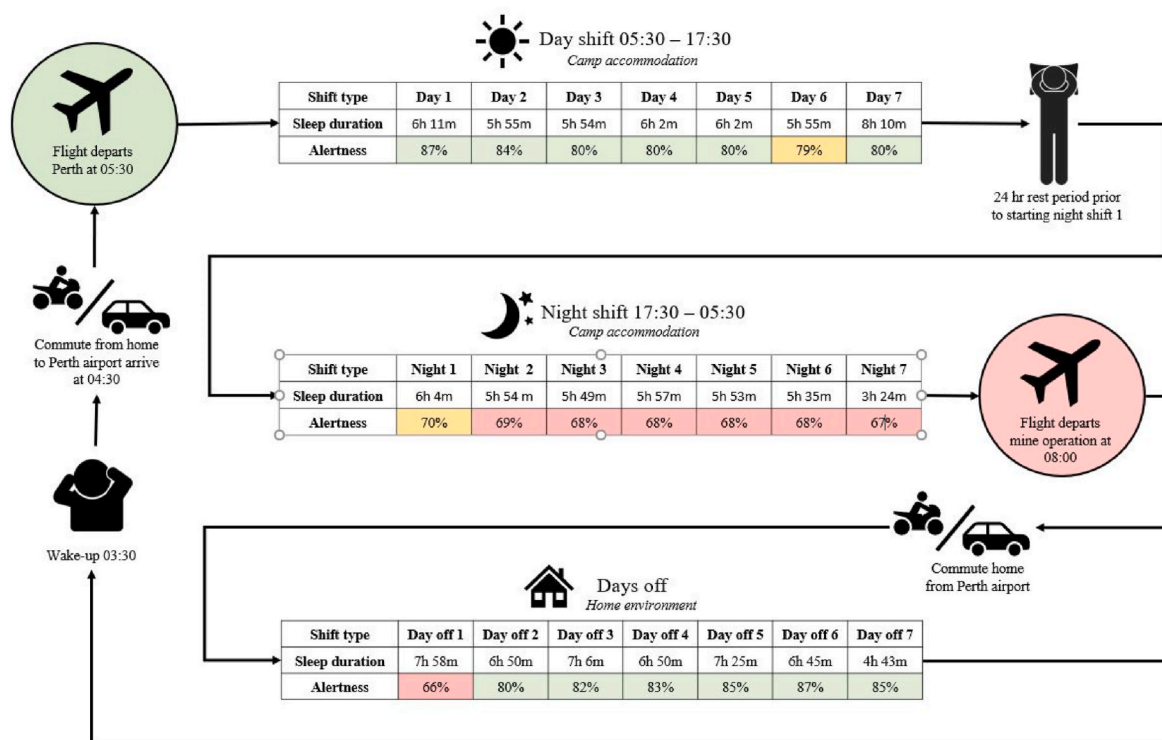**Notes:** Data are presented as counts and percentages (%).

Fig. 1. Schematic diagram of the seven-day shifts, seven-night shifts, followed by seven days off roster cycle. **Notes:** Schematic diagram of the roster cycle, including flights to and from the mining operation, commute periods to and from the airport, shift type and number. Sleep duration and alertness levels during work time and on days off are provided for each day/night of the 21-day roster cycle. The roster cycle commences with a 0530 flight to the mining operation at the start of day shift 1.

Table 3
Summary of sleep measures by day shift, night shift and days off.

Sleep Measure	Dayshift		Nightshift		Days off	
	Mean ± SE	95% CI	Mean ± SE	95% CI	Mean ± SE	95% CI
Sleep onset latency (min)	23 ± 2	18–28	21 ± 2	16–25	22 ± 2	17–26
Time at sleep onset (hh:mm)	21:37 ± 00:12*	21:11–22:02	08:54 ± 00:14*	08:25–09:22	22:59 ± 00:14	22:30–23.27
Sleep duration (min)	379 ± 15*	350–408	332 ± 15*	303–361	409 ± 15	379–438
Wake after sleep onset (min)	33 ± 10*	13–52	32 ± 10*	13–51	55 ± 10	36–75
Fragmentation index (count)	3 ± 1*	2–4	3 ± 1*	2–4	4 ± 1	3–5
Time at wake (hh:mm)	04:22 ± 00:09*	04:02–04:41	14:52 ± 00:11*	14:29–15:15	06:35 ± 00:11	06:13–06:59
Time in bed (min)	433 ± 15*	404–463	383 ± 15*	354–412	484 ± 16	453–515
Sleep efficiency (%)	88 ± 2*	84–92	86 ± 2	82–90	85 ± 2	81–89
Mid-sleep (hh:mm)	01:01 ± 00:09*	00:44–01:20	11:55 ± 00:11*	11:33–12:17	02:51 ± 00:10	02:29–03:12
Alertness (%)	84 ± 2	80–88	81 ± 2*	77–85	84 ± 2	80–88

Notes: Data are presented as means, standard error (±SE), and 95% confidence intervals. * indicated significant difference between day shift or night shift compared to days off (p < 0.05).

later by 497 min, resulting in delayed mid-sleep by 544 min (all p < 0.05). Sleep onset latency and sleep efficiency were not found to be significant.

3.3.3. Comparison within shift types by sleep measures

Measures of sleep were compared within shift type (i.e. shifts 1–7), using the first shift as the reference point (day shift 1, night shift 1, and day off 1), and significant differences were found (Fig. 2):

Sleep Duration (Fig. 2, panel A): Day shift 7 versus day shift 1 had a significant increase of 119 ± 21 min (CI = 52–187 min), night shift 7 versus night shift 1 had a significant decline of 160 ± 24 min (CI = 81–239 min), and day off 7 versus day off 1 had a significant decline of 196 ± 23 min, (CI = 125–267 min) (all p < 0.05).

Time in bed (Fig. 2, panel B): Day shift 7 versus day shift 1 had a significant increase of 173 ± 27 min (CI = 86–259 min), night shift 7 versus night shift 1 had a significant decline of 169 ± 28 min (CI =

75–263 min), and day off 7 versus day off 1 had a significant decline of 201 ± 27 min (CI = 117–285 min) (all p < 0.05).

Wake after sleep onset (Fig. 2, panel C): Day shift 7 versus day shift 1 had a significant increase by 53 ± 10 min (CI = 21–86 min) (all p < 0.05).

Fragmentation index (Fig. 2, panel F): Day shift 7 versus day shift 1 had a significant increase of 2 ± 1 events (CI = 1–4 events), and day off 7 versus day off 1 had a significant decline of 2 ± 0 events (CI = 0–3 events) (all p < 0.05).

3.3.4. Associations between sleep disorders, BMI, and age

Increased risk for OSA was associated with age and BMI. For every 1-year increase in age, the odds of risk for OSA increased by 6% (p < 0.05, OR = 1.057). Also, for every 1 unit increase in BMI, the odds of risk for OSA increased by 19% (p < 0.05, OR = 1.192).
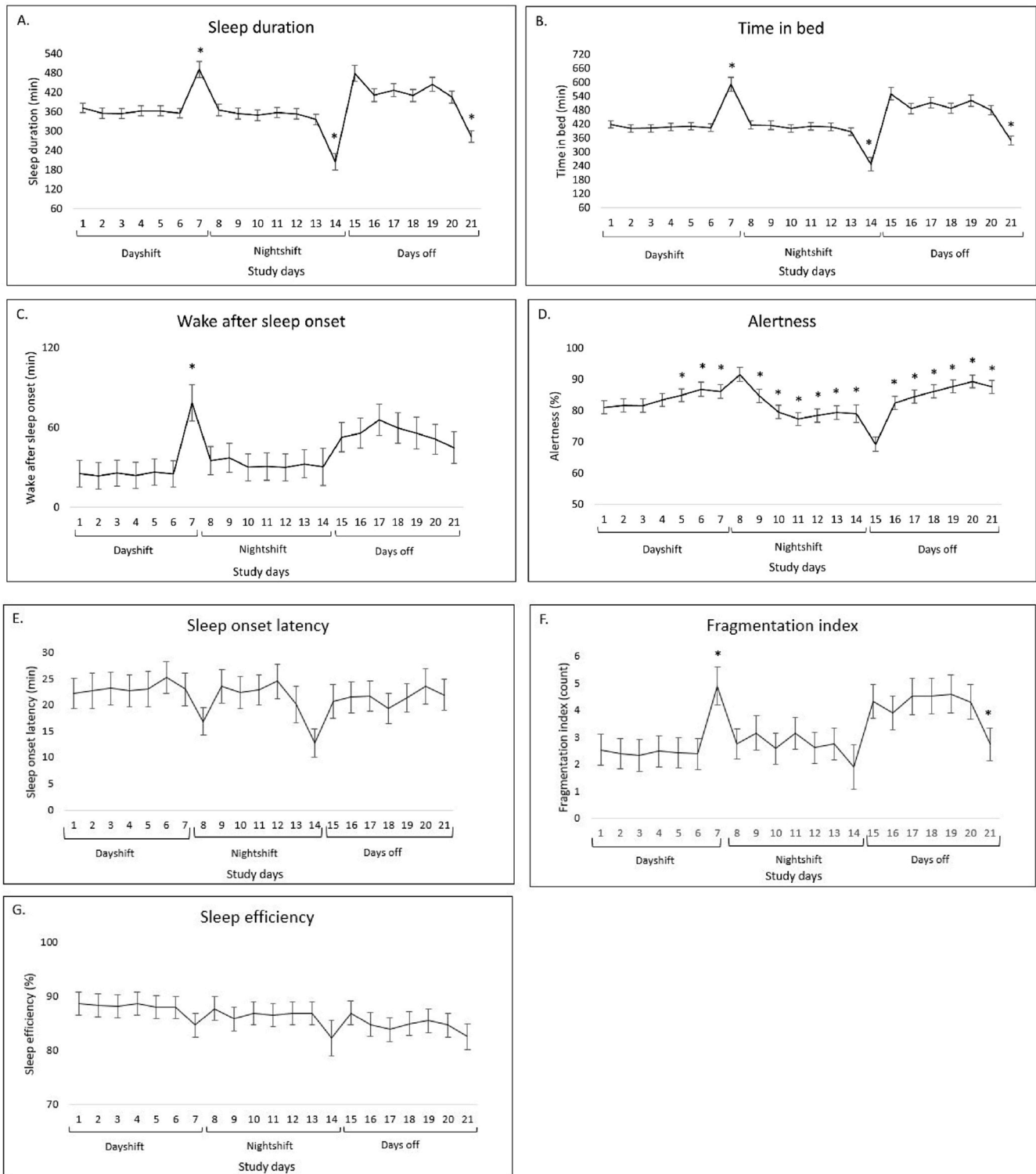
Fig. 2. Sleep measures across the 21-day roster cycle. **Notes:** The black lines represent means, and the error bars represent the standard error (±SE). * indicates a statistically significant difference to shift 1 for that shift type, p < 0.05.

3.3.5. Biomathematical modeling

The biomathematical model resulted in a 75% overall estimated mean alertness during work time (day shift and night shift), estimated mean alertness scores for every day shift and night shift (Table 4), and a graphical output depicting continuous estimated alertness across the overall 21-day roster cycle (Fig. 3).

4. Discussion

The current study is the first to determine sleep characteristics, the potential prevalence of risk for sleep disorders, and estimated alertness levels of shift workers in a remote FIFO mining operation. In this study we found that sleep loss (<7 h) accumulated with consecutive day shifts

Table 4
Biomathematical model estimated alertness during working time across the 21-day roster cycle.

Roster schedule	Estimated alertness
	(%)
Day shift 1	87
Day shift 2	84
Day shift 3	80
Day shift 4	80
Day shift 5	80
Day shift 6	79
Day shift 7	80
Mean day shift alertness	**81**
Night shift 1	70
Night shift 2	69
Night shift 3	68
Night shift 4	68
Night shift 5	68
Night shift 6	68
Night shift 7	67
Mean night shift alertness	**68**

Notes: Estimated alertness scores are presented as a percentage 0–100%. An alertness score of ≥90% is associated with a low accident risk and ≤70% is associated with increased accident risk.

(x7) and night shifts (x7), resulting in an estimated acute sleep loss of 13 h and a 20% reduction in alertness for these 14 workdays and nights. Furthermore, we found a high prevalence of risk for sleep disorders including shiftwork disorder (44%) and OSA (31%). Of concern, we also found a significant number of shift workers were obese and/or consumed alcohol at a hazardous level.

As anticipated shift workers slept for longer on their days off when residing in their homes as they recovered from working the roster cycle. Upon returning to the mining operation sleep duration progressively declined with an average of 30 min less on day shifts and 1 h 30 min less on night shifts. These significant differences in sleep duration by shift type are consistent with the limited number of studies that have been conducted in mining operations reporting sleep patterns for day shift between 5 and 6 h, night shift 5–6 h and days off 7–7 h 30 min (Ferguson et al., 2010, 2012; Paech et al., 2010; Kecklund and Axelsson, 2016). In other similar shiftwork organizations such as oil and gas, 6 h 30 min sleep has been reported on day shifts when off-shore (Riethmeister et al., 2018). With consecutive night shifts, we found that sleep loss accumulated, resulting in a decline in alertness by 13%. This decline in alertness

resulting from circadian disruption is consistent with findings from similar shiftwork studies (Chellappa et al., 2019; Ganesan et al., 2019). Potentially this reduced sleep duration and alertness may result in performance decrements during the night shift, increasing the risk of an accident (Folkard and Lombardi, 2006).

A potential contributing factor to sleep loss is the design of shifts and roster cycles, which can significantly affect the timing of sleep-wake patterns. The biomathematical model estimated an overall alertness score during all working hours of 75% and lapses (long reaction time due to loss of alertness) were 5 times more likely compared to a well-rested worker. This alertness level is the equivalent experienced following being awake ~21 h or having a blood alcohol concentration (BAC) of ~0.08% (Dawson and Reid, 1997; Hursh et al., 2006). As hypothesized, alertness levels were 13% lower during the night shift compared to the day shift due to sleep loss resulting from circadian disruption and roster design elements such as long work hours (Akerstedt and Wright, 2009). On day shifts the early morning start time of 0530 is likely to contribute to sleep loss as shift workers depart the camp at 0440 and travel by bus to the mine site. This requires them to wake around 0415 to allow enough time for their morning routine before going to work. Our study showed that shift workers did attempt to compensate for this early morning start by going to bed earlier at 2130 the night before. However, considering the time taken to fall asleep (23 ± 2 min) and time awake after sleep onset (33 ± 10 min) this does not leave sufficient time to achieve the recommended minimum 7 h sleep. It may be suggested that shift workers should aim to go to bed earlier to increase sleep duration and efficiency, however physiologically sleep propensity is greatly reduced and alertness peaks between approximately 1800-2100, referred to as the wake maintenance zone (Folkard and Barton, 1993; McMahon et al., 2018).

During this study, we identified three periods of interest; fly-in day, change-over day, and fly-out day (Fig. 1).

Fly-in day refers to day shift 1 when shift workers travel by air from the state capital to the mining operation before commencing their first-day shift. Time at wake was 0345 allowing for airport check-in by 0430. This reduced their sleep opportunity by ~2 h 30 min, and as a result, shift workers started day shift 1 with an acute sleep debt of ~2 h. Shift workers were therefore awake for ~14 h from the time at wake until the end of their shift, resulting in 87% estimated alertness on day shift 1, which continued to decline with consecutive shifts (day and night) by 20% (Table 4). On day shift 1 the biomathematical model estimated that shift workers were twice as likely to experience a lapse, increasing the likelihood of an accident during this shift compared to a well-rested person.
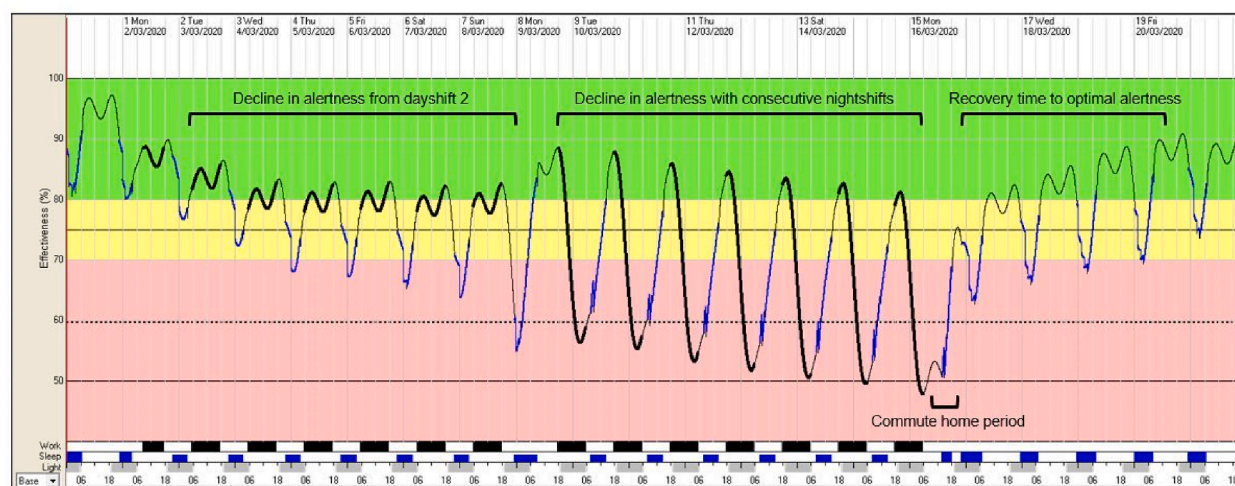

Fig. 3. Graphical output from SAFTE™ biomathematical model. **Notes:** This SAFTE™ biomathematical model output depicts the 7 days/7 nights/7 days off roster cycle worked by all participants. See Supplementary Fig. 1 for a description of interpreting the SAFTE™ model output.

Change over day refers to the rest period between the end of day shift 7 and the start of night shift 1. Shift workers in our study finished day shift 7 at 1730 and commenced night shift 1 the following day at 1730, allowing a rest period of 24 h. As anticipated, sleep duration was ~2 h longer following day shift 7, compared to the mean sleep duration on day shifts 1–6. This may be attributed to the increased sleep opportunity and the need to recover accumulated sleep loss, thereby potentially reducing the risk of adverse health and safety outcomes. Attention should be given to alcohol during this 24 h rest period as the workplace culture may support increased alcohol consumption as a means of relaxation and socialization. However, consumption during this rest period may result in further sleep loss adversely affect the health and safety of shift workers (Tynan et al., 2017).

Fly-out day refers to the end of night shift 7 when shift workers travel by air to the state capital and then commute home for seven days off to rest and recover. As anticipated, we found that sleep duration was ~2 h 45 min less following night shift 7. Shift workers departed the mining operation at 0800, approximately 2 h 30 min after finishing their last night shift, flying back to the state capital and commuting home from the airport during a period of low alertness (<55%) (Fig. 3). This indicates a potential high accident risk if shift workers are then to operate a motor vehicle as their mode of transport home. Studies show that the risk of a motor vehicle accident while commuting home following night shift work to be high due to sleep loss and circadian disruption (Akerstedt et al., 2005; Lee et al., 2016), and ≤2 h sleep, in the preceding 24 h to driving, may impair an individual's ability to safely drive (Czeisler et al., 2016; Dawson et al., 2020). At the time shift workers were commuting home they had been awake for an estimated >20 h, an equivalent estimated BAC of 0.08% (Dawson and Reid, 1997; Hursh et al., 2006). Legal precedence has established that this may represent not only a health and safety risk for mining operations but a financial and reputational risk if an accident commuting home is to occur. In response to a Queensland coal miner sustaining a serious injury following a motor vehicle accident whilst commuting home after four consecutive night shifts, the court ruled that the mining company failed to reduce his risk of fatigue awarding significant compensation damages (Supreme Court of Queensland, 2016).

In our study, we found the prevalence of risk for OSA to be 23% higher than the Australian general population (Deloitte Access Economics, 2017) and shiftwork disorder was consistent with rates reported in other shiftwork industries, such as health care, manufacturing, police, and oil and gas, ranging from 23% to 63% (Vanttola et al., 2019). Studies exist on the prevalence of sleep disorders in the general population and shift work populations such as health care and the police (Rajaratnam et al., 2011; Kaushik and Prakash, 2017; Booker et al., 2018), however, no studies exist in the mining industry. A study involving 416 shift workers from the health care sector found 41% screened positive for a sleep disorder, and a positive sleep disorder screening was associated with an 83% increase in safety incidence (Weaver et al., 2018). Of concern is the high prevalence of sleep disorders reported in our study and the potential for them to negatively impact sleep, alertness, and the long-term health and safety of shift workers if left undiagnosed and untreated (Wardle-Pinkston et al., 2019). Given this, mining operations should consider sleep disorder screening and treatment interventions to reduce this risk.

The prevalence of obesity in this study (23%) was found to be 8% lower than the general population (31%) (Australian Bureau of Statistics, 2019), and 5% lower than reported in another Australian mining study (Street and Thomas, 2017). We found that the risk of OSA increased with BMI and age and is consistent with other studies (Senaratna et al., 2017). Furthermore, we found hazardous levels of alcohol consumption among shift workers that were 19% higher than general population estimates of 17% (Health and Welfare, 2019), and surprisingly 10% lower than reported in the Australian coal mining industry (Tynan et al., 2017). This alarmingly high consumption of alcohol may be a contributing factor to the high prevalence of obesity among shift

workers due to a greater energy intake from the caloric content of alcohol (Traversy and Chaput, 2015), and if consumed directly before bedtime may adversely affect sleep (Richter et al., 2020). This highlights the need for mining operations to focus fitness for work programs on healthy weight and safe alcohol consumption interventions.

4.1. Potential study limitations

A potential limitation of our study was the sample size. Our final sample of 75 shift workers represents 7% of shift workers working the 7 days/7 nights/7 days off roster cycle for the participating mining operation. However, this is the largest study to date as other studies have reported sleep characteristics with sample sizes of no more than n = 51 (Paech et al., 2010; Ferguson et al., 2012; Legault et al., 2017). Furthermore, no other studies have reported the prevalence of risk for sleep disorders in a mining population or used biomathematical modeling to quantify and depict the estimated alertness of a specific roster design.

The lack of PSG to clinically assess the prevalence of sleep disorders is a potential limitation in this study. This was mainly due to the high cost and accessibility to shift workers to undertake any form of PSG. The use of self-reported screening tools, therefore, provided a cost-effective, practical approach compared to PSG. Our approach provides a valuable insight into the prevalence of risk for sleep disorders on a FIFO mining operation.

Finally, in this study, we did not identify shift workers that reside either outside of the state in which the mining operation is located (interstate shift workers) or overseas. However, estimates show that ≤10% of shift workers in the Australian mining industry travel from interstate or overseas, many of whom are in specialized roles that are not required on-site all the time (Pupazzoni, 2020).

4.2. Practical application: recommended interventions to reduce risk in FIFO mining operations

Our findings suggest that the design of shifts and roster cycles, the presence of sleep disorders, obesity, and hazardous alcohol consumption are all possible contributing factors to the sleep loss and alertness decrements experienced by shift workers in the mining industry. A multi-faceted approach with targeted strategies that aim to increase sleep duration and alertness is therefore required to improve health and safety outcomes (James et al., 2017; Chellappa et al., 2019), and support retention of staff, productivity, and financial outcomes (Lerman et al., 2012).

It may be proposed that the elimination of FIFO operations in favor of a residential township in proximity (<20 kms) to a mine operation is beneficial to reduce this risk. However, this would require federal, state, and local government cooperation to develop infrastructures and services such as utilities, roads, health, and education. In addition, the "life of mine" plan and the economic factors including market forces and cost constraints should be considered as part of such an approach.

The contemporary legislative approach to managing work health and safety is based on consultation, cooperation, and coordination between employers and workers (Safe Work Australia, 2018). Given this, we recommend employers design and implement a two-pronged approach focusing on organizational and individual responsibilities (Dawson and McCulloch, 2005).

Organizational responsibility interventions to be considered include:

(i) **Shift and roster design** using biomathematical modeling to assess the level of risk associated with shift and roster cycles.
(ii) Following a period of consecutive night shifts (nights 1–6), **shift workers** should be provided with an additional **sleep opportunity on their last night shift (0300–0700)** prior to departing the

site, to reduce the risk of a motor vehicle accident during their commute home from the airport.

(iii) The provision of **wrist-activity monitor technology** to shift workers to measure and monitor sleep and alertness levels and to identify potential risk for sleep disorders.

(iv) Scientifically based **sleep disorder screening and treatment programs** to identify and manage shift workers with sleep disorders.

(v) **Sleep, performance, and fatigue management** education programs that promote good sleep hygiene practices and healthy lifestyles.

Individual responsibility interventions to be considered include:

(i) **Present fit for work** for each shift and effectively communicate to leaders if they believe they are fatigued.

(ii) Self-monitor and **minimize alcohol consumption** and maintain a healthy body weight.

(iii) Maintain a current **commute plan** to reduce risk and eliminate driving after the night shift period.

4.3. Future research

Given the potentially adverse impact of sleep loss on the mining industry, future research should focus on the effectiveness of industry-specific interventions. A recent paper published on the methodology for a randomized control trial to determine evidence-based interventions to improve the sleep of shift workers in a remote mining operation may inform interventions at an individual and organizational responsibility level (Maisey et al., 2021).

5. Conclusion

Our study provides an alarming insight into the acute sleep loss and reduced alertness across a roster cycle on a remote FIFO mining operation, that may create a largely preventable health and safety risk. The high prevalence of risk for shiftwork disorders and OSA, in addition to a high prevalence of obesity and alcohol consumption, may be contributing factors to this sleep loss.

Author contributions

Gemma Maisey designed the study, collected the data, and drafted the manuscript. Marcus Cattani, Amanda Devine, Ian C Dunican, and Johnny Lo assisted in designing the study and editing the manuscript. Johnny Lo and Shih Ching Fu provided support with statistical analysis.

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Declaration of competing interest

The authors declare the following financial interests/personal relationships which may be considered as potential competing interests: Ian C Dunican is the Chair of the Scientific Advisory Board for Fatigue Science, Canada, and received no financial or other incentives related to this research project. Gemma Maisey is employed on a casual basis by Melius Consulting Pty Ltd, for which Ian C Dunican is the Director and Chief Adviser.

Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.apergo.2021.103617.

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