Applied Ergonomics 42 (2011) 202–209

Contents lists available at ScienceDirect

Applied Ergonomics

journal homepage: www.elsevier.com/locate/apergo

Work hours, workload, sleep and fatigue in Australian Rail Industry employees

Jillian Dorrian*, Stuart D. Baulk [1], Drew Dawson [1]

The Centre for Sleep Research, The School of Psychology, Social Work and Social Policy, The University of South Australia, P7-35 City East Campus, Frome Rd, Adelaide 5000, Australia

ARTICLE INFO

Article history:
Received 1 February 2010
Accepted 15 June 2010

Keywords:
Rail industry
Work hours
Workload
Fatigue
Sleep

ABSTRACT

Research suggests that less than 5 h sleep in the 24 h prior to work and/or more than 16 h of wakefulness can significantly increase the likelihood of fatigue-related impairment and error at work. Studies have also shown exponential safety declines with time on shift, with roughly double the likelihood of accident or injury after 10 h relative to the first 8 h. While it is acknowledged that reduced sleep, increased wakefulness and longer work hours produce work-related fatigue, few studies have examined the impact of workload on this relationship. Studies in the rail industry have focused on drivers. This study investigated fatigue in a large sample of Australian Rail Industry Employees. Participants were from four companies ($n = 90$: 85m, 5f; mean age 40.2 ± 8.6 y). Data was analysed for a total of 713 shifts. Subjects wore wrist actigraphs and completed sleep and work diaries for 14-days. They also completed the Samn–Perelli Fatigue Scale at the beginning and end of shifts, and the NASA-TLX workload scale at least twice during each shift. Average ($\pm$SD) sleep length (7.2 ± 2.6 h), prior wake at shift end (12.0 ± 4.7 h), shift duration (8.0 ± 1.3) and fatigue (4.1 ± 1.3, "a little tired, less than fresh") were within limits generally considered acceptable from a fatigue perspective. However, participants received 5 h or less-sleep in the prior 24 h on 13%, were awake for at least 16 h at the end of 16% and worked at least 10 h on 7% of shifts. Subjects reported that they felt "extremely tired, very difficult to concentrate," or "completely exhausted, unable to function effectively" on 13% of shifts. Sleep length ($OR = 0.88$, $p < 0.01$), shift duration ($OR = 1.18$, $p < 0.05$), night shift (REF = morning shift, $OR = 2.12$, $p < 0.05$) and workload ratings ($OR = 1.2$, $p < 0.05$) were significant predictors of ratings of extreme tiredness/exhaustion (yes/no). While on average, sleep loss, extended wakefulness, longer work hours and work-related fatigue do not appear problematic in this sample, there is still a notable percentage of shifts that are likely to be associated with high levels of work-related fatigue. Given the size of the Australian Rail Industry, with thousands of shifts occurring each day, this is potentially of operational concern. Further, results indicate that, in addition to sleep length, wakefulness and work hours, workload significantly influences fatigue. This has possible implications for bio-mathematical predictions of fatigue and for fatigue management more generally.

1. Introduction

1.1. Shiftwork and fatigue

Shiftwork disrupts the sleep–wake cycle (Ferguson et al., 2008; Tepas and Mahan, 1989), leading to sleepiness, fatigue and performance impairment, with implications for occupational health and safety (Åkerstedt, 1991; Folkard and Monk, 1979). While a consensus definition of fatigue is difficult, it is generally accepted that fatigue and fatigue-related impairment are influenced by prior sleep history, time spent at work and length of time spent awake (Dawson and McCulloch, 2005). A recent review of laboratory and field data suggested that having less than 5 h sleep in the 24 h prior to starting work, and having less than 12 h sleep in the 48 h prior to starting work may result in increased risk of fatigue and associated impairment (Dawson and McCulloch, 2005). This situation is common for shiftworkers (e.g. Dorrian and Dawson, 2005; Dorrian et al., 2008; Mitler et al., 1997). Research has demonstrated that the timing of shifts is important in determining sleep duration. Sleep may be shortened following a night shift, and workers may find it difficult to obtain adequate sleep before an early morning shift (e.g. Åkerstedt, 1995; Dorrian et al., 2008; Frese, 1984). As such, schedules involving these two shift types may result in sleep shortened by up to 4 h compared to normal night sleep (Åkerstedt, 1995; Frese, 1984).

* Corresponding author. Tel.: +61 8 8302 6624; fax: +61 8 8302 6623.
E-mail addresses: jill.dorrian@unisa.edu.au (J. Dorrian), sbaulk@hotmail.com (S.D. Baulk), drew.dawson@unisa.edu.au (D. Dawson).
[1] Tel.: +61 8 8302 6624; fax: +61 8 8302 6623.

0003-6870/$ – see front matter © 2010 Published by Elsevier Ltd.
doi:10.1016/j.apergo.2010.06.009

A key area of fatigue investigation in shiftwork research, and a significant topic of debate in many industries is that of shift *duration*. Previous research has shown that fatigue increases as shifts increase in length, with associated increases in accident likelihood. Studies have found a transient increase in risk after 2–4 h (Folkard, 1997), with much larger increases observed after 9–10 (Folkard and Tucker, 2003; Rosa, 1995) and 12 h (Folkard, 1997) on shift. A near two-fold increase in likelihood of incident or accident has been found following 10 h compared to 8 h on shift (Folkard and Tucker, 2003). A three-fold increase in accident likelihood has been found to occur after 16 h (Rosa, 1995).

Studies conducted in the laboratory have investigated the influence of wakefulness on sleepiness and fatigue. For example, one study comparing the effects of sleep loss to alcohol intoxication found that following 19 h awake, at 0800 h, an individual's performance was equivalent to that of an individual with a blood alcohol concentration (BAC%) of 0.05 (the legal driving limit in Australia), and after 24 h, performance was at the level of a person with BAC% = 0.10. Further, research has indicated that remaining awake for more than 16 h, particularly over a series of days, is associated with a "cumulative cost" to sleepiness and performance (van Dongen et al., 2003).

1.2. *Fatigue in the Rail Industry*

Train drivers are vulnerable to problems associated with fatigue (Pollard, 1991). Indeed, train drivers' schedules often result in increased sleep problems (Pilcher and Coplen, 2000), including reduced sleep (Foret and Latin, 1972), with a clear relationship between the length of time off, time-of-day and the amount of sleep obtained (Roach et al., 2003). Drivers must maintain vigilance, frequently under monotonous conditions (Edkins and Pollock, 1997). Not surprisingly, research indicates that they experience reduced alertness (Hildebrandt et al., 1974), extreme sleepiness (Härmä et al., 2002), decreased vigilance and uncontrolled incidences of sleep (Cabon et al., 1993; Torsvall and Åkerstedt, 1987) while at work. Further, rail accident investigations have identified drowsiness and failures to maintain wakefulness as contributors (Kogi and Ohta, 1975; Lauber and Kayten, 1988; Zhou, 1991). Hence, to date, most of the studies of sleep and fatigue in the rail industry have concentrated on train drivers. However, fatigue is an important issue for the rail industry as a whole. Other job roles within the industry, such as terminal operators, signallers and controllers, perform safety-critical tasks around-the-clock. Indeed, the research focus on drivers, and the necessity of studying all rail job roles has been commented on in the literature (Sussman and Coplen, 2000).

Apart from drivers, controllers (or dispatchers) have been the subject of a small number of studies of sleep and fatigue, published primarily in industry reports, but also journals. Extreme sleepiness has been found to be prevalent for controllers, with reported incidences on 25–50% of irregular shifts in varying combinations (Härmä et al., 2002; Sallinen et al., 2005). Gertler and Viale (2007) compared controller's sleep to other shiftworking populations and the general population, and, while there were methodological difficulties with the comparisons (acknowledged by the authors), provided evidence that controllers were getting less sleep than other shiftworkers and the general population. Gertler and Viale (2006) also investigated work hours and sleep in maintenance of way workers (MOW) – those responsible for track construction and maintenance. They found that while 39% of US adults get less than 7 h of sleep on workdays, this proportion is 66% for MOW.

Another factor known to influence fatigue is the workload (Popkin, 1999), which can be defined as "*(1) the demands of your work in terms of difficulty, complexity and time pressure; and (2) the effort you have to expend in meeting those demands*" (Popkin, 1999, p. 998). Numerous authors have highlighted the importance of workload research in rail (e.g. Coplen and Sussman, 2000; Pickup et al., 2005a; Popkin, 1999). However, the relationship between workload and fatigue has not been extensively studied. Popkin (1999) found that for rail controllers (dispatchers) subjective workload, measured via visual analogue scale, was consistent with recorded workload, in terms of numbers of trains and track users dealt with across a shift. Interestingly, this study indicated a low relationship (although not quantified statistically) between perceived workload and subjective fatigue.

Given the paucity of research into fatigue in rail in job roles other than drivers, and also in the relationship between workload and fatigue, this study investigated sleep, wake, work hours, workload and fatigue in a series of field studies involving a wide variety of job types in the Australian Rail Industry, including drivers, train controllers, guards, resurface crews, signallers, and terminal operators.

2. Methods

2.1. *Participants*

Participants were from four Australian Rail companies ($n = 90$: 85m, 5f; mean (±SD) age = 40.2 ± 8.6 y). They had a mean BMI of 29.0 ± 4.5, had worked in shiftwork for 16.6 ± 8.9 y, and drank 3.9 ± 2.3 caffeinated drinks per day (36% drank at least 5 cups/day). Data collection yielded a total of 713 shifts with sufficient sleep history (48 h) to perform the subsequent analyses. Participant were drivers ($n = 31$), controllers ($n = 10$), guards ($n = 11$), resurface crew ($n = 13$), signallers ($n = 13$) and terminal operators ($n = 12$).

2.1.1. *Drivers*

Train Drivers are responsible for operating trains between depots and stations, as well as some maintenance in certain areas. Whilst some technological safeguards are in place to assist drivers alertness in guiding trains safely to and from stations (such as vigilance and "dead man's handle" devices), their work is often repetitive and monotonous in nature, and can become tiring at difficult times of the day or night. In addition, workload may be considered high, due to the irregular nature of shifts, the fact that drivers must meet each train at a different locations/platforms at specific times, drive trains to a strict schedule and deal with a wide range of environmental cues and demands. Participant drivers in this study came from two rail companies and drove freight or passenger trains.

2.1.2. *Controllers*

Train controllers are responsible effectively for managing strategic overview of the whole metropolitan rail network. This includes dealing with, and arranging recovery from both normal (e.g. track work), and abnormal (e.g. accidents/incidents) disruptions to the service. Their work involves control-room operations with continuous monitoring of computer screens, telephone communication with stations, train drivers and signallers, and recording of information. Although this type of work is highly safety-critical, there are technological safeguards in place (e.g. electronic interlocking), acting as controls, which reduce the risk relative to human factors. The controllers in this study worked from a single control room.

2.1.3. *Guards*

Guards are responsible for the management of passengers on the trains. They operate the doors, communicate with and assist drivers, and are also responsible for protecting the train in the event of an incident. Their workload is largely affected therefore by passenger numbers (which is influenced by time-of-day and day of week, as well as special events) and attitudes. The guards in this study worked from three depots, covering a wide area in their daily work schedules.

2.1.4. Resurfacing crews

The work of the resurfacing crews is primarily to deal with the condition and maintenance of metropolitan infrastructure (that is, the rails, sleepers and ballast). They are small teams of employees with specialised skills or trades (e.g. electricians, engineers) who work together to ensure that the infrastructure maintenance program is kept to schedule. This work involves working with large, rail borne machines, which are used to lift, examine, replace and repair rails, as well as regulating and cleaning ballast/sleepers. Since this work is not possible during normal daytime operations, the crews work a high proportion of night work.

2.1.5. Signallers

Signallers cover a more tactical role, whereby they turn controllers plans into actions by operating the points and signals on the track to set routes for trains. The signallers in this study worked from a single control room.

2.1.6. Terminal operators

Shift schedules for terminal operations are dependent on train schedules, and more importantly, the actual times that trains arrive/depart. Terminal operators are responsible for a wide range of work tasks. Many of these are safety-critical due to the implications of errors for the moving train, and also to the operation of heavy machinery. Work may be administrative, involving train planning, computer work, paperwork and data logging. Work may be more operational, involving shunting (moving and connecting wagons), examining (safety checks on wagon couplings, brakes etc.), forklift driving and train loading (typically containers).

2.2. Studies

Field studies (2003–2005) ran for a standard 14-day period, during which time all participants continued their usual, rostered work schedule, and went about their normal duties except to complete relevant study testing. Local managers were aware of each study and able to provide simple support for the researchers where necessary, as well as allowing participants time for completing tests. Experimenters were either present at each worksite or visited regularly to achieve a rotation. They were also contactable by telephone at all times during each study period.

2.3. Measurements

2.3.1. Work hours

Participants completed daily work diaries, recording start and end dates and times, break time and duration and a very brief description of the type of work completed (e.g. loading, driving).

2.3.2. Sleep and wake

Participants were asked to provide detailed information about their sleep for the duration of the study using a sleep diary. For each sleep period (including naps), they recorded date/time of sleep onset, the final wake time and the number and length of awakenings during the sleep period. Participants also gave sleep quality ratings (1 = Very good, 2 = Good, 3 = Average, 4 = Poor, 5 = Very poor, 6 = Did not sleep).

Objective estimates of sleep/wake times were made using activity monitors and Actiware-sleep software (Cambridge Neurotechnology Ltd). Each activity monitor contained a piezo-electric accelerometer with a sensitivity of 0.1 g. The analogue sensor sampled movement every 125 ms and the information was stored in 1-min intervals for analysis. Participants were required to wear the activity monitor on their wrist at all times for the duration of the study, except whilst showering (or in any other situation where the device was likely to be damaged). Measures extracted from the activity monitors and sleep diaries were converted to parameters including a) sleep in the 24 h prior to start of shift; b) sleep in the 48 h prior to the start of shift; and c) total wakefulness at the end of shift.

2.3.3. Fatigue

Participants rated their level of fatigue before and after each shift using the work diary described above. This was completed using the 7-point Samn–Perelli Fatigue Scale (Samn and Perelli, 1982; 1 = Fully alert, wide awake, 2 = Very lively, responsive, but not at peak, 3 = Okay, somewhat fresh, 4 = A little tired, less than fresh, 5 = Moderately tired, let down, 6 = Extremely tired, very difficult to concentrate, 7 = Completely exhausted, unable to function effectively).

2.3.4. Workload

Workload was evaluated using the NASA–Task Load Index (NASA-TLX). Participants completed the NASA-TLX at the mid- and end-point of each shift (Hart and Staveland, 1988). The NASA-TLX has been described as the most widely used workload measure (Noyes and Bruneau, 2007; Pickup et al., 2005a), and has been shown to have high convergent validity with other workload measures (Rubio et al., 2004). The evaluation consists of scales divided into twenty equal intervals, manually marked between labels at each end from ‘Low’ to ‘High’ or ‘Good’ to ‘Poor’. There are six sub-scales, or dimensions: Mental demand, Physical demand, Time constraints, Performance, Effort required, and Frustration caused. Volunteers first evaluated the contribution of the six dimensions to the workload of their specific job roles, by circling the most important dimension in a list of pairs. This generated a workload rating, designed to account for (1) differences in workload definition between participants, and (2) differences in the sources of workload between tasks. Second, during and after work shifts, volunteers rated the degree to which each of the six dimensions contributed to their workload experience.

2.4. Analyses

Initially, 97 participants were recruited into the study. Data from seven participants were excluded due to excessive missing data in sleep and work diaries. From the 90 participants that remained, 713 shifts were associated with adequate sleep history (48 h) to conduct analyses.

Differences across job roles (driver, controller, guard, resurface crew, signaller, terminal operator) in demographic variables and workload weightings, collected once per participant, were assessed using univariate ANOVA.

Differences across job roles in weighted workload (maximum per shift), shift length, number of consecutive shifts, sleep in the 24 h and 48 h prior to commencing work, hours of wakefulness at the end of each shift and the maximum fatigue rating per shift, collected multiple times per participant, were assessed using mixed model ANOVA (random effect = subjectID).

Shifts were classified as morning (start times 0300–1059 h); afternoon (start times 1100–1859 h); and night (start times 1900–0259 h). Differences across job roles, with a dependent variable of morning shift (yes/no), afternoon shift (yes/no) or night shift (yes/no) were assessed using binary logistic regression for longitudinal data (panel variable = subjectID).

Table 1
Demographic characteristics within each job role: number (missing = number of participants in each job role with incomplete records for demographic or workload data), gender and mean (SD) age, BMI, years of shiftwork experience and number of caffeinated drinks per day. Workload characteristics by job role: mean (SD) for each dimension, rank within job role (1high–6low) for each dimension and mean (SD) total weighted workload.

	Driver		Controller		Guard		Resurface crew		Signaller		Terminal operator		Total		$F_{5,78}$
Demographics															
N (missing)	27 (4)		10		9 (2)		11 (2)		13		9 (3)		79 (11)		–
Gender	31m, 1f		9m, 1f		8m, 3f		13m		13m		12m		85m, 5f		–
Age (y)	41.7 (7.1)		36.6 (7.5)		40.2 (6.6)		38.6 (12.9)		38.2 (8.6)		42.2 (7.5)		40.2 (8.6)		1.3
BMI	30.4 (5.2)		29.2 (4.9)		28.4 (4.9)		27.9 (3.4)		28.9 (4.1)		27.3 (4.0)		29.0 (4.5)		0.9
Shiftwork (y)	20.5 (8.0)		17.8 (4.7)		14.2 (9.3)		9.3 (7.5)		21.2 (10.1)		13.9 (6.6)		16.6 (18.9)		5.5*
Caffeine (cups)	4.0 (1.9)		2.7 (1.6)		4.1 (3.0)		4.2 (2.5)		4.8 (3.4)		3.4 (1.9)		3.9 (2.3)		0.9
Workload															
Mental	3.8 (1.5)	1	3.9 (0.7)	1	2.3 (1.6)	3	3.1 (1.0)	3	4.2 (0.7)	1	2.3 (1.9)	5	3.4 (1.5)	2	4.8*
Physical	1.2 (1.2)	6	0.2 (0.4)	6	2.1 (1.6)	5	0.6 (0.8)	6	0.7 (1.0)	6	1.2 (1.4)	6	1.1 (1.3)	6	4.0*
Time	3.3 (1.1)	2	3.7 (0.8)	2	3.3 (1.3)	1	3.3 (0.8)	2	3.4 (1.2)	2	3.2 (1.0)	2	3.4 (1.0)	1	0.5
Effort	2.5 (1.0)	3	1.9 (0.9)	5	2.2 (1.4)	4	4.2 (1.1)	1	2.2 (1.2)	4	2.6 (1.6)	3	2.6 (1.3)	4	4.5*
Performance	2.4 (1.5)	4	2.4 (1.3)	4	3.3 (1.9)	2	2.5 (1.4)	4	2.8 (1.5)	3	3.2 (0.8)	1	2.7 (1.5)	3	1.0
Frustration	1.9 (1.6)	5	2.9 (1.9)	3	1.7 (1.5)	6	1.4 (1.3)	5	1.9 (1.5)	5	2.4 (1.6)	4	2.0 (1.6)	5	1.0
Max total weighted	5.3 (1.9)		6.6 (2.2)		5.3 (1.8)		5.8 (1.2)		5.7 (1.7)		5.5 (1.6)		5.6 (1.9)		1.4

*Univariate ANOVA indicated significant difference across job roles, $p < 0.001$.

Thresholds for increased likelihood of fatigue and related impairment were devised, based on previous literature. Specifically, these were:

- having less than 5 h sleep in the 24 h prior to starting work (Dawson and McCulloch, 2005);
- having less than 12 h sleep in the 24 h prior to starting work (Dawson and McCulloch, 2005);
- working for 10 or more hours in a single shift (Folkard and Tucker, 2003);
- being awake for 16 or more hours (van Dongen et al., 2003); and
- having a Samn–Perelli Fatigue Rating of 6 or 7 ("extremely tired"/"completely exhausted")

Each shift was analysed for breaches of these thresholds. A total threshold breach count was calculated per shift, which yielded a number from 0 to 5. Poisson regression for longitudinal data (GEE, panel variable = subjectID) was used to investigate significant predictors of threshold breach count.

Predictors of reporting a 6 or a 7 on the fatigue scale (yes/no) were investigated using binary logistic regression for longitudinal data (GEE, panel variable = subjectID).

3. Results

3.1. Participant demographics

Participant demographics are displayed in Table 1. Overall, demographics were consistent across job roles. The only significant difference ($p < 0.001$) was for years of shiftwork experience, in particular, resurfacing crew had a lower level of experience relative to other job roles.

3.2. Workload

Mean (SD) workload weightings (relative importance of each dimension to participants within each job role, 1–5) and their relative rank (1–6) are displayed in Table 1. Overall, mental and time dimensions were rated highly, and physical workload was perceived as least important. However, there were significant differences in mental, physical and effort dimensions across job role ($p < 0.001$). Guards and terminal operators rated their mental workload as lower relative to other job roles. Guards had a higher mean weighting for physical workload relative to other job roles (although it was still ranked 5 for guards relative to the other dimensions). Resurfacing crews had a higher mean weighting for

Table 2
Shift Characteristics by job role: number of shifts, shift length (mean (SD), minimum–maximum), shift types (%morning, afternoon, night) and number of consecutive shifts (mean (SD), minimum–maximum). Sleep, wake and fatigue by job type: mean (SD) sleep in the 24 h and 48 h prior to starting work and total wake (h) at the end of the shift.

	Driver	Controller	Guard	Resurface crew	Signaller	Terminal operator	Total	Sig.
Work hours								
N shifts	221	99	89	88	128	88	713	–
Shift length	8.0 (0.9)	7.1 (1.3)	7.8 (0.7)	7.8 (1.7)	8.7 (1.6)	8.2 (1.6)	8.0 (1.3)	$F_{5,91.7} = 9.0$*
min–max	5–11	4–12	5–10	4–16	6–12	3–12	3–16	
%morning shift	46	40	49	16	33	40	39	$\chi^2_5 = 7.9$
%afternoon shift	23	26	42	0	41	41	29	$\chi^2_5 = 8.5$
%night shift	31	33	9	84	26	19	33	$\chi^2_5 = 64.9$**
Consec. shifts	3.1 (1.7)	3.2 (2.4)	2.8 (1.7)	4.5 (2.6)	2.8 (1.9)	4.9 (2.3)	3.4 (2.2)	$F_{5,88.3} = 13.4$*
min–max	1–7	1–11	1–8	1–10	1–9	1–11	1–11	
Sleep, fatigue								
Sleep prior 24 h	7.6 (2.5)	6.8 (2.3)	7.7 (3.7)	6.4 (3.0)	6.6 (2.5)	7.6 (1.4)	7.2 (2.6)	$F_{5,76.6} = 3.7$*
Sleep prior 48 h	15.1 (4.8)	12.9 (4.5)	15.5 (7.3)	11.8 (5.4)	12.5 (4.4)	14.9 (3.1)	14.0 (5.2)	$F_{5,76.9} = 5.5$*
End shift wake	11.1 (4.0)	11.8 (4.2)	12.0 (3.8)	12.0 (6.1)	13.8 (5.8)	12.4 (3.2)	12.1 (4.7)	$F_{5,80.7} = 3.4$*
Max fatigue	4.0 (1.4)	4.3 (1.3)	3.2 (1.2)	4.0 (1.2)	4.3 (1.1)	3.9 (2.3)	4.0 (1.3)	$F_{5,89.8} = 2.0$

*Mixed model ANOVA (random effect = subjectID) indicated significant difference across job roles, $p < 0.001$.
**Binary logistic regression for longitudinal data (panel variable = subjectID) indicated significant difference across job roles, $p < 0.001$, with a significant model fit (Wald χ^2) $p < 0.001$.

Table 3
Mean (SD) parameters and percentage of shifts that breached the thresholds.

Parameter	Mean (SD)	Threshold	%breach
Sleep in prior 24 h	7.2 (2.6)	<5 h in prior 24 h	12.9
Sleep in prior 48 h	14.0 (5.2)	<12 h in prior 48 h	24.7
Shift length	8.0 (1.3)	>=10 h	6.7
Prior wake	12.1 (4.7)	>=16 h	15.6
Fatigue rating (1–7)	4.0 (1.3) *"a little tired, less than fresh"*	>=6 *"extremely tired/ completely exhausted"*	13.2

effort, and overall effort was their top rated dimension. There were no significant differences in total weighted workload ratings across job roles.

3.3. Work hours

Table 2 summarises work hour data. Overall, average shift length was 8 h (±1.3 h). There were significant differences across job role ($p < 0.001$). Mean shift length was lower for controllers (7.1) and higher for signallers (8.7) relative to the other roles. The maximum shift length (16 h) occurred within the resurfacing crew.

There was an approximately even distribution of morning, afternoon and night shifts (39, 29 and 33% respectively). Resurface crew did no afternoon shifts and a smaller percentage of morning shifts (16%). Differences in percentages of night shift were significantly different across job roles ($p < 0.001$). While guards did only 9% night shifts, resurface crews did 84% night shifts.

Overall, the average number of consecutive shifts was 3.4. There was a significant difference in the number of consecutive shifts across job roles ($p < 0.001$), with terminal operators (4.9) and resurfacing crew (4.5) with the highest, and guards and signallers with the lowest (2.8). The range was 1–11 shifts, with all job roles having a maximum of at least 7 consecutive shifts.

3.4. Sleep, wake and fatigue

Table 2 also summarises sleep, wake and fatigue data. Overall, mean sleep in the 24 h and 48 h before starting a shift was 7.2 h and 14.0 h respectively. There were significant differences across job roles ($p < 0.001$), with resurfacing crew having the lowest amount of sleep and guards the highest (mean difference of >1 h in the prior 24 h and >3 h in the prior 48 h).

There was also a significant difference in time spent awake at the end of the shift ($p < 0.001$), with signallers accruing the highest amount of wake and drivers the lowest (mean difference of >2 h).

The mean maximum Samn–Perelli Fatigue rating per shift was 4.0 ("a little tired, less than fresh"). There was no significant difference across job roles.

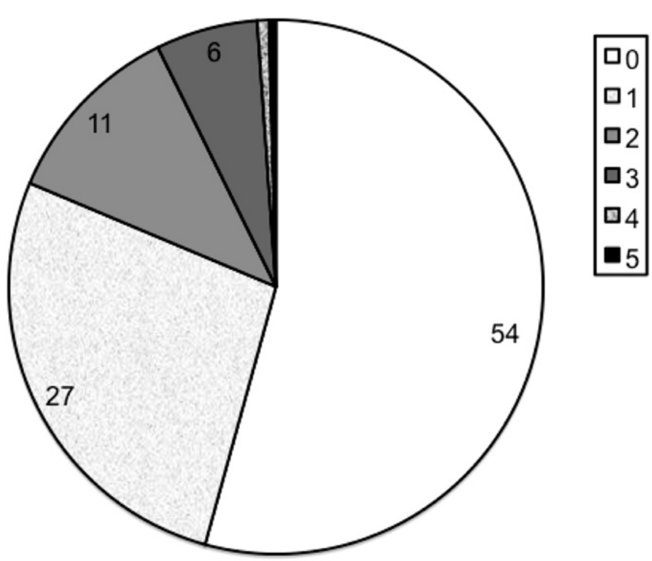

Fig. 1. Percentage of shifts with 1, 2, 3, 4 or 5 threshold breaches.

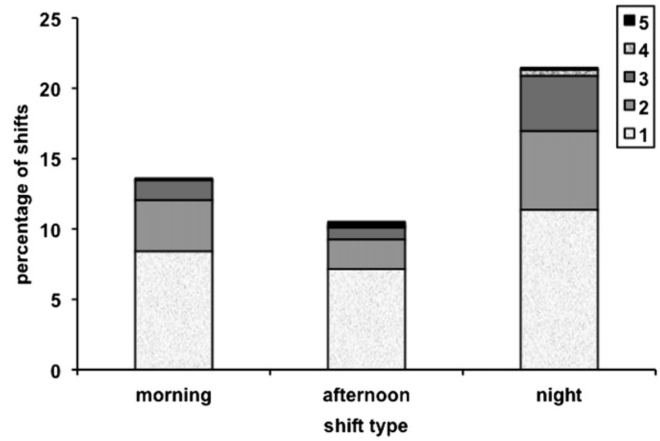

Fig. 2. Percentage of total shifts with thresholds breached by shift type (morning, afternoon, night).

3.5. Thresholds and breaches

Thresholds for increased likelihood of fatigue and related impairment, devised based on previous literature, as described in the methods section, are displayed in Table 3, column 3. Each shift was analysed for breaches of these thresholds. Table 3 also displays mean (SD) values for sleep in the prior 24 h and 48 h, shift length, prior wake and maximum fatigue rating per shift, alongside these thresholds and the percentage of shifts in breach of each threshold. Nearly one in eight shifts (12.9%) began with a participant who had less than 5 h sleep in the prior 24 h. One in four began with less than 12 h sleep in the prior 48 h. Nearly 7% of shifts were in excess of 10 h. Participants had been awake for at least 16 h at the end of one in every six shifts. Participants reported feeling extremely tired or completely exhausted on one in eight shifts. Overall, 46% of shifts were associated with at least one threshold breach, with nearly 20% of shifts breaching more than one threshold (Fig. 1).

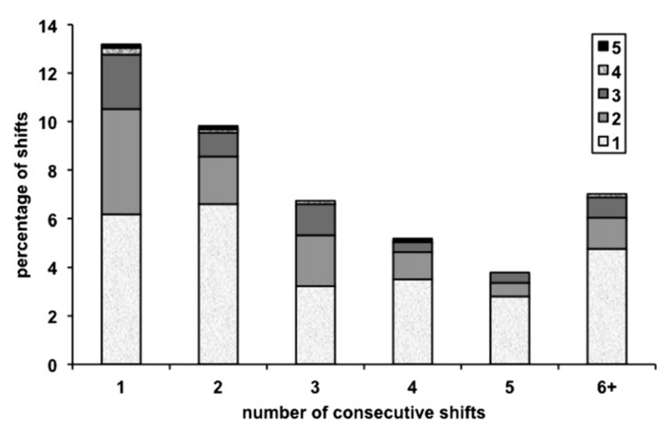

Fig. 3. Percentage of total shifts with thresholds breached by number of consecutive shifts.

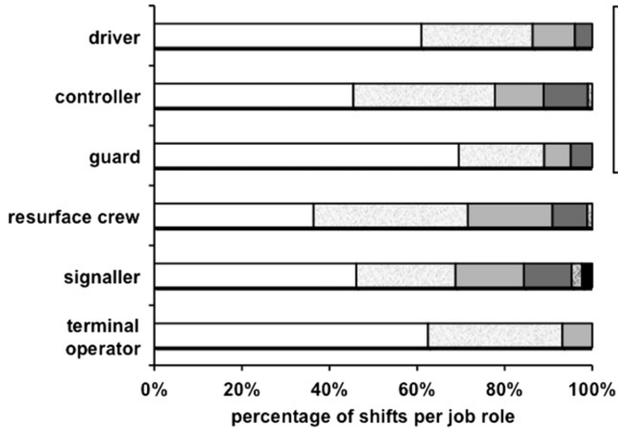

Fig. 4. Percentage of shifts with thresholds breached as a relative proportion of shifts for each job role.

Fig. 2 illustrates shifts associated with threshold breaches as a percentage of total shifts, as distributed across morning shifts, afternoon shifts and night shifts. As can be seen from the figure, more than 20% of shifts that breached at least one threshold (nearly half of the shifts in breach) were night shifts.

Fig. 3 displays shifts associated with threshold breaches as a percentage of total shifts, as distributed across number of consecutive shifts. One in fourteen shifts were associated with at least one breach and were at least the sixth consecutive shift.

Fig. 4 shows the percentage of shifts with thresholds breached as a relative proportion of shifts within each job role. Controllers, resurface crew and signallers work shifts associated with greater frequency and number of breaches than drivers, guards and terminal operators. In fact, more than 50% of shifts for controllers, resurface crew and guards were associated with at least one breach.

A total threshold breach count was calculated per shift, which yielded a number from 0 to 5. Poisson regression for longitudinal data (Table 4) indicated that shift type and job role were significant predictors of threshold breach count, with night shifts significantly different from morning shifts ($p < 0.001$) and signallers significantly different from drivers ($p < 0.001$). Number of consecutive shifts was not a significant predictor.

Interestingly, only 47% of reports of extreme tiredness and exhaustion (Samn–Perelli = 6 or 7) occurred on shifts where other thresholds were breached. Other factors, beyond simple threshold breaches were likely to be associated with tiredness and exhaustion. Binary logistic regression (dependent variable: fatigue = 6 or 7, yes/no) for longitudinal data indicated that shift length, shift type, sleep in the prior 24 h and maximum weighted workload rating per shift were significant predictors ($p < 0.05$). Odds ratios, confidence intervals and model fit are displayed in Table 5.

4. Discussion

Average sleep length (7.2 h), prior wake at shift end (12 h), shift duration (8 h) and fatigue ("a little tired, less than fresh") were within limits generally considered acceptable from a fatigue perspective. Thresholds for increased likelihood of fatigue and related impairment were devised, based on previous literature (as outlined above in Section 2.4). Each shift was analysed for breaches of these thresholds. While average sleep loss, extended wakefulness, longer work hours and work-related fatigue did not appear problematic in this sample, there was a notable percentage of shifts (45%) associated with at least one threshold breach. Moreover, 21% of shifts were associated with threshold breaches and were night shifts. Therefore, a number of shifts in this sample are likely to be associated with high levels of work-related fatigue.

4.1. Differences between job roles

To date, investigations of sleep loss and fatigue in rail have primarily focused on train drivers (Sussman and Coplen, 2000), with few studies involving other job roles (Gertler and Viale, 2006, 2007; Härmä et al., 2002; Sallinen et al., 2005). Certainly, the safety-critical nature of the train driving task also extends to job roles that maintain optimal operation of trains, tracks, points and signals and operation of heavy machinery.

Differences in work hours (shift length, percentage night shifts and number of consecutive shifts), sleep and wake were found across different job roles. Resurfacing Crew worked a high percentage of night shifts (>80%) due to the fact that most track repairs are scheduled at night to avoid daytime traffic. Consistent with the high degree of night work, resurfacing crew had the lowest average sleep durations, at less than six and a half hours. Signallers (who also had the highest prior wake durations) and controllers also had less than 7 h sleep on average. This is in line with Gertler and Viale (2007) who reported that controllers obtained 6.4–7 h sleep on workdays and Popkin (in Sussman and Coplen, 2000) who reported an average of 7 h sleep. Drivers, guards and Terminal Operators obtained comparably more sleep (>7.5 h).

The threshold analysis described above was compared across job roles. The total number of thresholds breached was counted for each shift, which yielded a number from 0 to 5 (one possible point per threshold breached). In particular, more than half of the shifts for controllers, resurface crew and signallers were associated with breaches. Overall, results indicate that reduced sleep, extended periods of wake and work and in turn, fatigue at work is likely to be as prevalent for other job roles (e.g. signallers) as it is for drivers. This supports the need to extend the research focus in rail beyond drivers.

Differences in reported workload across job role were clear and consistent with the nature of each role. For example, signallers and

Table 4
Significant predictors of threshold breaches: results of Poisson regression (count outcomes) for longitudinal data (panel variable = subjectID).

Predictor	Level	Coefficient	z	p	95% CI low	95%CI high	Wald χ^2_7	p
Shift type	Morning	ref	–	–	–	–	68.63	<0.001
	Afternoon	0.03	0.23	ns	−0.23	0.29		
	Night	0.65	5.38	<0.001	0.41	0.88		
Job role	Driver	ref	–	–	–	–		
	Controller	0.35	1.65	ns	−0.65	0.76		
	Guard	−0.25	−0.93	ns	−0.76	0.27		
	Resurface	0.25	1.26	ns	−0.14	0.63		
	Signaller	0.62	3.45	<0.001	0.27	0.97		
	Terminal operator	−0.75	−0.75	ns	−0.69	0.31		

Table 5
Significant predictors of fatigue rating indicating extreme tiredness or exhaustion (scale = 6 or 7): results of binary logistic regression for longitudinal data (panel variable = subjectID).

Predictor	Level	Odds Ratio	z	p	95% CI low	95%CI high	Wald χ^2_5	p
Shift length	–	1.18	2.26	<0.05	1.02	1.37	25.78	<0.001
Shift type	Morning	ref	–	–	–	–		
	Afternoon	1.14	0.40	ns	0.60	2.15		
	Night	2.12	2.45	<0.05	1.16	3.85		
Sleep in the prior 24 h	–	0.88	−3.20	<0.01	0.82	0.95		
Maximum workload	–	1.20	2.46	<0.05	1.04	1.38		

controllers reported higher mental workload than other roles and resurface crew reported higher effort demands. Interestingly however, while there were significant differences across job role in terms of work, sleep, wake and workload, there were no differences in self-reported fatigue level, with average reports of “okay, somewhat fresh,” and “a little tired, less than fresh.” Therefore, secondary analyses specifically investigated the relationship between fatigue ratings and the other variables.

4.2. Predictors of fatigue ratings

Sleep length, shift duration, night shift and workload rating were significant predictors of ratings of extreme tiredness/exhaustion, such that every hour of sleep resulted in a 12% reduction and every hour of work resulted in an 18% increase in likelihood of reporting a six or seven on the Samn–Perelli Fatigue Scale. On night shift, participants were more than twice as likely, and each extra point on the workload scale was associated with a 20% increase in reporting extreme tiredness/exhaustion. It should be noted that the confidence intervals for these estimates were large.

The suggested relationship in the current study appears inconsistent with Popkin (1999) who found minimal relationship between workload and subjective fatigue. However, the previous study used visual analogue scales (anchored with “very low” and “very high”) to measure workload and fatigue. In contrast, the current study used the NASA-TLX for workload and the Samn–Perelli for fatigue. In particular, a relationship between work/performance and fatigue is implicit in anchors on the Samn–Perelli: “difficult to concentrate,” “unable to function effectively.” This may render the scale more sensitive to differences in workload.

A relationship between workload and fatigue, particularly high levels of fatigue, has possible implications for fatigue management. Currently, the tools used to evaluate the risk of fatigue (such as bio-mathematical models of fatigue), concentrate on the number of hours worked and the timing of shifts, rather than the nature of the work itself. The inclusion of workload parameters may improve fatigue prediction approaches.

4.3. Limitations

There are several limitations to the current study that must be noted. First, this study focused on actigraphy, diaries, actual roster information and subjective fatigue. No objective performance indicators were analysed for this manuscript. Such measures may be of benefit; particularly access to operational records of performance, incidents, accidents or near misses during the study would have been of benefit had they been available.

Second, while the threshold values used in the current study are based on previous literature, they are roughly defined and likely debatable. However, it is clear that the issues addressed in this paper are complex, and even if breaching one threshold in isolation may not cause immediate concern, the high proportion of shifts breaching multiple thresholds as well as the number of threshold breaches coincident with night shifts, are still likely to be a cause for reflection.

Finally, the NASA-TLX was chosen for the current study as it has been validated (Hart and Staveland, 1988; Rubio et al., 2004) and widely used (Noyes and Bruneau, 2007; Pickup et al., 2005a), and was considered to be the optimal choice at the time the studies were conducted (2002–05). More recently, the NASA-TLX has been criticized for focusing on a single task, while work in rail, for example the work of signallers, is multidimensional. In addition, it has been criticized logistically, and importantly, it has been suggested that it may not encompass all relevant influencing factors, particularly for signallers (Pickup et al., 2005a). Newer tools specifically tailored to rail have been developed specifically for signallers (Pickup et al., 2005a,b). Use of such measures may be more appropriate in future studies in rail. Nevertheless, application of the scale in this study presented no logistic problems and the data appears to at least be sensitive to differences across job characteristics in rail.

4.4. Summary/conclusions

Taken together, results of the current study suggest that while on average, sleep loss, extended wakefulness, longer work hours and work-related fatigue do not appear problematic in this sample, there is still a notable percentage of shifts that are likely to be associated with high levels of work-related fatigue. Given the size of the Australian Rail Industry, with thousands of shifts occurring each day, this is potentially of operational concern. Further, results indicate that, in addition to sleep length, wakefulness and work hours, workload significantly influences fatigue. This has possible implications for bio-mathematical predictions of fatigue and for fatigue management more generally. Overall, we need to look at the exceptional circumstances, not just the average.

Acknowledgements

This study was supported by the Australian Rail Consortium Shiftwork and Workload Study. The authors would like to thank Frank Hussey, Ryan Higgins, Sally Ferguson, Katie Kandelaars and Sarah Biggs for their assistance in project design, data collection and manuscript preparation and the support and assistance of the participating rail operators and study volunteers.

References

Åkerstedt, T., 1991. Sleepiness at work: effects of irregular work hours. In: Monk, T.H. (Ed.), Sleep, Sleepiness and Performance. Wiley, New York, pp. 131–152.

Åkerstedt, T., 1995. Work hours, sleepiness and the underlying mechanisms. J. Sleep Res. 4 (2), 15–22.

Cabon, P., Coblentz, A., Mollard, R., Fouillot, J.P., 1993. Human vigilance in railway and long-haul flight operation. Ergonomics 36 (9), 1019–1033.

Coplen, M., Sussman, D., 2000. Fatigue and alertness in the United States railroad industry, part 2: fatigue research in the Office of Research and Development at the Federal rail Administration. Trans. Res. Part F 3, 221–228.
Dawson, D., McCulloch, K., 2005. Managing fatigue: it's about sleep. Sleep Med. Rev. 9 (5), 365–380.
Dorrian, J., Tolley, C., Lamond, N., et al., 2008. Work hours, sleep and errors in a Group of Australian Hospital Nurses at work and during the commute. Appl. Ergon. 39 (5), 605–613.
Dorrian, J., Dawson, D., 2005. Modeling the relationship between sleep/wake history and fatigue-related truck accidents. In: Proceedings of the International Conference on Fatigue Management in Transportation, Seattle, USA, September 2005.
Edkins, G.D., Pollock, C.M., 1997. The influence of sustained attention on railway accidents. Accid. Anal. Prev. 29 (4), 533–539.
Ferguson, S.A., Lamond, N., Kandelaars, K.J., et al., 2008. The impact of short, irregular sleep opportunities at sea on the alertness of marine pilots working extended hours. Chronobiol. Int. 25, 399–411.
Folkard, S., 1997. Black times: temporal determinants of transport safety. Accid. Anal. Prev. 29 (4), 417–430.
Folkard, S., Monk, T.H., 1979. Shiftwork and performance. Hum. Factors 21 (4), 483–492.
Folkard, S., Tucker, P., 2003. Shift work, safety and productivity. Occup. Med. 53, 95–101.
Foret, J., Latin, G., 1972. The sleep of train drivers: an example of the effects of irregular work hours on sleep. In: Colquhoun, W.P. (Ed.), Aspects of Human Efficiency. English Universities Press, London.
Frese, M., 1984. Shiftwork and the length and quality of sleep. J. Occup. Med. 26 (8), 561–565.
Gertler, J., Viale, A., 2006. Work Schedules and Sleep Patterns of Railroad Maintenance of Way Workers. US Department of Transportation, Federal Railroad Administration. DFRA.010350.002.
Gertler, J., Viale, A., 2007. Work Schedules and Sleep Patterns of Railroad Dispatchers. US Department of Transportation, Federal Railroad Administration. DFRA.010350.
Härmä, M., Sallinen, M., Ranta, R., et al., 2002. The effect of an irregular shift system on sleepiness at work in train drivers and railway traffic controllers. J. Sleep. Res. 11 (2), 141–151.
Hart, S.G., Staveland, L.E., 1988. Development of NASA-TLX (Task Load Index): results of empirical and theoretical research. In: Hancock, P.A., Meshkati, N. (Eds.), Human Mental Workload. North Holland Press, Amsterdam, pp. 239–250.
Hildebrandt, G., Rohmert, W., Rutenfranz, J., 1974. Twelve and twenty-four hour rhythms in error frequency of locomotive drivers and the influence of tiredness. Int. J. Chronobiol. 2, 97–110.
Kogi, K., Ohta, T., 1975. Incidence of near accidental drowsing in locomotive driving during a period of rotation. J. Hum. Ergol. 4 (1), 65–76.
Lauber, J.K., Kayten, P.J., 1988. Sleepiness, circadian dysrythmia, and fatigue in transportation accidents. Sleep 11 (6), 503–512.
Mitler, M.M., Miller, J.C., Lipsitz, J.J., et al., 1997. The sleep of long-haul truck drivers. NEJM 337 (11), 755–761.
Noyes, J.M., Bruneau, D.P., 2007. A self-analysis of the NASA-TLX workload measure. Ergonomics 50 (4), 514–519.
Pickup, L., Wilson, J.R., Sharpies, S., et al., 2005a. Fundamental examination of mental workload in the rail industry. Theor. Issues Ergon. Sci. 6 (6), 463–482.
Pickup, L., Wilson, J.R., Norris, B.J., et al., 2005b. The Integrated Workload Scale (IWS): a new self-report tool to assess railway signaller workload. Appl. Ergon. 36, 681–693.
Pilcher, J.J., Coplen, M.K., 2000. Work/rest cycles in railroad operations: effects of shorter than 24-h shift work schedules and on-call schedules on sleep. Ergonomics 43 (5), 573–588.
Pollard, J., 1991. Issues in Locomotive Crew Management and Scheduling. Federal Railroad Administration, US Department of Transportation, Washington D.C.
Popkin, S.M., 1999. An examination and comparison of workload and subjective measures collected from railroad dispatchers. In: Proceedings of the Human Factors and Ergonomics Society 43rd Annual Meeting.
Roach, G.D., Reid, K.J., Dawson, D., 2003. The amount of sleep obtained by locomotive engineers: effects of break duration and time of break onset. Occup. Environ. Med. 60 (12), e17.
Rosa, R., 1995. Extended workshifts and excessive fatigue. J. Sleep Res. 4 (Suppl. 2), 51–56.
Rubio, S., Diaz, E., Martin, J., et al., 2004. Evaluation of subjective mental workload: a comparison of SWAT, NASA-TLX, and workload profile methods. Appl. Psychol. 53 (1), 61–86.
Sallinen, M., Härmä, M., Mutanen, P., Ranta, R., Virkkala, J., Müller, K., 2005. Sleepiness in various combinations of irregular shift systems. Ind. Health 43, 114–122.
Samn, S.W., Perelli, L.P., 1982. Estimating Aircrew Fatigue: A Technique with Application to Airlift Operations. Brooks AFB, USAF School of Aerospace Medicine. Technical Report SAM-TR-82-21.
Sussman, D., Coplen, M., 2000. Fatigue and alertness in the United States railroad industry, part 1: the nature of the problem. Trans. Res. Part F 3, 211–220.
Tepas, D.I., Mahan, R.P., 1989. The many meanings of sleep. Work Stress 3, 93–102.
Torsvall, L., Åkerstedt, T., 1987. Sleepiness on the job: continuously measured EEG changes in train drivers. Electroencephalogr. Clin. Neurophysiol. 66, 502–511.
van Dongen, H.P.A., Maislin, G., Mullington, J.M., et al., 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 2, 117–126.
Zhou, D.S., 1991. Epidemiological features and causes of railway traffic accidents. Zhonghua Yu Fang Yi Xue Za Zhi 25 (1), 26–29.