OPEN

Sleep Quantity and Quality of Ontario Wildland Firefighters Across a Low-Hazard Fire Season

Zachary McGillis, MHK, Sandra C. Dorman, PhD, Ayden Robertson, MHK, Michel Larivière, PhD, Caleb Leduc, MHK, Tammy Eger, PhD, Bruce E. Oddson, PhD, and Céline Larivière, PhD

Objective: The aim of the study was to assess the sleep quality, quantity, and fatigue levels of Canadian wildland firefighters while on deployment. **Methods:** Objective and subjective sleep and fatigue measures were collected using actigraphy and questionnaires during non-fire (Base) and fire (Initial Attack and Project) deployments. **Results:** Suboptimal sleep quality and quantity were more frequently observed during high-intensity, Initial Attack fire deployments. Suboptimal sleep was also exhibited during non-fire (Base) work periods, which increases the risk of prefire deployment sleep debt. Self-reported, morning fatigue scores were low-to-moderate and highest for Initial Attack fire deployments. **Conclusions:** The study highlights the incidence of suboptimal sleep patterns in wildland firefighters during non-fire and fire suppression work periods. These results have implications for the health and safety practices of firefighters given the link between sleep and fatigue, in a characteristically hazardous occupation.

Wildland firefighters (also known as FireRangers in Ontario) are key members of the Canadian Fire Management Operation and play an important role in fire management. During the Canadian fire season (April to October), these workers labor in harsh environmental conditions with a multitude of hazards, including heat, smoke, poor terrain, and unpredictable weather.[1] Their work schedules vary, depending on the severity of the fire season, but they can work up to 14 consecutive days (8 to 16 hours of service/day), with 2 days of travel at either end, before a minimum of 2 days rest is mandated (*Ontario Ministry of Natural Resources and Forestry (OMNRF) Work/Rest Directives, 2011*). These periods of wildland firefighting are referred to as fire deployments and are further categorized as either Initial Attack fires or Project Fires.

Initial Attack fire deployments include the first actions to take place after a fire is identified and assessed (eg, for fuel load, weather topography, fire behavior, hazards, and valuable properties). Firefighters deployed to an Initial Attack are the first responders to a new fire, usually by helicopter, and therefore they are responsible for initiating fire suppression efforts. These efforts include starting water hose suppression, base camp set-up, and forest clearing for helicopter landing. The physical intensity and workload depend largely on fire severity, but Initial Attack fires can be the most personally intense deployments, due to the unpredictable nature of these fires.[1–8] Project Fire deployments in contrast are the fire suppression efforts involved in any large fire requiring extensive management and the establishment of a temporary infrastructure to support firefighting efforts, such as fire camps. Fire crews travel to the fire (can be throughout Canada if they are needed out-of-province) and the first few days of work are dedicated to travel, base set-up, and initial briefing before heading to the fire line. During a Project Fire, firefighters typically stay at a centralized base camp, where upward of 1000 firefighters are stationed and travel to and from designated fire lines. The level of work intensity depends on the terrain and the area of Canada, but typically this work is less physically intense compared with Initial Attack fire deployments, which is due to more strategic and conservative fire suppression efforts.[4] When firefighters are not required on a fire line, they have scheduled work periods at their local Fire Management Headquarters (non-fire or Base deployment); here they engage in training, daily fitness, as well as rotating shifts "on alert" for fire line deployment.

In general, poor sleep is known to increase fatigue and the risk of workplace injury in other occupations.[9–12] Understanding these implications, the sleep behaviors of Australian and American wildland firefighters have been investigated.[13–18] The subjective sleep behavior of American wildland firefighters, as assessed by Gaskill and Ruby[19] revealed that the average sleep time was 7.0 ± 1.4 hours per night during fire line work periods. This level is generally considered optimal sleep duration (ie, 7 to 9 hours) and is the minimal level typically required for adults to optimize daily performance.[20] Similarly, a study with Australian wildland firefighters indicated that sleep quantity, measured objectively, was significantly lower when firefighters were exposed to poor sleep conditions (ie, sleeping in tents), long work shifts (>14 hours), and early morning start times without impacting subjective fatigue measures.[14] Furthermore, one study also assessed the impact of sleep restriction (4-hour sleep opportunity/night for 4 nights) and the effects on performance during simulated fire suppression tasks as compared with control groups (8-hour sleep opportunity/night) in Australian wildland firefighters.[13] The results showed that both sleep patterns (4 and 8 hours/night) were either adequate or had no effect on physical performance. Additional analyses investigating the impact of sleep restriction combined with higher working temperatures, demonstrated that shortened sleep and hot working conditions did not significantly affect performance compared with temperate working conditions and optimal sleep duration.[21] However, studies using simulated fire conditions have demonstrated that sleep restriction (4 hours/night) can in fact impact physiological processes related to stress and acute inflammatory responses.[22–23] These findings support the idea that sleep restriction can contribute to negative stress and inflammatory responses, with the potential to impact worker health and well-being.

Successive days of sleep loss can cause sleep debt, defined as the accumulated difference between the actual number of hours a person sleeps and the ideal nightly hours of sleep a person should be getting.[24] Sleep debt is in turn associated with performance deficits, poor judgment, deflated mood, and ill health.[24–27] Certain work

From the Centre for Research in Occupational Safety and Health (CROSH), Laurentian University, Sudbury, Ontario, Canada (Mr McGillis, Dr Dorman, Mr Robertson, Dr Larivière, Mr Leduc, Dr Eger, Dr Oddson, Dr Larivière); School of Human Kinetics, Laurentian University, Sudbury, Ontario, Canada (Mr McGillis, Dr Dorman, Mr Robertson, Dr Larivière, Mr Leduc, Dr Eger, Dr Oddson, Dr Larivière); Northern Ontario School of Medicine, Sudbury, Ontario, Canada (Dr Dorman, Dr Larivière, Dr Larivière).
Funding: Ontario Ministry of Labour—"Bridging the Gap" program (Grant #12104). Ontario Ministry of Natural Resources and Forestry (OMNRF).
The authors report no conflicts of interest.
Address correspondence to: Céline Larivière, PhD, RKin, School of Human Kinetics, Laurentian University, 935 Ramsey Lake Road, Sudbury, Ontario P3E 2C6, Canada (clariviere@laurentian.ca).

DOI: 10.1097/JOM.0000000000001175

characteristics of fire deployment may create situations where sleep loss is inevitable. Typical working characteristics may include any of the following: extended (up to 14 days) and consecutive (minimum 2-day rest between) fire suppression efforts, lengthy individual shifts, and overtime[14–15,28–34] and early shift start times[14,35] resulting in reduced opportunity for sleep. It is well known that these shift characteristics, which may result in shortened sleep and in extended wakefulness, can lead to circadian rhythm and homeostatic sleep process disruptions.[9,12,25] To the authors' knowledge, this is the first study to objectively assess the sleep quantity and quality of Canadian wildland firefighters across different work deployments. Furthermore, the association between sleep quality and quantity with shift length, shift start time, and extended work periods is the first analysis to be performed in this particular workforce.

Therefore, the purpose of this study was to objectively assess the sleep quality and quantity of Ontario wildland firefighters while on Initial Attack and Project Fire deployments and while working at Fire Management Headquarters (Base). To more comprehensively gauge the levels of fatigue of these workers, subjective measures of fatigue and recovery, as well as objective reaction time scores, were also collected. We expected that sleep quality and quantity would be suboptimal, that reaction time scores and self-reported fatigue levels would be greater, and that self-reported recovery would be worse, during Initial Attack compared with Project Fire deployments and Base work.

METHODS

Participant Recruitment

During the 2014 fire season, 23 (response rate: 32%) Canadian wildland firefighters from the province of Ontario were recruited to participate in this study. Two participants withdrew from the study: one sustained an injury and was therefore absent from the workplace; and one voluntarily withdrew for personal reasons, resulting in a final sample of 21 participants ($n = 21$). All participants provided written, informed consent before the start of data collection, and this study received ethics approval from the Laurentian University Research Ethics Board.

Study Design

Participants met with researchers twice: in early (May to June) and late (July to September) parts of the fire season. During visit one, baseline measures were taken and the participants were shown how to use the study equipment (w-ActiSleep-BT watch, log booklet [sleep log; morning fatigue and evening recovery questionnaires], iPod touch [Apple Inc.—Psychomotor Vigilance Test Application], Anker Astro Pro2 20000 mAh Multi-Voltage external battery pack). Measures included age, work experience level, and the Short Form-36 question Health Survey (SF-36).[36] The SF-36 Health Survey generates a Physical Component Score (PCS) and Mental Component Score (MCS) used to identify the perception of personal health and well-being.

Participants were provided with a personalized bag, identified with their participant number, for transporting study devices, which are detailed below.[4] During visit two, the study equipment was collected. It should be noted that researchers collected and returned the equipment periodically between deployments to extract data from the ActiSleep software, replace log booklets, and charge all electrical equipment.

During the fire season while working on fire line deployments (Initial Attack and Project Fire) and when working at Fire Management Headquarters (Base), participants were asked to collect personal data regarding three factors outlined below: (1) objective sleep data, (2) subjective fatigue/recovery data, and (3) reaction time data.

Objective Sleep Data

Participants were instructed to wear the w-ActiSleep-BT watches (ActiGraph Corporation, Pensacola, FL), which are validated against gold standard polysomnography,[37–39] before sleep periods each evening postwork period, on the dominant wrist.[39] These devices were not utilized during work periods due to the risk of equipment damage. Participants were also asked to fill out sleep logs (date/time) each morning and evening specifying their time in bed and time out of bed. This information was used to help assess sleep quantity and quality.[40] Consistent with prior research, the sampling rate of the w-ActiSleep-BT watches was set at 30 Hz and data were saved in 60-second epochs.[41] The ActiLife 6.11.5 data analysis software (ActiGraph Corporation) was used to analyze the data recordings from the watches, and the following variables were derived to assess sleep quantity and quality: total sleep time (TST), sleep efficiency (SE), and wake after sleep onset (WASO) (Table 1).

Subjective Fatigue/Recovery Data

Participants were asked to complete a daily, single-item, subjective fatigue questionnaire in the morning upon waking (one-item questionnaire—"how fatigued do you currently feel" (1 = no fatigue and 10 = extreme fatigue scale)[42] and a 16-item, recovery questionnaire in the evening before sleep periods, which is divided into four subscales including (1) psychological detachment from work, (2) relaxation, (3) mastery, and (4) control.[43] For each item, 1 = no recovery and 5 = full recovery. Total score range would be situated between 16 (4 items $\times$ 4 scales $\times$ 1 no recovery = 16) and 80 (4 items $\times$ 4 scales $\times$ 5 full recovery = 80)[43] (see Table 1).

Reaction Time Data

Each morning and evening, participants were instructed to complete a validated 5-minute version of the psychomotor vigilance test (PVT) (on the iPod touch) (Mind Metrics application, Proactive Life LLC).[44–47] This platform has been validated[46]; however, average reaction time was the only variable collected due to limitations of the platform to collect sleep sensitive variables (ie, number of lapses <500 ms) as discussed in Basner and Dinges.[47] The application date- and time-stamped data and the reaction times were then manually extracted from these outputs for further analyses. In addition, it is worth noting that the timing of the PVT reaction time tests could not be standardized for all participants due to variability in the shift start and end times. These times were within the period of waking and commencing work for the morning data collection, as well as the period of completing work and induction of sleep for the evening data collection.

Data Analyses

Data were analyzed using IBM SPSS (version 20.0). Dependent variables included sleep measures (TST [minute], SE [%], WASO [minute]), morning subjective fatigue score, evening subjective recovery score, and morning and evening average reaction time (milliseconds [ms]) (Table 1). Data were assessed according to deployment types: (1) Non-Fire or Base work, (2) Initial Attack fire deployments, and (3) Project Fire deployments. For a separate analysis with Project Fire deployment conditions only, the dependent variables were also analyzed according to (1) consecutive work periods (1 to 3 days, 4 to 7 days, and >7 days), (2) shift length (<12 hours, 12 to 13 hours, >13 hours), (3) shift start time (5 to 6 AM, 6 to 7 AM, and 7 to 8 AM), and (4) shift end time (≤7 PM, 7 to 8 PM, 8 to 9 PM, >9 PM). Data collected during Non-Fire (Base) work periods were excluded from this latter analysis as the shift characteristics were consistent and would not distribute across these subcategories (ie, similar and predetermined shift length, start time, and end time). Similarly, Initial Attack data were excluded from this analysis due to a small sample size and because the data would not distribute across these subcategories. Furthermore, a side-by-side

TABLE 1. Deployment Dependent Variables and Definitions

Variable	Definition
Base (non-fire)	Standard work periods consisting of training, daily fitness, and ''alert'' periods awaiting fire line deployment
Initial Attack	Initial fire suppression deployment; historically of high physical intensity and lengthy individual shifts
Project Fire	Border suppression deployments on large active fires; level of intensity is dependent on terrain, but typically less stressful relative to Initial Attack fires
Sleep efficiency (%)	Proportion of time spent asleep to time in bed (total sleep time/time in bed)
Wake after sleep onset (min)	Time awake throughout sleep period, after initial sleep onset
Total sleep time (min)	Total amount of time spent asleep
Recovery opportunity time (hr)	Period of time between reported shift end time and bed time
AM subjective fatigue[42]	One-item questionnaire —''how fatigued do you currently feel'' (1 = no fatigue to 10 = extreme fatigue scale)
PM subjective recovery[43]	Sixteen-item questionnaire to understand subjective recovery on four scales: (1) psychological detachment from work, (2) relaxation, (3) mastery, and (4) control. For each item, 1 = no recovery and 5 = full recovery. Total score range would be situated between 16 (4 items × 4 scales × 1 no recovery = 16) and 80 (4 items × 4 scales × 5 full recovery = 80)
AM/PM PVT (ms)	Five-minute reaction time test measuring average reaction time in milliseconds—performed in the morning and evening during work periods via Mind Metrics Application on iPod touch

comparison of Project Fire and Initial Attack data based on shift characteristics was not possible due to the small sample size of the Initial Attack.

Normality was assessed using the Shapiro–Wilk test. One-way ANOVAs were performed for normally distributed data, whereas the Kruskal–Wallis *H*-test was used when the data were not normally distributed. When significant differences were noted, post hoc analyses were performed using either Tukey's test or Dunn's procedure[48] with a Bonferroni correction for multiple comparisons for one-way ANOVA and Kruskal–Wallis tests, respectively. Adjusted P values were then used to identify these differences. In all instances, the P value was set at <0.05.

RESULTS

Participant Information

All participants ($n = 21$) were male, with a mean age of 29.9 ± 8.4 years (range: 18 to 50 years), and were seasonal fire-fighters employed by the OMNRF. In total, 11 participants (28.4 ± 6.1 years; range: 22 to 39) consistently collected actigraphy data, routinely completed their sleep log, morning fatigue questionnaire, and evening recovery inventory, as well as completed their morning/evening psychomotor vigilance test. Furthermore, the analysis of the SF-36 Health Survey scores revealed: (1) PCS of 54.2 ± 7.8 and (2) MCS of 54.7 ± 6.1, indicating relatively high self-perceived health scores before study commencement.[36]

Deployment Information

Average descriptive statistics for shift characteristics according to Base work, Initial Attack, and Project Fire deployments can be found in Table 2.

Actigraphy Sleep Data, According to Deployment Type

TST and SE were significantly different between deployment type (see Table 3). Initial Attack TST was significantly lower $F(2, 146) = 15.221$, $P = 0.000$) than TST achieved for Base work ($P = 0.001$) and Project Fire ($P = 0.000$). This translates to 84.4 minutes (95% CI [41.1 to 127.7]) and 86.2 minutes less sleep (95% CI [48.8 to 123.5]) during Initial Attack fires than during Base work and during Project Fire deployment, respectively. Initial Attack fires had a significantly lower SE than that observed for Project Fires ($P = 0.016$) ($\chi^2(2) = 8.178$, $P = 0.017$). Although WASO was not significantly different ($\chi^2(2) = 5.074$, $P = 0.079$) between deployment conditions, the values would be considered poor (ie, >31 minutes), with multiple awakenings during sleep periods. Overall, sleep duration in this sample was relatively low for all deployment types, with a large proportion of the sample falling below the recommended sleep time of 7 to 9 hours for adults[20] (see Table 3). In addition, WASO was above recommended standards (ie, >31 minutes)[49] (see Table 3).

Actigraphy Sleep Data by Consecutive Work Period: 1 to 3 Days, 4 to 7 Days, and >7 Days

Project Fire deployment sleep data were analyzed by consecutive work periods, defined as short (1 to 3 days, $n = 24$), medium (4 to 7 days, $n = 40$), or long (>7 days, $n = 42$). There were no significant differences in TST between short (367.4 ± 64.0 minutes), medium (364.6 ± 46.9 minutes), and long (385.1 ± 56.0 minutes) consecutive work periods ($F(2,103) = 1.633$, $P = 0.200$). However, TST tended to be less than the 7 to 9 hours of recommended sleep for adults.[20] Similarly, SE scores were not different between short (90.1 ± 6.7%), medium (87.2 ± 7.7%), and long

TABLE 2. Shift Characteristics for Base, Initial Attack, and Project Fire

	Base			Initial Attack			Project Fire		
	Mean	SD	Range	Mean	SD	Range	Mean	SD	Range
Shift length (hr:min)	8:48	0:54	8.5–13.0 hr	13:18	3:24	8.5–18.5 hr	12:30	1:0	9.0–15.5 hr
Shift start[a] (time: AM)	10:12	1:6	5.5–10.5 AM	7:12	2:0	5.0–10.5 AM	7:18	0:48	5.0–8.0 AM
Shift end[a] (time: PM)	7:06	0:18	7.0–8.0 PM	9:12	2:6	3.5–11.5 PM	7:54	1:0	5.5–11.0 PM
Recovery opportunity time (hr:min)	4:48	0:54	3.0–7.0 hr	2:8	2:0	1.0–9.0 hr	3:6	1:12	0.5–6.5 hr

Number of shifts in each deployment category: Base ($n = 28$), Initial Attack ($n = 15$), and Project Fire ($n = 106$).
[a]These values are expressed as mean ± SD time (ie, morning and evening exact time ± hours).

TABLE 3. Sleep Measurement Data by Deployment Type and Percent Distribution of Sleep Measures Falling Outside the Range of Optimum Sleep Quality and Quantity

	TST (min)			SE (%)			WASO (min)		
Deployment Type	**Mean**	**SD**	**<7 hr[a]**	**Mean**	**SD**	**<85%[a]**	**Mean**	**SD**	**>31 min[a]**
Base	371.6	58.1	85.7%	85.7	8.0	50.0%	58.8	33.9	75.0%
Initial Attack	287.2[b]	69.3	100%	75.6[c]	19.2	60.0%	92.8	82.8	86.6%
Project Fire	373.4	55.1	81.1%	87.6	7.9	33.0%	51.4	33.7	68.8%

[a]Correspond to the percent distribution of measures <7 hours (<360 minutes) for total sleep time (TST), <85% for sleep efficiency (SE), and >31 minutes for wake after sleep onset (WASO).
[b]Significant difference between Initial Attack and Project Fire and Base for TST only.
[c]Significant difference between Initial Attack and Project Fire for SE only.

(86.6 ± 8.6%) (F(2,103) = 1.572, P = 0.213) work periods, with average scores above the optimum cutoff of 85%. Furthermore, WASO scores were consistently higher than the ideal standard (ie, >31 minutes), and no significant differences between short (40.1 ± 28.1 minutes), medium (55.3 ± 36.8 minutes), and long (54.1 ± 32.8 minutes) (F(2,103) = 1.768, P = 0.176) work periods were noted.

Actigraphy Sleep Data, According to Project Fire Deployment Shift Characteristics

Project Fire deployment sleep data were analyzed according to shift characteristics, including shift length, shift start time, and shift end time. The shift length analysis revealed no statistically significant differences in TST scores between the <12 hours (380.7 ± 61.9 minutes), 12 to 13 hours (375.3 ± 48.7 minutes), and >13 hours (364.0 ± 66.3 minutes) shift length (F(2,100) = 0.479, P = 0.621) categories (see Table 4). Not surprisingly, there was a downward trend in sleep quantity, or TST, from shorter shifts to lengthier shifts. The SE analysis similarly revealed no statistically significant differences between the <12 hours (87.6 ± 7.4%), 12 to 13 hours (87.7 ± 7.7%), and >13 hours (86.3 ± 8.8%) shift length (F(2,100) = 0.287, P = 0.751) categories. All scores were above the threshold of 85% indicating no effect from shift length on this aspect of sleep quality. Furthermore, WASO scores were also not significantly different between the <12 hours (57.8 ± 38.4 minutes), 12 to 13 hours (49.3 ± 28.9 minutes), and >13 hours (59.2 ± 43.4 minutes) shift (F(2,100) = 0.906, P = 0.408) categories. However, all categories indicate that WASO scores were above the threshold (ie, >31 minutes) highlighting poor sleep quality regardless of shift duration.

For the shift start time analyses on Project Fire deployments, TST was the lowest for the earliest shift start time of 5 to 6 AM (F(2,99) = 12.427, P = 0.000). Surprisingly, there was no predictable upward trend in sleep duration with respect to later shift start times. In particular, TST was 75.9 minutes less when shifts started between 5 and 6 AM (323.4 ± 46.3) compared with shifts starting between 6 and 7 AM (399.2 ± 57.3) (P = 0.000). TST was 44.5 minutes less when shifts started at 5 to 6 AM, compared with shifts starting at 7 to 8 AM (367.9 ± 45.3) (P = 0.013). Unexpectedly, significant differences were also apparent between 6 to 7 AM and 7 to 8 AM (P = 0.012) shift start times with a decrease of 31.5 minutes TST when shifts commenced later. Interestingly, both SE and WASO analyses exhibited no significant differences across shift start times with SE scores situated above the optimal threshold (ie, 85%) and WASO scores were higher than ideal levels (ie, >31 minutes) for all categories (see Table 4).

Lastly, the shift end time analysis revealed no significant differences for TST (F(3,99) = 2.586, P = 0.057). In particular, TST was consistent across ≤7 PM (391.5 ± 54.1 minutes), 7 to 8 PM (357.2 ± 52.0 minutes), 8 to 9 PM (381.2 ± 55.0 minutes) and >9 PM (378.4 ± 41.7 minutes), with no evident or predictable trend. In terms of sleep quality, SE scores were not statistically different between conditions (≤7 PM [88.3 ± 6.2%], 7 to 8 PM [88.9 ± 7.4%], 8 to 9 PM [84.4 ± 9.4%], and >9 PM [86.3 ± 7.4%]) (F(3,100) = 2.126,

TABLE 4. Sleep Measures for Project Fire Deployments According to Shift Characteristics

			Mean ± SD		
Analysis	**Shift Category**	**Sample Size (*n*)**	**TST (min)**	**SE (%)**	**WASO (min)**
Shift length (hr)	<12	10	380.7 ± 61.9	87.6 ± 7.4	57.8 ± 38.4
	12–13	70	375.3 ± 48.7	87.7 ± 7.7	49.3 ± 28.9
	>13	23	364.0 ± 66.3	86.3 ± 8.8	59.2 ± 43.4
Shift start (AM)	5–6	14	323.4 ± 46.3[a]	88.1 ± 4.6	43.7 ± 18.2
	6–7	40	399.3 ± 57.3	87.4 ± 7.9	58.3 ± 38.9
	7–8	48	367.9 ± 45.3	88.2 ± 8.8	44.9 ± 31.4
Shift end (PM)	≤7	25	391.5 ± 54.1	88.3 ± 6.2	53.3 ± 31.3
	7–8	44	357.2 ± 52.0	88.9 ± 7.4	41.5 ± 24.1
	8–9	27	381.2 ± 55.0	84.4 ± 9.4	67.0 ± 42.8
	>9	7	378.4 ± 41.7	86.3 ± 7.4	60.9 ± 34.0

AM, morning period; PM, evening period; SD, standard deviation; SE, sleep efficiency; TST, total sleep time; WASO, wake after sleep onset.
[a]Significant differences within each shift characteristic category.

$P = 0.102$). Nevertheless, it is notable that SE is generally above or near ideal thresholds (ie, ≥85%) regardless of shift end time. Similarly, WASO scores were not significantly different between shift end times ($F(3,100) = 0.906$, $P = 0.408$), but the ≤7 PM (53.2 ± 31.3 minutes), 7 to 8 PM (41.5 ± 24.1), 8 to 9 PM (67.0 ± 42.8), and >9 PM (60.9 ± 34.0) categories were still consistently higher than ideal levels (ie, >31 minutes) (see Table 4).

Psychomotor Vigilance Reaction Time According to Deployment Type

Psychomotor vigilance test (PVT) average reaction time data (ms) were collected to determine whether cognitive alertness in the morning and evening would differ according to deployment type. Scores during morning periods were significantly higher for Initial Attack ($N = 6$, 424.8 ± 51.3 ms) compared with Project Fire ($N = 66$, 372.4 ± 51.1 ms) ($P = 0.014$) ($\chi^2(2) = 8.097$, $P = 0.017$), but no difference was found with Base scores ($N = 19$, 385.7 ± 64.2 ms). No significant differences were observed for evening reaction times for all work conditions, with Initial Attack ($N = 5$, 363.2 ± 34.7 ms), Project Fire ($N = 63$, 381.1 ± 59.1 ms), and Base ($N = 17$, 373.0 ± 53.7 ms) ($\chi^2(2) = 0.776$, $P = 0.678$) scores all within normal limits. The cumulative score lapses (>500 ms) were fairly low for all deployment types, with morning scores having lapses in 5.3% (Base), 16.7% (IA), and 1.5% (PF) of the sample, and evening scores having lapses in 5.9% (Base), 0% (IA), and 6.4% (PF) of the sample.

Self-Reported Fatigue Measures

Self-reported fatigue was found to be significantly different between deployment types, with post hoc analyses revealing higher fatigue levels for Initial Attack compared with Base ($\chi^2(2) = 10.054$, $P = 0.006$), but no other significant differences were identified (see Table 5). With regard to shift-specific analyses, Project Fire data revealed no significant differences in self-reported fatigue between short to long consecutive work periods (days) ($\chi^2(2) = 1.662$, $P = 0.436$). Similarly, shift length did not appear to affect self-reported fatigue ($\chi^2(2) = 0.487$, $P = 0.784$). However, the analyses according to shift start time revealed that self-reported fatigue was highest for the 7 to 8 AM shift start time compared with the 6 to 7 AM ($P = 0.000$) and 5 to 6 AM ($P = 0.003$) start times ($\chi^2(2) = 26.674$; $P = 0.000$). For shift end times, self-reported fatigue was highest for the later categories ($\chi^2(3) = 28.241$, $P = 0.000$; Table 5). Specifically, significant differences were identified between ≤7 PM and 8 to 9 PM ($P = 0.000$), ≤7 PM and >9 PM ($P = 0.006$), 7 to 8 PM and 8 to 9 PM ($P = 0.001$), as well as 7 to 8 PM and >9 PM ($P = 0.032$) shift end conditions. The majority of the self-reported fatigue scores, reported in Table 5, were 5 or less, thereby indicating that self-reported fatigue was generally considered low-to-moderate in this study.

TABLE 5. Self-Reported Fatigue According to Deployment Type and Shift Characteristics

Analysis	Category	N	Mean ± SD
Deployment type	B	27	2.7 ± 2.0
	IA	15	4.3 ± 1.6[b]
	PF	103	3.5 ± 1.8
CWP[a] (d)	1–3	24	3.4 ± 1.8
	4–7	39	3.2 ± 1.5
	>7	40	3.8 ± 2.1
Shift length[a] (hr)	<12	10	3.8 ± 1.9
	12–13	68	3.5 ± 1.9
	>13	22	3.3 ± 1.9
Shift start[a] (AM)	5–6	13	2.5 ± 1.1
	6–7	39	2.6 ± 1.7
	7–8	47	4.3 ± 1.6[c]
Shift end[a] (PM)	≤7	25	2.6 ± 1.6
	7–8	42	3.0 ± 1.5
	8–9	26	4.7 ± 1.6[d]
	>9	7	5.3 ± 2.0[d]

AM, morning; B, Base; CWP, consecutive work period; IA, Initial Attack; N, observations; PF, Project Fire; PM, evening.
Scale is from 1 (not fatigued) to 10 (extreme fatigue).
[a]Analyses included Project Fire data only.
[b]Difference between IA and B/PF.
[c]Difference for 7 to 8 AM compared with 5 to 6 AM, 6 to 7 AM.
[d]Differences for both 8 to 9 PM and >9 PM compared with ≤7 PM and 7 to 8 PM.

Self-Reported Recovery Measures According to Deployment Type

Self-reported recovery was similar between deployment types. All scores were above the midrange of the scale (scale from 16—no recovery to 80—full recovery, see "Methods" for complete details), suggesting that participants perceived that they were adequately recovered. In particular, there were no significant differences between reported recovery during Base work ($N = 27$, 54.2 ± 9.9), Initial Attack ($N = 15$, 52.5 ± 8.5), and Project Fire ($N = 103$, 51.0 ± 8.4) deployments. These recovery scores were also consistently reported, regardless of the amount of recovery opportunity time (ROT) allocated per night during these work activities (ROT: Base, 4.8 ± 0.9 hours; Initial Attack, 2.9 ± 2.0 hours; and Project Fire, 3.1 ± 1.2 hours).

DISCUSSION

In the present study, we found that the sleep quality and quantity in a group of Canadian wildland firefighters, as well as self-reported fatigue levels differed according to the type of deployment and the characteristics of the work schedules. These measures tended to be suboptimal, particularly during Initial Attack fire deployments. It was also noted that between one-third and two-thirds of the sleep measures collected during all three deployment types (ie, Base, Initial Attack Fires, and Project Fires) fell outside the optimal ranges recommended for adults.[20,49–51]

Sleep Behavior and Performance During Non-Fire and Fire Deployments

In the current investigation, TST on Initial Attack (4.8 hours) deployments was significantly lower compared with Base (6.2 hours) and Project Fire (6.2 hours), whereas SE on Initial Attack (75.6%) was significantly lower than Project Fire (87.6%) deployments. In particular, two-thirds of the SE observations collected for Initial Attack deployments fell below the recommended threshold of 85% for SE.[49–51] In addition, the average TST for Initial Attack fire deployments was well below recommendations for adults (4.8 ± 1.2 hours compared with 7 to 9 hours).[20] Interestingly, WASO scores in the current investigation were not different between deployment types; however, a substantial percentage of the observations fell above the recommended threshold (ie, more awakenings) regardless of work performed,[49–51] which indicates poor quality sleep in general. In line with these results, the reaction time in the morning before work periods on Initial Attack deployments was significantly higher than Project Fire (with no difference compared with Base work), indicating a decline in alertness and performance. These results could be due to a number of factors (eg, sleep conditions, nonproductive rumination, etc.) that were not systematically investigated in this specific study.

The issue of acute sleep deprivation caused by low sleep duration and poor sleep quality can have immediate effects such as decreased alertness, impaired cognitive ability, and psychological stress.[8,25–26] Furthermore, chronic sleep deprivation can also increase the rates of mortality as well as increased health-related problems.[27] In our sample of firefighters, TST of less than 6 hours was observed at a high frequency for all three work conditions (ie, Initial Attack, Project Fire, and Base) indicating that our participants were at risk of sleep debt. Upward of five consecutive nights of potential sleep debt was accumulated during Base work periods, two nights of sleep debt during Initial Attack and upward of six nights during Project Fire deployments. These results indicate that some firefighters are accumulating sleep debt for upward of six consecutive days, at least in this study, which has been previously identified as problematic in terms of performance and health.[25,27] However, even with lengthy consecutive periods of poor sleep, performance on the reaction time test in the present study was not significantly hindered during both Base and Project Fire deployments. The highest reaction times were noted for the Initial Attack deployments even though these were the shortest consecutive work periods in this study. This may suggest that acute periods of suboptimal sleep as observed for Initial Attack deployments in combination with the intensity of the work[4] and lengthy shifts (early start times and late shift end times for Initial Attack) may have a greater impact on reaction time performance.

Another surprising result from this study is that half of the SE measures recorded for Base work were also below the optimal 85% SE cutoff, and TST (6.2 ± 1.0 hours) was generally lower than what is recommended for adults.[20] This was also marginally lower than what was reported in Vincent et al[14] for non-fire periods (7.0 ± 0.9 hours) among Australian firefighters. This was somewhat disconcerting given that firefighters working at the Base in the present study were typically sleeping in their home environment. However, we did not take into consideration aspects of the home environment that could disrupt the recovery process, such as nonwork stressors (demands from family/friends and personal conflicts) and low social activity.[52,53] Nevertheless, the finding that firefighters may not be achieving optimal sleep while on Base suggests that they may be at risk of sleep debt and suboptimal recovery, which could impact workplace performance, mood, and well-being before lengthy fire deployments.[25,54]

Work Shift Parameters and Sleep Quantity and Quality

The literature is fairly consistent regarding long work hours and increased risk for sleep deprivation, sleepiness, and poor sleep behavior.[29–32] This said, Waage et al[55] describe a steady decline in sleep quality as work periods lengthen for shift workers in the offshore oil industry, working 2-week/12-hour shifts, providing evidence that lengthy work periods (accumulation of long working hours) can also affect sleep behavior. However, in the current analysis of Project Fire deployments, no significant change in sleep parameters with lengthy work periods or shift length was observed. These shift conditions, along with early morning start times and late shift end times, would be expected to impact the timing and duration of sleep periods, which have been identified as determinants of sleep outcomes.[14,35,56] Although our overall sleep outcomes during Project Fire deployments were generally unaffected by shift characteristics, we did find that early shift start times (5 to 6 AM) reduced TST (44.5 to 75.9 minutes less TST) compared with later shift start times (see Table 4). Others have noted that early morning shift start times are not typically associated with worse sleep quality;[35] rather they are associated with a decline in sleep duration due to maladjusted bed times. Accordingly, the recovery opportunity time the night before 5 to 6 AM start times was typically lower than for all other shift start conditions and this combination of shift characteristics is typically encountered when fire suppression is at a high-alert phase. Similar results were obtained by Vincent et al.[14] In their sample of wildland firefighters, shifts beginning before 6 AM resulted in sleep duration 60 minutes lower than other shift start times. Although early shift start times may be necessary to ensure adequate fire suppression outcomes, it would be advised whenever possible to consider the shift length and the sleep duration or opportunity the night prior when setting the shift start times the following day, especially after multiple days of intense fire suppression activities. Similar recommendations have been published in other wildland firefighting research.[14]

Self-Reported Recovery and Recovery Opportunity Time

A closer look at recovery opportunity time after work periods and evening self-reported recovery suggests that the firefighters in the present study, characterized as an unusually low-hazard fire season, considered themselves to be reasonably well recovered irrespective of the length of recovery time, which varied according to shift length. We would have expected the self-reported recovery scores to be lower particularly during Initial Attack deployments, which were associated with longer shift lengths, shorter recovery opportunity time, and suboptimal sleep parameters, yet the scores obtained for all deployment types were within the midrange of the perceived recovery scale. Of note, Querstret and Cropley[57] have reported that long hours, highly strenuous work, and long work periods lead to individuals actively ruminating, or thinking, about work during evening recovery periods, which can cause psychophysiological arousal that is counterintuitive to the recovery process (ie affective rumination). Furthermore, affective rumination has been associated with poor sleep.[57] Given the nature of wildland firefighting, it would be realistic to assume affective rumination may be a real cause of sleep disturbances. However, it remains to be determined if and how firefighters would optimize their recovery opportunity time, particularly during a high-hazard firefighting season. Intervention strategies could target this specific off-work period to promote psychological detachment from work, thereby maximizing recovery and possibly improving sleep.

Fatigue and Wildland Firefighting

Worker fatigue is an area of concern for many occupations including wildland firefighters, particularly during fire suppression and related activities.[9,12,14,18,33,34,58–61] The suboptimal sleep patterns reported herein over a relatively low-hazard wildland firefighting season indicate that these sleep patterns may be exacerbated during a high-hazard fire season, potentially increasing fatigue levels. The subjective fatigue measures reported by participants in the present study would suggest that they were minimally to moderately fatigued in the context of a low-hazard firefighting season and that the highest fatigue scores were for Initial Attack deployments. This said a larger sample size is required to understand whether subjective reporting of fatigue could be utilized to gauge when wildland firefighters require breaks or if they should be pulled off the fire line. In relation to this, Smith et al[60] identified that self-reporting of fatigue was a potentially useful and cost-effective practice within a sample of 91 rural firefighters. However, in order for this fatigue self-assessment tool to be effective, education, fatigue symptom awareness, and quite possibly an optimization of the safety culture would need to be considered.

The research on fatigue management in the workplace has expanded in the past decade, with multiple methods proposed for mitigating the effects of fatigue in various occupational settings.[62–64] Unfortunately, in the context of wildland firefighting operations, it is difficult to implement prescription-of-hours or reduce the period of time these individuals consecutively work due to the nature of the work (eg, out-of-control bush fires and danger to rural communities). Nevertheless, there are possible ways to help optimize sleep opportunity for wildland firefighters to combat fatigue symptoms; this could include good design of work hours and fatigue and sleep hygiene education.[64–66] Good design of work hours would include later shift start times (≥7 AM) and more time between shifts (≥12 hours) when possible.[67] These guidelines may be easier to implement during Project Fire rather than Initial Attack deployments due to the nature of the fire suppression activities. For Initial Attack suppression, it may be wise to limit the shortened sleep periods as much as possible to reduce performance deficits and fatigue-related errors in judgment. Lastly, fatigue mitigation training programs are not ideal for managing/eliminating fatigue as compared with decreased work hours and increased recovery time between shifts, but they have been found to be useful for self-assessment of fitness-for-duty and risk-assessment in different occupational contexts.[66,68–70] Overall, a combination of sleep hygiene training, fatigue awareness, schedule adaptation/management, and further research on the specifics of fire suppression sleep conditions[14] may help to optimize sleep behavior.

Lastly, it is worth noting that the data were collected in a fire season that saw the lowest number of fires in Ontario in over 50 years, reflecting an extremely low-hazard fire season (*Canadian Interagency Forest Fire Centre, 2014 Canadian Report*), particularly with respect to Initial Attack deployments. Contextually, results may underestimate the impact of sleep debt as data were collected during a low-hazard fire season.

Future Directions

First, we suggest that attention be given to sleep behaviors during Base work and interventions for this could include the promotion of good sleep hygiene to reduce the impact of sleep debt-related performance deficits before lengthy fire deployments. Second, future studies should assess sleep conditions on both types of fire deployments, over the course of lengthy work periods and on multiple back-to-back deployments (typical of high-hazard fire seasons) to determine the precise causes of the suboptimal sleep behavior. With this in mind, although early shift start times may be necessary to ensure adequate fire suppression outcomes on both types of deployments, it would be advised whenever possible to consider the shift length and the sleep duration or sleep opportunity the night prior when setting the shift start times the following day, especially after multiple days of intense fire suppression activities. This could be implemented immediately and it should be noted that similar recommendations have been published in other wildland firefighting research.[14] Overall, a combination of sleep hygiene training, fatigue awareness, schedule adaptation/management, and further research on the specifics of fire suppression sleep conditions[14] may help to optimize sleep behavior in this occupation.

Limitations

A few limitations should be noted for the present study. First, the sleep, fatigue, and recovery data were collected during a record, low-hazard fire season, and the results may not be reflective of a typical fire season. This is an important consideration for data interpretation given that a high-hazard fire season may result in significantly worse sleep outcomes. The current results may be an indication of a larger concern during more severe fire seasons. Second, self-reported shift start and end times were used to generate the shift categories in this study and formal reports of these shifts were not available to the researchers. Another limitation is the fact that baseline sleep data were not collected during nonwork periods, so we are not able to draw conclusions on whether the sleep results were due to work or if participants are naturally sleeping as such. It would be recommended to collect baseline sleep data before the fire season to gauge the effects of wildland firefighting work periods on sleep behavior. Fourth, our sample size limited our ability to detect small effect sizes and the low number of observations for Initial Attack and Base work, relative to Project Fire deployments limited our ability to compare sleep profiles by shift characteristics according to deployment type. To determine the factors that best predict fatigue in these workers, larger participant numbers would be required. Finally, because the subjects were largely young males, the results for this study may not be generalizable and should be interpreted with caution.

CONCLUSIONS

Wildland firefighters in Ontario have a high injury rate compared with other occupations and it is reported anecdotally that fatigue is a likely risk factor (*OMNRF Health & Safety Reports, 2012–2014*). Fatigue risk management systems tailored to wildland firefighters should be evidenced-based. Accordingly, the present study analyzed the sleep behavior and subjective fatigue of wildland firefighters to quantify this component of fatigue in this population. This study indicates that a large proportion of sleep quantity and quality measures fell outside the recommended thresholds while participants worked at the Base and during both types of fire suppression deployments. Initial Attack deployments resulted in the worst sleep behavior out of the three conditions and this should be considered an area for targeted intervention. Sleep behavior at the Base was unexpectedly poor; therefore, better sleep hygiene practices should be promoted during this work period to avoid sleep debt before fire deployments. It is recommended that the impact of shift start and end time adjustments and shift length combinations should be further investigated. Furthermore, sleep hygiene education and self-awareness training on fatigue symptoms to self-assess personal fit-for-duty, particularly during high alert and lengthy fire suppression activities, should be considered.

REFERENCES

1. Aisbett B, Wolkow A, Sprajcer M, Ferguson SA. "Awake, smoky, and hot": providing an evidence-base for managing the risks associated with occupational stressors encountered by wildland firefighters. *Appl Ergon*. 2012;43:916–925.
2. Heil DP. Estimating energy expenditure in wildland fire fighters using a physical activity monitor. *Appl Ergon*. 2002;33:405–413.
3. Ruby BC, Shriver TC, Zderic TW, Sharkey BJ, Burks C, Tysk S. Total energy expenditure during arduous wildfire suppression. *Med Sci Sports Exerc*. 2002;34:1048–1054.
4. Robertson AH, Larivière C, Leduc CR, et al. Novel tools in determining the physiological demands and nutritional practices of Ontario firerangers during fire deployments. *PLoS One*. 2017;12:e0169390.
5. Ferguson SA, Smith BP, Browne M, Rockloff MJ. Fatigue in emergency services operations: assessment of the optimal objective and subjective measures using a simulated wildfire deployment. *Int J Environ Res Public Health*. 2017;13:171–182.
6. Wolkow A, Aisbett B, Ferguson SA, Reynolds J, Main LC. Psychophysiological relationships between a multi-component self-report measure of mood, stress and behavioural signs and symptoms, and physiological stress responses during a simulated firefighting deployment. *Int J Psychophysiol*. 2016;110:109–118.
7. Cuddy JS, Ruby BC. High work output combined with high ambient temperatures caused heat exhaustion in a wildland firefighter despite high fluid intake. *Wilderness Environ Med*. 2011;22:122–125.
8. Cuddy JS, Sol JA, Hailes WS, Ruby BC. Work patterns dictate energy demands and thermal strain during wildland firefighting. *Wilderness Environ Med*. 2015;26:221–226.
9. Dinges DF. An overview of sleepiness and accidents. *J Sleep Res*. 1995;4(s2):4–14.
10. Bunn TL, Slavova S, Struttmann TW, Browning SR. Sleepiness/fatigue and distraction/inattention as factors for fatal versus nonfatal commercial motor vehicle driver injuries. *Accid Anal Prev*. 2005;37:862–869.
11. Patterson PD, Weaver MD, Frank RC, et al. Association between poor sleep, fatigue, and safety outcomes in emergency medical services providers. *Prehosp Emerg Care*. 2012;16:86–97.
12. Williamson A, Lombardi DA, Folkard S, Stutts J, Courtney TK, Connor JL. The link between fatigue and safety. *Accid Anal Prev*. 2011;43:498–515.

13. Vincent G, Ferguson SA, Tran J, Larsen B, Wolkow A, Aisbett B. Sleep restriction during simulated wildfire suppression: effect on physical task performance. *PLoS One*. 2015;10:e0115329.
14. Vincent G, Aisbett B, Hall SJ, Ferguson SA. Fighting fire and fatigue: sleep quantity and quality during multi-day wildfire suppression. *Ergonomics*. 2016;59:932–940.
15. Vincent G, Aisbett B, Hall SJ, Ferguson SA. Sleep quantity and quality is not compromised during planned burn shifts of less than 12 h. *Chronobiol Int*. 2016;33:657–666.
16. Cater H, Clancy D, Duffy K, Holgate, A, Wilison B, Wood, J. Fatigue on the fireground: the DPI experience. In *Australasian Fire Authorities Council/Bushfire Co-Operative Research Centre Annual Conference*, Hobart, Grand Chancellor, September 19–21, 2007.
17. Budd GM, Brotherhood JR, Hendrie AL, et al. Project Aquarius 1. Stress, strain, and productivity in men suppressing Australian summer bushfires with hand tools: background, objectives, and methods. *Int J Wildland Fire*. 1997;7:69–76.
18. Aisbett B, Nichols D. Fighting fatigue whilst fighting bushfire: an overview of factors contributing to firefighter fatigue during bushfire suppression. *Aust J Emerg Manage*. 2007;22:31–39.
19. Gaskill SE, Ruby BC. Hours of reported sleep during random duty assignments for four type I wildland firefighter crews [online resource]. 2004. Available at: http://www.coehs.umt.edu/departments/hhp/research/fatigue/Fatigue/Hours%20of%20Reported%20Sleep%202001-02.pdf. Accessed January 30, 2017.
20. Hirshkowitz M, Whiton K, Albert SM, et al. National Sleep Foundation's sleep time duration recommendations: methodology and results summary. *Sleep Health*. 2015;1:40–43.
21. Cvirn MA, Dorrian J, Smith BP, Jay SM, Vincent GE, Ferguson SA. The sleep architecture of Australian volunteer firefighters during a multi-day simulated wildfire suppression: impact of sleep restriction and temperature. *Accid Anal Prev*. 2017;99(Pt. B):389–394.
22. Wolkow A, Aisbett B, Reynolds J, Ferguson SA, Main LC. The impact of sleep restriction while performing simulated physical firefighting work on cortisol and heart rate responses. *Int Arch Occup Environ Health*. 2016;89:461–475.
23. Wolkow A, Ferguson SA, Vincent GE, Larsen B, Aisbett B, Main LC. The impact of sleep restriction and simulated physical firefighting work on acute inflammatory stress responses. *PloS One*. 2015;10.
24. Van Dongen H, Rogers NL, Dinges DF. Sleep debt: theoretical and empirical issues. *Sleep Biol Rhythms*. 2003;1:5–13.
25. Dinges DF, Pack F, Williams K, et al. Cumulative sleepiness, mood disturbance and psychomotor vigilance performance decrements during a week of sleep restricted to 4–5 hours per night. *Sleep*. 1997;20:267–277.
26. Banks S, Dinges DF. Behavioral and physiological consequences of sleep restriction. *J Clin Sleep Med*. 2007;3:519–528.
27. Van Dongen H, Maislin G, Mullington JM, Dinges DF. The cumulative cost of additional wakefulness: dose-response effects on neurobehavioral functions and sleep physiology from chronic sleep restriction and total sleep deprivation. *Sleep*. 2003;26:117–129.
28. Dembe AE, Erickson JB, Delbos RG, Banks SM. The impact of overtime and long work hours on occupational injuries and illnesses: new evidence from the United States. *Occup Environ Med*. 2005;62:588–597.
29. Caruso CC. Possible broad impacts of long work hours. *Ind Health*. 2006;44:531–536.
30. Sallinen M, Kecklund G. Shift work, sleep, and sleepiness—differences between shift schedules and systems. *Scand J Work Environ Health*. 2010;36:121–133.
31. Virtanen M, Ferrie J, Gimeno D, et al. Long working hours and sleep disturbances: the Whitehall II prospective cohort study. *Sleep*. 2009;32:737–745.
32. Parkes KR. Sleep patterns of offshore day-workers in relation to overtime work and age. *Appl Ergon*. 2015;48:232–239.
33. Åkerstedt T, Fredlund P, Gillberg M, Jansson B. Work load and work hours in relation to disturbed sleep and fatigue in a large representative sample. *J Psychosom Res*. 2002;53:585–588.
34. Åkerstedt T, Knutsson A, Westerholm P, Theorell T, Alfredsson L, Kecklund G. Sleep disturbances, work stress and work hours: a cross-sectional study. *J Psychosom Res*. 2002;53:741–748.
35. Åkerstedt T, Kecklund G, Selén J. Early morning work—prevalence and relation to sleep/wake problems: a national representative survey. *Chronobiol Int*. 2010;27:975–986.
36. Ware JE, Snow KK, Kosinski M, Gandek B. *SF-36 Health Survey: Manual and Interpretive Guide*. Boston, MA: The Health Institute, New England Medical Center; 1993.
37. Slater JA, Botsis T, Walsh J, King S, Straker LM, Eastwood PR. Assessing sleep using hip and wrist actigraphy. *Sleep Biol Rhythms*. 2015;13:172–180.
38. Marino M, Li Y, Rueschman MN, Winkelman JW, et al. Measuring sleep: accuracy, sensitivity, and specificity of wrist actigraphy compared to polysomnography. *Sleep*. 2013;36:1747–1755.
39. Ancoli-Israel S, Cole R, Alessi C, Chambers M, Moorcroft W, Pollak C. The role of actigraphy in the study of sleep and circadian rhythms. American Academy of Sleep Medicine Review Paper. *Sleep*. 2003;26:342–392.
40. Darwent D, Lamond N, Dawson D. The sleep and performance of train drivers during an extended freight-haul operation. *Appl Ergon*. 2008;39:614–622.
41. Berger AM, Wielgus KK, Young-McCaughan S, Fischer P, Farr L, Lee KA. Methodological challenges when using actigraphy in research. *J Pain Symptom Manage*. 2008;36:191–199.
42. Van Hooff ML, Geurts SA, Kompier MA, Taris TW. "How fatigued do you currently feel?" Convergent and discriminant validity of a single-item fatigue measure. *J Occup Health*. 2007;49:224–234.
43. Sonnentag S, Fritz C. The Recovery Experience Questionnaire: development and validation of a measure for assessing recuperation and unwinding from work. *J Occup Health Psychol*. 2007;12:204–221.
44. Dinges DF, Powell JW. Microcomputer analyses of performance on a portable, simple visual RT task during sustained operations. *Behav Res Methods Instrum Comput*. 1985;17:652–655.
45. Lamond N, Jay SM, Dorrian J, Ferguson SA, Roach GD, Dawson D. The sensitivity of a palm-based psychomotor vigilance task to severe sleep loss. *Behav Res Methods*. 2008;40:347–352.
46. Gartenberg D, McGarry R, Pfannenstiel D, Cisler D, Shaw T, Parasuraman R. Development of a Neuroergonomic application to evaluate arousal. *Adv Cogn Eng Neuroergon*. 2012;16:239.
47. Basner M, Dinges DF. Maximizing sensitivity of the psychomotor vigilance test (PVT) to sleep loss. *Sleep*. 2011;34:581–591.
48. Dunn OJ. Multiple comparisons using rank sums. *Technometrics*. 1964;6:241–252.
49. Lichstein KL, Durrence HH, Taylor DJ, Bush AJ, Riedel BW. Quantitative criteria for insomnia. *Behav Res Ther*. 2003;41:427–445.
50. Ohayon MM, Carskadon MA, Guilleminault C, Vitiello MV. Meta-analysis of quantitative sleep parameters from childhood to old age in healthy individuals: developing normative sleep values across the human lifespan. *Sleep*. 2004;27:1255–1274.
51. Girschik J, Fritschi L, Heyworth J, Waters F. Validation of self-reported sleep against actigraphy. *J Epidemiol*. 2012;22:462–468.
52. Fritz C, Sonnentag S. Recovery, health, and job performance: effects of weekend experiences. *J Occup Health Psychol*. 2005;10:187–199.
53. Zijlstra FR, Sonnentag S. After work is done: psychological perspectives on recovery from work. *Eur J Work Org Psychol*. 2006;15:129–138.
54. Scott JP, McNaughton LR, Polman RC. Effects of sleep deprivation and exercise on cognitive, motor performance and mood. *Physiol Behav*. 2006;87:396–408.
55. Waage S, Pallesen S, Moen BE, Bjorvatn B. Sleep and health in oil rig workers—before and after a two week work period offshore. *Ind Health*. 2013;51:172–179.
56. Jay SM, Aisbett B, Sprajcer M, Ferguson SA. Sleeping at work: not all about location, location, location. *Sleep Med Rev*. 2015;19:59–66.
57. Querstret D, Cropley M. Exploring the relationship between work-related rumination, sleep quality, and work-related fatigue. *J Occup Health Psychol*. 2012;17:341–353.
58. Britton C, Lynch CF, Torner J, Peek-Asa C. Fire characteristics associated with firefighter injury on large federal wildland fires. *Ann Epidemiol*. 2013;23:37–42.
59. Gordon H, Larivière M. Physical and psychological determinants of injury in Ontario forest firefighters. *Occup Med*. 2014;64:583–588.
60. Smith BP, Browne M, Armstrong TA, Ferguson SA. The accuracy of subjective measures for assessing fatigue related decrements in multi-stressor environments. *Saf Sci*. 2016;86:238–244.
61. Swaen GMH, Van Amelsvoort LGPM, Bültmann U, Kant IJ. Fatigue as a risk factor for being injured in an occupational accident: results from the Maastricht Cohort Study. *Occup Environ Med*. 2003;60:i88–i92.
62. Dawson D, McCulloch K. Managing fatigue: it's about sleep. *Sleep Med Rev*. 2005;9:365–380.
63. Dawson D, Chapman J, Thomas MJ. Fatigue-proofing: a new approach to reducing fatigue-related risk using the principles of error management. *Sleep Med Rev*. 2012;16:167–175.
64. Williamson A, Friswell R. Fatigue in the workplace: causes and consequences. *Fatigue Biomed Health Behav*. 2013;1:81–98.

65. Caldwell JA, Caldwell JL, Schmidt RM. Alertness management strategies for operational contexts. *Sleep Med Rev*. 2008;12:257–273.
66. Caldwell JA. Crew schedules, sleep deprivation, and aviation performance. *Curr Dir Psychol Sci*. 2012;21:85–89.
67. Yeung J, Sletten TL, Rajaratnam SM. A phase-advanced, extended sleep paradigm to increase sleep duration among early-morning shift workers: a preliminary investigation. *Scand J Work Environ Health*. 2011;37:62–69.
68. Lerman SE, Eskin E, Flower DJ, et al. Fatigue risk management in the workplace. *J Occup Environ Med*. 2012;54:231–258.
69. Davy J. Good sleep, good health, good performance. It's obvious, or is it? The importance of education programmes in general fatigue management. *Ergono SA*. 2014;26:64–73.
70. Randolph SA. Fatigue risk management. *Workplace Health Saf*. 2015;63:236.

