

The sleep behaviour and fatigue trends of wildland firefighters
during non-fire and fire deployments

by

Zachary McGillis

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APPROVED/APPROUVÉ

Thesis Examiners/Examineurs de thèse:

Dr. Céline Larivière
(Supervisor/Directrice de thèse)

Dr. Sandra Dorman
(Committee member/Membre du comité)

Dr. Tammy Eger
(Committee member/Membre du comité)

Dr. Brent Ruby
(External Examiner/Examineur externe)

Approved for the Faculty of Graduate Studies
Approuvé pour la Faculté des études supérieures
Dr. David Lesbarrères
Monsieur David Lesbarrères
Dean, Faculty of Graduate Studies
Doyen, Faculté des études supérieures

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Abstract

Ontario wildland firefighting is a hazardous and safety-critical operation with relatively high injury rates. This is indicated by the 10-year average of 4.46 lost-time injuries per 100 workers in Ontario wildland firefighting compared to 0.95-1.88 lost-time injuries in other occupations, as reported by the Workplace Safety and Insurance Board (WSIB). There is anecdotal evidence that fatigue is a major contributor to injury; however, evidence to support this is limited. Understanding fatigue trends, potential causes, and areas for intervention within the wildland firefighting profession were the main goals of the study.

Accordingly, contributors to fatigue were assessed during non-fire and fire deployments by collecting objective sleep (Actigraphy) and vigilance (Psychomotor Vigilance Test) measures, as well as subjective measures of fatigue and recovery (questionnaires). Data were collected from wildland firefighters during the high-risk months of the fire season within the province of Ontario.

Sleep duration less than six hours, sleep efficiency below 85%, and wake after sleep onset greater than 30 min were more frequently observed during high intensity, Initial Attack deployments. Sleep duration less than six hours were routinely observed in non-fire work periods, placing workers at risk of pre-deployment sleep-debt. Self-reported morning fatigue scores were low-to-moderate and were best predicted by Initial Attack deployment work conducted the day prior. Reaction times were slightly worse in morning periods during Initial Attack deployments, but scores were generally within acceptable ranges. Self-reported recovery scores were generally good regardless of work performed.

The current study highlights suboptimal sleep behaviours during both non-fire and fire suppression work, with sleep measures below recommended standards. High-intensity fire suppression periods (i.e. Initial Attacks) were predictably associated with the worst sleep and fatigue levels; but it is worth noting that the data were collected during a record low-hazard, firefighting season and may not reflect the sleep behaviours and fatigue levels encountered during a high-hazard fire season. Interventions for sleep/fatigue hygiene and awareness should be explored and are further discussed in this paper. The research methodology employed in the current study could be used in future investigations to determine the sleep behaviours and fatigue levels of wildland firefighters during a high hazard fire season.

Keywords

Wildland firefighter, Fatigue, Sleep, Actigraphy, Injury-risk

Co-Authorship Statement

Chapter 2 is presented as a manuscript for publication. The manuscript was submitted for publication to the *Journal of Occupational and Environmental Medicine* on April 28, 2017.

Author contributions:

Zachary McGillis assisted with the conceptualization of the study, led data collection, conducted all data analyses, and wrote the manuscript.

Dr. Sandra C. Dorman conceptualized the study, supervised the collection of data, assisted with data analyses and reviewed the manuscript.

Ayden Robertson assisted with conceptualization of the study, data collection and reviewed the manuscript.

Dr. Michel Larivière assisted with the study design, data analyses and reviewed the manuscript.

Caleb Leduc assisted with data collection and reviewed the manuscript.

Dr. Tammy Eger assisted with the study design, data analyses and reviewed the manuscript.

Dr. Bruce Oddson assisted with the data analyses and reviewed the manuscript.

Dr. Céline Larivière conceptualized the study, supervised the collection of data, assisted with data analyses and reviewed the manuscript.

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Abbreviations

AFFES – Aviation, Forest Fire, and Emergency Services

B – Base

CWP – Consecutive Work Period

FRMS – Fatigue Risk Management System

GPA – Global Plan of Action

IA – Initial Attack

JSS – Job Stress Survey

LTI – Lost-Time Injury

MCS – Mental Component Score

OMNRF – Ontario Ministry of Natural Resources and Forestry

PCS – Physical Component Score

PF – Project Fire

PSD – Partial Sleep Deprivation

PVT – Psychomotor Vigilance Test

ROT – Recovery Opportunity Time

SAFTE – Sleep, Activity, Fatigue, and Task Effectiveness

SE – Sleep Efficiency

TIB – Time in Bed

TSD – Total Sleep Deprivation

TOB – Time out of Bed

TST – Total Sleep Time

WASO – Wake After Sleep Onset

WHO – World Health Organization

WSIB – Workplace Safety and Insurance Board of Ontario

Chapter 1

1 Introduction and Literature Review

The following reviews existing literature on wildland firefighting, in particular, its relationship with fatigue and sleep behaviour. These issues are discussed within the context of occupational health and wellbeing. The concepts of recovery, alertness, and stress are also explored as well as the manner they affect sleep and fatigue in the workplace. To this end, a theoretical model is offered as a framework to guide interventions for the wellbeing of those involved with wildland firefighting operations.

1.1 World Health Organization: Healthy Workplace Model

Worker health is an important consideration on matters of population health (World Health Organization [WHO], 1996). Recently, the WHO provided the Global Plan of Action (GPA) on Workers' Health 2008-2017 stating that health and safety practices in the workplace contributes to global public health security (Kortum, 2014). The GPA considers various overlapping aspects of the workplace that can affect occupational health and safety. Moreover, the WHO has developed a Healthy Workplace Model (WHO, 2010; Kortum, 2014), which serves as a template for organizations to improve the health and safety of their workers. This model adapts well to unique workplace cultures, legislations and frameworks (Kortum, 2014). As depicted in Figure 1, the model incorporates four overlapping “avenues”:

1. *“Health and safety concerns in the physical environment;*
2. *Health, safety and well being concerns in the psychosocial work environment including organization of work and workplace culture;*
3. *Personal health resources (available choices) in the workplace provided by the employer; and*

4. *Ways of participating in the community to improve the health of workers, their families, and other members of the community”* (Kortum, 2014, p. 154-155)

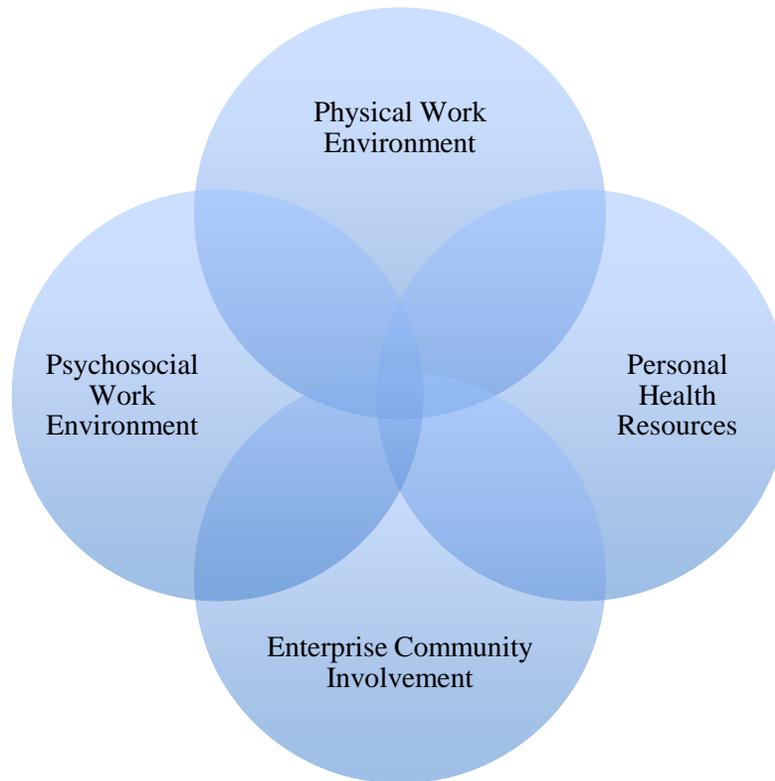


Figure 1: The WHO Healthy Workplace Model. Adapted from “The WHO Healthy Workplace Model: Challenges and Opportunities”, by E. Kortum, 2014, *Contemporary Occupational Health Psychology: Global Perspectives on Research and Practice*, 3, p. 156. Copyright 2014 John Wiley & Sons, Ltd.

In terms of emergency-service occupations such as wildland firefighting, this model can be used to formulate targeted health and safety interventions. However, the avenues focused on the physical and psychosocial work environments are particularly relevant to wildland firefighting given the risks of this occupation (i.e., Aisbett, Wolkow, Sprajcer & Ferguson, 2012; Gordon & Larivière, 2014; Resources OMNRF, 2012-14; Larivière, Kerekes & Valcheff, 2016).

The physical avenue includes the conditions in which the employee works, sleeps, and lives during fire suppression deployments. This environment is made harsh at times by exposure to extreme heat and smoke, which in turn leads to increased physical stress and overexertion (Ruby et al., 2002; Aisbett & Nichols, 2007; Aisbett et al., 2012; Cuddy, Sol, Hailes, & Ruby, 2015; Robertson et al., 2017). The psychosocial avenue would include the organization of the workplace as well as the workplace culture. This avenue would involve firefighter operations, relationship with management and the workplace culture during non-fire and fire work periods. Based on the above description of the physical environment and the structure of the organization, it may also be possible for the psychosocial avenue to interact with wildland firefighting operations, and direct health and safety interventions. As can be seen, the WHO Healthy Workplace Model is a potentially useful framework for organizations and researchers to study occupational risk factors and design targeted interventions to mitigate possible risks to employees.

1.2 Canadian Wildland Firefighting

Canadian wildland firefighters are emergency responders who participate in operational training for expeditious deployments to bush fires in both rural and urban regions (T. Shannon OMNRF-AFFES, personal communication, March, 2014). These workers help ensure community safety by deterring the effects of unpredictable forest fires, particularly in densely forested regions. The Ontario Ministry of Natural Resources and Forestry (OMNRF) division of Aviation, Forest Fire and Emergency Services (AFFES) deems firefighter safety to be a high priority. However, the unpredictable and dangerous working conditions place workers at risk of injury and/or illness. Fatigue is a

putative risk factor for injury among wildland firefighters. Indeed, it is cited frequently in existing literature as a correlate to mistakes, accidents, and injury (Mitler et al., 1988; Dinges, 1995; Hursh & Van Dongen, 2010; Williamson et al., 2011; Satterfield & Van Dongen, 2013). Other variables include job stress, personality, (e.g., Hilton & Whiteford, 2010; Clarke & Robertson, 2008), high workload, and harsh physical work environments are associated with fatigue and injury occurrence in many different occupations, including wildland firefighting (Dinges, 1995; Akerstedt, Kecklund, Alfredsson & Selen, 2007a; Akerstedt, Fredlund & Jansson, 2002a; Akerstedt et al., 2002b; Swaen, Van Amelsvoort, Bültmann & Kant, 2003; Dembe, Erickson, Belbos & Banks, 2005; Cuddy & Ruby, 2011; Williamson et al., 2011; Britton et al., 2013a; Gordon & Larivière, 2014; Cuddy, Sol, Hailes, & Ruby, 2015; Larivière, Kerekes & Valcheff, 2016). It is clear that fatigue could be an issue in safety-critical operations leading to a higher risk of injury.

1.3 Background on Wildland Firefighters in Ontario

Wildland firefighters in Ontario are typically seasonal employees for the OMNRF-AFFES operating across roughly 20 bases during the fire season (April-October) and staffed with firefighters who are trained, equipped, and readily available for emergency deployment (AFFES, 2011; AFFES, 2014). The Emergency Operations Center is located in Sault Ste. Marie, Ontario and two Regional Fire Centers are located in Sudbury and Dryden. These centers are considered to be the main Fire Management Headquarters. They border the region between larger northern populations (i.e., Sudbury, Sault Ste. Marie, and Thunder Bay) and the northern rural populations extending beyond

these city limits, which are highly susceptible to fire during hot and dry periods due to the vast, dense forest coverage (i.e., July-September).

These firefighters must complete and pass the WFX-FIT test protocol annually, which tests individuals in terms of aerobic fitness, muscular strength and muscular endurance (CIFFC, 2011). This testing was implemented to reduce injury due to poor physical fitness, as well as to assess fitness for duty prior to employment in this occupation, as the context of the job is similar to that of military-style operations. As such, the job includes long hours traversing through the wilderness, sleeping in tents for up to 14 consecutive days, long daily work hours (up to 16 hrs/day), teamwork (crews of four), and self-regulation under sub-optimal conditions (e.g., smoke exposure, insects, cold/hot temperatures). Wildland firefighters control and/or extinguish fires in wildland regions by various methods, including digging out barriers, and using water and/or chemicals to smother the flames. As such, physical endurance, communication, and teamwork are operational requirements of OMNRF wildland firefighters (T. Shannon OMNRF-AFFES, personal communication, March, 2014).

Fire-line deployments vary according to fire severity and may last for hours to weeks. By law, the maximum deployment length is 14 days on the fire-line with a minimum of 2 days rest. However, these individuals can be mobilized for a maximum of 18 consecutive days (including travel time), which includes the 14-day fire or emergency assignment period (Resources OMNRF, 2011a). While on deployment, workdays vary between 8 to 16 (or more) hours and overtime may be required (Resources OMNRF, 2011a).

Due to the significant differences in the seasons in northern Ontario, firefighters witness changing fire characteristics over the course of a fire season. Greater precipitation in the spring (April-June) usually results in fewer severe fires and therefore shorter deployment lengths. The decreased precipitation of summer leads to hotter and drier conditions. Forest fires during the months of July-September typically burn deeper into the foliage and are therefore more difficult to extinguish. During this time, deployment lengths are often longer and work hours are frequently extended (Gordon, 2013; Britton, Lynch, Torner & Peek-Asa, 2013b). Of course, weather is often unpredictable on a seasonal, and even daily basis.

For Ontario wildland firefighters, work is typically between the base (non-fire) and fire-line, with fire-line deployment categorized as either Initial Attack or Project Fire. Base work includes training and emergency preparedness. With respect to Initial Attack suppression, this is indicated when firefighters respond to a newly developed wildfire and this type of suppression is typically of increased physical intensity (Robertson et al., 2017), with lengthier shifts (incorporating early starts and late end times). This can last from a few hours to 14 days. Project Fires are a deployment in which a fire is too large to extinguish and border suppression techniques are applied to keep the fire from spreading. This type of work is typically of lower intensity (Robertson et al., 2017) with generally consistent workdays (12 hrs on/12 hrs off) for up to 14 consecutive days.

Finally, the difference between early and late season have been distinguished according to low and peak fire severity levels, defining the same timelines as mentioned earlier (Britton et al., 2013b). These authors indicate that injuries tend to occur significantly more in the peak months of the fire season (June-August), which

underscores the need to identify patterns of fatigue throughout the high-risk months. At the present time, it is not known whether fatigue levels differ in early versus late season deployments for Canadian wildland firefighters. Targeted research into late season firefighter work may further our understanding of fatigue as a potential contributor to the high incidence of firefighter injury.

1.4 Wildland Firefighter Injury Classification and Rates

Wildland firefighters are exposed to dangerous and hostile conditions during the fire season, increasing the risk of injury. The OMNRF-AFFES categorizes these as either 1) first aid injury, or 2) Workplace Safety & Insurance Board (WSIB) injury. These injuries are further divided into lost-time (LTI) and non-lost time injuries (Resources OMNRF, 2011b). The difference is that first aid injuries are typically treated on-site, whereas any claim to the WSIB requires medical attention and/or time off work (Gordon & Larivière, 2014). The purpose of this OMNRF-AFFES annual health and safety report is to monitor internal lost-time statistics, first aid-injuries, contributing factors, and divisions at risk (i.e., firefighters). Table 1 provides OMNRF-AFFES wildland firefighter injury rates as well as comparative data from other occupations.

Table 1: Ontario wildland firefighter lost-time injury and comparative data.

Year	Ont. Fire Rangers per year	Hours Worked (x1000)	No. of Fires	Lost Time Injuries (LTI)	No. of Lost Days	Ont. Fire Ranger LTI/100	*Ont. Forestry LTI/100	*Ont. Health Care LTI/100
2004	751	567	432	20	146	2.66	3.26	2.16
2005	692	917	1961	32	243	4.62	2.58	2.14
2006	692	972	2300	56	633	8.09	2.67	2.04
2007	692	1026	2300	26	121	3.76	2.75	1.98
2008	740	756	342	36	449	4.86	2.32	1.99
2009	780	775	387	31	362	3.97	1.79	1.80
2010	788	875	931	30	237	3.81	2.05	1.77
2011	780	929	1334	55	322	7.05	1.86	1.46
2012	772	879	1621	43	397	5.57	1.65	1.50
2013	772	738	581	18	463	2.33	1.54	1.37
2014	784	757	303	18	322.5	2.30	n/a	n/a
Average	749.4	835.5	1136	33.2	336	4.46	**2.25	**1.82

*Adapted from *By the Numbers: 2013 WSIB Statistical Report – Schedule 1*
**Average values do not include 2014 data (due to lack of 2014 WSIB data for comparison)
Ont.=Ontario, Fire Ranger=Ontario-based wildland firefighter, No.=number, n/a=not available
LTI/100 – Lost-time Injury rate per 100 workers

The values recorded for Ontario wildland firefighters are relatively high in view of LTI rates over the past decade with comparable occupations (in terms of stress and physical environment). By way of comparison, the annual “*By the Numbers: 2013 WSIB Statistical Report*” (Workplace Safety and Insurance Board [WSIB], 2014) indicates that the overall LTI rate per 100 workers for all Ontario WSIB covered occupations has declined from 1.88 (2004) to 0.95 (2013). Even compared to occupations that operate in similar terrain (i.e., Forestry workers) or high-stress environments (i.e., Healthcare workers), the firefighter LTI rate remains significantly higher (WSIB, 2014; Resources OMNRF, 2012-14). This average is discussed in the 2012-14 OMNRF annual reports that underline that fatigue-related overexertion events are the leading cause of injury, specifically when working on fire suppression deployments. Fatigue-related workplace

injuries are commonly discussed in the occupational health and safety literature (e.g., Williamson et al., 2011), but little has been published on Canadian wildland firefighters.

Britton and colleagues (2013a) analyzed the epidemiology of injuries in wildland firefighters working in North America and reported upwards of 1300 non-fatal injuries (five-year period), highlighting slips/trips/falls (STFs) as the leading cause of injury. These were more frequent during the peak firefighting season of July-September (OR=2.24, CI=1.23-4.10). Overexertion and fatigue was proffered to be a frequent cause of injury, but further investigation is required. Britton's work (2013a) was the first available large-scale epidemiological investigation of wildland firefighter injury. With respect to Ontario-based wildland firefighters, the only published study to assess injury rate and causation was offered by Gordon and Larivière (2014). These authors examined the relationships between personality characteristics, perceived job stress and the occurrence of first aid or lost-time injuries. The results indicated that individual factors, such as personality and perceived job stress were moderately associated with injury-causation in this occupational group. Thus, specific determinants of injury causation among wildland firefighters are beginning to emerge and it would appear that fatigue is salient among these (e.g., Dinges, 1995; Williamson et al., 2011).

1.5 Fatigue: Defined, Health Effects and Occupational Impact

Fatigue is a commonly used term for which there is no universally accepted definition (Dinges, 1995; Phillips, 2015). For their part, the Canadian Centre for Occupational Health and Safety identifies it as *“the state of feeling very tired, weary or sleepy resulting from insufficient sleep, prolonged mental or physical work, or extended*

periods of stress or anxiety” (“Fatigue” CCOHS, 2012). Similarly, Dingess (1995) discusses fatigue as being the result of working too long, working following too little rest, and being unable to sustain a certain level of performance on a task. These definitions of fatigue describe some potential causes of fatigue in wildland firefighters including poor sleep, elevated physical or mental stress, and insufficient recovery.

Fatigue can be further classified as: acute, or chronic; as well as physical, or mental (Shen, Barbera & Shapiro, 2006; Zijlstra, Cropley & Rydstedt, 2014). Acute fatigue results from short-term sleep loss or from short periods of heavy physical or mental work (e.g., one poor night of sleep, followed by subsequent recovery sleep). Chronic fatigue can occur when a person does not have a sufficient period of recovery over a prolonged period of time (e.g., sleeping less than recommended with no recovery, for an extended period of time). Physical and mental fatigue can contribute to both acute and chronic fatigue, but are thought to be separate phenomenon; however there is still debate over the interchangeability of these two processes (Satterfield & Van Dongen, 2013). Physical fatigue is “*a loss of maximal force-generating capacity during muscular activity*” (Shen et al., 2006, p. 70), which may be brought on by high-energy consumption and may be associated with fever, sleep disturbances, and infection for example. Mental fatigue is considered “*a state of weariness related to reduced motivation*” (Shen et al., 2006, p.70) and may be more prevalent in workplace incidents as it can contribute to symptoms such as decreased alertness, mood, well-being, judgment and cognition (Dawson & McCulloch, 2005; Shen et al., 2006; Satterfield & Van Dongen, 2013) and also contribute to negative perceptions regarding physical activity/work performance (Shen et al., 2006). Mental fatigue has been found to be due primarily to sleep loss/poor

quality sleep, stress, workload, extended wakefulness, and incomplete recovery (Dawson & McCulloch, 2005; Ekstedt et al., 2006; Shen et al., 2006; Satterfield & Van Dongen, 2013).

In general, fatigue has been implicated in both occupational and non-occupational accidents and injuries (e.g., Mitler et al., 1998; Dinges, 1995; Williamson et al., 2011); however, a large portion of the fatigue literature fails to separate occupational and non-occupational-related fatigue (Williamson & Friswell, 2013). This is relevant when applying fatigue-related research to safety-critical occupations (i.e., healthcare, aviation, emergency services) and then using these general population studies to direct this fatigue-related research. In the context of critical operations, fatigue-related incidents/accidents risk is of greater severity (Mitler et al., 1988; Dinges, 1995; Williamson et al., 2011). In this sense, fatigue can be considered a hazard in the workplace that may cause harm through its effects on performance (Williamson & Friswell, 2013) and judgment (Dawson & McCulloch, 2005), and must be assessed in the context of safety-critical environments. The general agreement is that fatigue is associated with impaired cognitive function, impaired task performance, increased errors and accidents, and reduced safety behaviour (Dinges, 1995; Philip et al., 2003; Goel, Rao, Durmer & Dinges, 2009; Dawson, Chapman & Thomas, 2012; Williamson & Friswell, 2013). Fortunately, multiple studies have assessed fatigue in the context of occupational shift work and 24-hour operations (albeit not necessarily safety-critical environments), with irregular and extended work hours being the most common environments for fatigue research (i.e., Boivin, Tremblay & James, 2007; Sallinen & Kecklund, 2010).

In terms of health and wellbeing, fatigue is a common symptom of many physical and mental illnesses, such as cancer (Cella, Lai, Chang, Peterman & Slavin, 2002) and depression (Mckinley, Ouellette & Winkel, 1995). It is also the primary symptom in individuals diagnosed with chronic fatigue syndrome (i.e., Holmes et al., 1988; Aaronson et al., 1999). Not surprisingly, fatigue is prominent in the general population; a byproduct of our modern working society (Weber & Jaekel-Reinhard, 2000). Fatigue in otherwise healthy individuals has been linked with burnout (Weber & Jaekel-Reinhard, 2000; Akerstedt et al., 2004; Ekstedt et al., 2006; Melamed, Shirom, Toker, Berliner & Shapira, 2006), low mood (i.e., Dinges et al., 1997), and compromised immune functioning (Heiser et al., 2001; Gaskill & Ruby, 2004). These health consequences can be present with acute fatigue, but may be more pronounced when fatigue becomes chronic, impeding the impact of short recovery periods (i.e., may not illicit full recovery) and eventually time lost from work may occur (Janssen, Kant, Swaen, Janssen & Schroer, 2003; Akerstedt et al., 2007a).

Shift characteristics that affect fatigue include timing of the shift (conflicting with circadian/homeostatic sleep processes) (e.g., Williamson & Friswell, 2013; Satterfield & Van Dongen, 2013), irregular shift types with impact on circadian rhythm and mismatch of alertness with circadian processes (Akerstedt, Ingre, Broman & Kecklund, 2008; Williamson & Friswell, 2013), time-of-day exposure to light (Cajochen, 2007; Satterfield & Van Dongen, 2013), physical and mental work loads and physical environment (Akerstedt et al., 2002a; Aisbett et al., 2012), irregular shift patterns or multiple consecutive shifts with sub-optimal recuperative total sleep time and accumulation of sleep debt (Belenky, Wesensten, Thorne, Thomas, & Sing, 2003; Williamson & Friswell,

2013), total weekly work hours of >50-55 hrs/week (Akerstedt et al., 2002a; Sallinen & Kecklund, 2010; Williamson & Friswell, 2013), and extended wakefulness of >16 hours (Van Dongen, Maislin, Mullington & Dinges, 2003).

There is currently no gold standard objective measure of fatigue (Shen et al., 2006), rather only subjective measures in the form of questionnaires, which have limitations. Occupational research has thus incorporated other factors related to fatigue in order to describe this construct in the workplace. Objective measures of sleep (quantity/quality) and performance (e.g., Psychomotor Vigilance Test) have been utilized as indirect measures of fatigue given the associations between sleepiness, fatigue and performance (Dinges et al., 1997; Belenky et al., 2003; Williamson & Friswell, 2013).

1.6 Sleep: Defined, Health and Performance Impact; Association with Fatigue

Sleep is a natural restorative behaviour for all, but the length of sleep can vary greatly between individuals based on factors such as age, sex, and genetics (Hume, Van & Watson, 1998; Hirshkowitz et al., 2015; Barclay & Gregory, 2013). There are two processes proposed that impact sleep behaviour: the circadian rhythm or 24-hour internal clock, and the homeostatic sleep process (Borbely, 1982; Daan, Beersma, & Borbely, 1984; Satterfield & Van Dongen, 2013). The circadian rhythm is a natural process that increases alertness during the day and sleepiness during the night (or vice-versa with permanent nightshift work), with fluctuations throughout the day. The low circadian troughs or increased sleepiness pressure for a typical Monday-Friday worker generally occur in the early afternoon and early hours of the morning (Williamson & Friswell, 2013). The other process is the homeostatic sleep pressure, which is impacted by prior

sleep and wakefulness, creating an steadily increasing pressure to sleep with extended periods of wakefulness (Borbely, 1982; Daan et al., 1984; Satterfield & Van Dongen, 2013). Current research indicates that extended wakefulness of >16 hours is required to produce significant homeostatic pressure to sleep after a normal eight hour sleep (Van Dongen et al., 2003), with performance deficits comparable to being intoxicated (Dawson & Reid, 1997; Williamson & Feyer, 2000; Falleti, Maruff, Collie, Darby & McStephen, 2003; Williamson & Friswell, 2013). This threshold of 16 hours is largely dependent on the duration of prior sleep, such that previous poor sleep can reduce this threshold value and increase sleep homeostatic pressure (Van Dongen et al., 2003). Not surprisingly, both processes may be impacted by a change in routine (i.e., waking up earlier than usual can affect circadian rhythm, and on the other hand, poor sleep can increase homeostatic sleep pressure during the work period). For example, hours of service at work, physical/mental workload, light exposure, and timing of shift (Akerstedt et al., 2002a; Folkard & Lombardi, 2004; Sallinen & Kecklund, 2010; Williamson & Friswell, 2013) may interact with these sleep processes and can influence feelings of fatigue on a day-to-day basis. Overall, sleep is a homeostatic drive and is the most obvious way to help recover from periods of wakefulness, and reduce fatigue levels (Williamson & Friswell, 2013).

With industrialization and modernization, Western society is increasingly sleeping less, on average, due to job pressures and around the clock production (Luckhaupt, Tak & Calvert, 2010). With this said, it has been reported that young adults require 7-9 hours of sleep per 24-hour period in order to achieve good health and optimal daily vigilance (Hirshkowitz et al., 2015). In the context of 24-hour work environments

and emergency services (i.e., safety-critical work environments), this daily sleep parameter may not be possible to obtain and may lead to consistent sleep loss or sleep deprivation. Sleep deprivation can increase the homeostatic pressure to sleep, thus causing sleepiness during waking hours, reducing alertness and causing significant deficits in neurobehavioural functioning (Doran, Van Dongen, Dinges, 2001; Goel et al., 2009).

In general, total sleep deprivation (TSD) (>24 hours of no sleep) and partial sleep deprivation (PSD) (less than seven hours sleep per 24 hours) (Goel et al., 2009) are two descriptive parameters of poor sleep, and can be either acute or chronic. Between these two parameters, partial sleep deprivation is more likely to occur in working populations provided the reports of <7 hours sleep per workday on average, in American-based national studies (see Luckhaupt, Tak & Calvert, 2010). However, there are far fewer studies investigating the impacts of PSD, as compared to laboratory studies studying the outcomes of TSD (Pilcher & Huffcutt, 1996; Goel et al., 2009). Acute PSD may be alleviated by recovery sleep, but chronic PSD (i.e., consecutive days with less than six hours sleep) results in cumulative adverse effects on neurobehavioural functioning (Dinges et al., 1997). The most detailed study to date by Van Dongen and colleagues (2003) highlights that two weeks of six hours time in bed per night is equivalent to one night of TSD in terms of performance and functioning and has been compared to being intoxicated at the 0.1% blood alcohol level (Williamson et al., 2001; Goel et al., 2009). Still, it is accepted that anything less than seven hours sleep per night can be considered sleep deprivation, with chronic (i.e., multiple days) periods resulting in “sleep debt”, essentially producing neurocognitive deficits that may accumulate to significant levels

over time (Dawson & McCulloch, 2005; Goel et al., 2009; Darwent, Dawson, Paterson, Roach & Ferguson, 2015).

It is generally accepted that sleep and fatigue are directly associated with poor sleep behaviour contributing to increased fatigue, with performance deficits and poor neurobehavioural functioning (Dinges et al., 1997; Doran et al., 2001; Goel et al., 2009, Rosekind et al., 2010). Subsequently, in the context of the workplace, there are many factors that contribute to poor sleep and thus impact perception of fatigue (e.g., organization of work, shift types, and consecutive shifts; Williamson & Friswell, 2013). The association of sleep and fatigue is well documented in a range of work settings including white-collar organizations, healthcare, air transportation, railway transportation and offshore drilling (Dahlgren, Kecklund & Akerstedt, 2005; Geiger-Brown et al., 2012; Petrilli, Roach, Dawson & Lamond, 2006; Raslear, Gertler & DiFiore, 2013; Sneddon, Mearns & Flin, 2013). The consensus is that when sleep is disrupted, mental fatigue can persist (e.g., Akerstedt et al., 2004), typically with a decline in performance and safety behaviour (Doran et al., 2001; Satterfield & Van Dongen, 2013), as well as an increase in injury-risk (Akerstedt et al., 2002a; Akerstedt et al., 2002b; Swaen et al., 2003; Dinges, 1995; Williamson et al., 2011; Satterfield & Van Dongen, 2013). Furthermore, it has been proposed that fatigue is directly linked to the two processes that govern sleep, the circadian rhythm and homeostatic sleep pressure (Satterfield & Van Dongen, 2013). This information suggests that the primary cause of fatigue during shift work and 24-hour work operations is the misalignment of work periods and sleep regulation (Satterfield & Van Dongen, 2013). Unfortunately, this relationship between sleep and fatigue in the workplace is complex with many compounding factors (see page 12). Clearly, there are

multiple factors in any given workplace that may interact with both sleep and fatigue. This becomes an issue when attempting to identify key areas of the workplace contributing to fatigue, highlighting the fact that multidisciplinary approaches should be taken while observing/researching occupations.

When considering safety-critical operations, the consequences of fatigue can be serious, including death in some instances (Mitler et al., 1988). However, research of these issues is conducted retrospectively and it is difficult to infer causality. Other studies that involve quantitative and qualitative research in various field settings provide more insight into the involvement of fatigue. A large number of articles have been published on fatigue and accidents/injury in the healthcare sector, such as nursing (e.g., Rogers, Hwang, Scott, Aiken & Dinges, 2004; Scott, Rogers, Hwang & Zhang, 2006) and with medical residents/students (e.g., Landrigan et al., 2004; Barger et al., 2006). These studies are important as the consequences of fatigue affect patient care and health outcomes. As mentioned above, other occupations studied in terms of fatigue, sleep and safety include operations in: offshore drilling (Sneddon, et al., 2013), railway systems (Raslear et al., 2013), air transportation (Petrilli et al., 2006), underground mining (Legault, Clement, Kenny, Hardcastle & Keller, 2017), and various types of shiftwork (Takahashi, 2014). Unfortunately, little research on sleep, fatigue and safety has been reported in Canadian wildland firefighters. Due to the safety-critical nature, relatively high injury rate, and the consequences on the individual and society as a whole (Resources OMNRF 2012-2014; WSIB, 2014), this lack of evidence-based research is surprising. Furthermore, this operation encompasses most of the typical shift characteristics compounding sleep and fatigue, such as lengthy shifts, early start times,

irregular work periods, and lengthy consecutive work periods (i.e., 14 days), thus identifying the need for interventional research.

The current literature on wildland firefighters is limited to specific geographical regions, with most research performed in Australia (e.g., Budd et al, 1997; Aisbett & Nichols, 2007; Aisbett et al., 2012; Vincent et al., 2015; Vincent, Aisbett, Hall, & Ferguson, 2016a; Vincent, Aisbett, Hall & Ferguson, 2016b) and the United States (e.g., Ruby et al., 2002; Gaskill & Ruby, 2004; Britton et al., 2013a; Britton et al., 2013b). In terms of sleep behaviour, Australian researchers have identified sleep to be poor while on fire suppression deployments (6.1 ± 1.7 hrs), as compared to non-fire periods (7.0 ± 0.9 hrs) (Vincent et al., 2016a). These authors also identify sleep disruption when shifts start between 5-6 am, as well as when shifts are >14 hours in duration. Although not directly measured, these patterns seem to reflect the disruption of the circadian and homeostatic sleep processes. Further research in Australia, including simulated fire suppression, identified no significant differences in daytime performance between participants in either the 4-hour or 8-hour 'time in bed' groups, over the course of three days (Vincent et al., 2015). These results indicate that sleep may not be a factor in performance over a short work period (i.e., a couple of days). Similar research has also suggested that shifts >12 hours may hinder sleep behaviour, whereas shifts <12 hours may provide conditions for adequate sleep opportunity (Vincent et al., 2016b). However, all of this research is limited to short work periods and lack intense wildfire conditions, and as previous research suggests, lengthy work weeks (>50-55 hours), lengthy work days (>16 hours), and consecutive and irregular shifts (Akerstedt et al., 2002a; Sallinen & Kecklund, 2010; Williamson & Friswell, 2013) may be some of the work conditions required to hinder

sleep behaviour and elicit fatigue. Other research with American wildland firefighters has reported average hours of total sleep time of 7.02 ± 1.42 hours (Gaskill & Ruby, 2004). Of note, Budd et al., (1997) had identified the effects of physiological stress on fatigue, unsafe behaviour, performance/judgment and accidents amongst Australian wildland firefighters. Also in accordance with the effects of stress, Ruby and colleagues (2002) conducted research on American wildland firefighters and concluded that sustained fatigue diminished firefighter immune response, leaving them susceptible to illness.

The relationship between sleep and fatigue may only be quantifiable in these wildland firefighting operations with extensive field-research. The sleep and fatigue research performed in Australia and the United States may not be directly applicable to Canadian wildland firefighters given the differences in the landscape, operational framework, overall fire behaviour (typically due to differing weather systems and foliage) (Krawchuk, Mortiz, Parisien, Van Dorn & Hayhoe, 2009; Flannigan, Krawchuk, de Groot, Wotton & Gowman, 2009), and suppression tactics. Research aimed at further understanding sleep and fatigue behaviour in Canadian wildland firefighters is therefore warranted in order to foster a safe work environment with evidence-based interventions for injury-reduction and overall improved worker wellbeing.

1.7 Recovery, Stress and Alertness: Association with Sleep and Fatigue

The off-work recovery process is critical in reducing sleepiness and fatigue and is required for sustaining performance and good safety behaviour in the workplace (Akerstedt, Kecklund & Axelsson, 2007b; Berset, Elfering, Luthy, Luthi & Semmer,

2011; Querstret & Cropley, 2012; Querstret, Cropley, Kruger & Heron, 2016). Extended periods of insufficient recovery can lead to chronic fatigue associated with more serious complications such as poor health and wellbeing (Sonnentag & Zijlstra, 2006). Recovery during extended work periods is thus an important issue and should be targeted in occupational safety research.

Zijlstra, Cropley and Rydstedt (2014) have addressed the issues surrounding current recovery theories (i.e., Hobfoll, 1989: personal resources to spend on work; Meijman & Mulder, 1998: motivational aspects for performing work (e.g., financial)) by combining existing frameworks and ultimately viewing recovery in a different way. They discuss recovery as a dynamic process, rather than a static construct, which is primarily how recovery is reported in the literature (Zijlstra, Cropley & Rydstedt, 2014). In terms of mental fatigue and subsequent recovery, it has been found that working late into the evening and work-demands linked with stress and poor sleep have been associated with a lack of recovery (Zijlstra et al., 2014). This association of recovery and sleep with work-related stress (i.e., workload, environmental conditions, perceived ability to cope; Akerstedt et al. 2002a; Greenberg, Carr & Summers, 2002; Staal, 2004) is well documented in the literature (Fritz, Sonnentag, Spector, & McInroe, 2010; Querstret et al., 2016). Thus it is important to consider the nature of the work environment (i.e., workload, stressors, recovery time, sleep behaviour) when assessing recovery in occupational health and safety research.

Sleep plays a pivotal role in the recovery process (Porkka-Heiskanen, Kalinchuk, Alanko, Urrila, & Stenberg, 2003; Querstret et al., 2016), and when this process is disrupted by increased levels of arousal during pre-sleep periods (see Querstret &

Cropley, 2012), incomplete recovery can result (Zijlstra et al., 2014). The evening recovery period is therefore not always impactful, even when given the opportunity to rest in the absence of work and this is due to the complex nature of mental fatigue, work-related demands, and the individual's ability to psychologically detach from work (Sonnentag, Binnewies & Mojza, 2008). Poor sleep and limited recovery can then be extended to 'not feeling recovered' in the morning prior to a work-period. This concept of morning recovery indicates that feeling recovered before work is a strong indicator of positive daily job performance (Binnewies, Sonnentag & Mojza, 2009). It is this combination of evening and morning recovery that is of utmost importance to recovery researchers and still remains an active area of research in the occupational health and safety literature.

The topic of 'recovery opportunities' is discussed at length (Taris et al., 2006; Sonnentag & Krueger, 2006; Sonnentag & Zijlstra, 2006), but to our knowledge only one study to date has measured this concept in the workplace (Rodriguez-Munoz, Sanz-Vergel, Demerouti & Bakker, 2012). Efficient recovery time means that reasonable periods of time are provided in order to recover, which involves temporarily relieving work-related demands in order to restore personal resources. This period of time is varied, as there is not one defined period of time required for optimal recovery from various work demands. Thus, within safety-critical operations such as wildland firefighting, this leads to the topic of *quality* of recovery time rather than *quantity* of time, due to time constraints during periods of intense fire suppression. In order to improve the quality of recovery time in these highly demanding work environments, changes could be implemented at the organizational level, which would then "*promote the development of*

leisure activities to help (workers) disengage from the daily strains of work” (Rodriguez-Munoz et al., 2012, p.93; Sonnentag, 2003; Sonnentag & Zijlstra, 2006). Interestingly, there is little information regarding the recovery experiences of workers in high-risk occupations. For wildland firefighting, a highly demanding emergency-based occupation, the topic of recovery is highly relevant. Provided the nature of the occupation, it would be ideal that efficient recovery measures be set in place each evening (whenever possible) during deployment. Furthermore, due to the typical lengthy workdays in an outdoor setting, the condition known as ‘spillover’ may be present in this occupation. Spillover is the incomplete unwinding of workers over periods of time, leading to chronic incomplete recovery, which may lead to mental and physical health problems if left untreated (Dienstbier, 1989). Finally, without adequate recovery, it has been shown that job performance decreases significantly and that feelings of burnout can result (Fritz & Sonnentag, 2005).

Job performance is largely based on level of alertness and ability to sustain good judgment and decision-making, which is generally impacted by sleep, recovery and fatigue (Dinges et al., 1997; Jewett, Dijk, Kronauer & Dinges, 1999; Belenky et al., 2003; Van Dongen et al., 2003; Williamson & Friswell, 2013). Depending on the nature of the job, this performance can have a significant impact on worker wellbeing (e.g., Scott et al., 2007) as well as community safety (e.g., Mitler et al., 1988). Not surprisingly, Lim and Dinges (2008) describe a link between sustained attention and sleep as both “*intimate and inextricable*” (p. 305), indicating that the two concepts are so highly related, at the most general level, that one can almost predict the other. Williamson and colleagues (2011) further discuss vigilance (or alertness) as being a component of cognition and

being impacted by fatigue, as seen in sleep-deprived individuals. They interpret this connection in terms of human functioning, with regards to our reservoir of mental resources. Sleep loss is known to cause increased levels of fatigue, which could lead to a depletion of mental resources and increase the effort required to perform vigilance tasks at work (Williamson et al., 2011; Hockey, Wastell & Sauer, 1998). Subsequently, mental resource depletion has been known to affect vigilance (Smit, Eling, Hopman & Coenen, 2005) and thus tasks that require more resources and that are increasingly difficult for the individual (subjective workload), will tend to cause distress and feelings of fatigue (Warm, Parasuraman & Matthews, 2008). These feelings of distress have been discussed as major concerns in worker health, safety and productivity (Nickerson, 1992; Strauch, 2002). It is clear that performance, in terms of vigilance or alertness is associated with sleep, fatigue, recovery, stress and occupational health and safety behaviour. Consequently, recovery, stress and alertness are all important variables to consider when studying aspects of occupational health and safety. These factors are related to sleep and fatigue and thus occupational injury risk.

1.8 Overview of Study Variables

Study measures included objective sleep (Actigraphy), subjective fatigue and recovery questionnaires, as well as objective vigilance (Psychomotor Vigilance Test). These measures have been validated and tested for use in research and these are used to identify trends of sleep behaviour, perceived fatigue and recovery and alertness.

The first variable of interest is objective sleep and as mentioned earlier this is a key determinant of fatigue. In order to identify sleep patterns during fire-line and base

work periods, actigraphy (ActiGraph Corporation, Pensacola, FL) watches are being utilized. Actigraph is a “miniaturized, computerized, wristwatch-like device that monitors and collects data generated by movements” (Sadeh & Acebo, 2002). This device has been compared to the gold standard of measuring sleep patterns, polysomnography (PSG), with correlations over 0.80 between whole night measures of sleep duration and sleep efficiency for normal individuals and has been validated for use in the field (Sadeh & Acebo, 2002). Also, in order to achieve accurate sleep values, detailed documentation in daily logs of sleep-wake periods is critical (Sadeh & Acebo, 2002). Sleep logs are a key part of actigraphy monitoring as it provides the researcher with detailed information about sleep periods to help analyze the resulting data. Thus participants will fill out a sleep log to record when they actually go to sleep and precisely when they wake up so that raw data can be accurately analyzed with valid results.

The next variables are subjective fatigue and recovery, which are being assessed in the morning and evening periods, respectively. After a sleep period and before work initiation, self-reported fatigue via a 1-item questionnaire (Van Hooff et al., 2007) is to be completed. This validated questionnaire is easy to use and low maintenance for the group in question to complete, and provides a value of perceived fatigue prior to beginning a work shift. The recovery questionnaire is to be administered post-work shift during evening recovery periods and is a validated, 16-item questionnaire (Sonnentag & Fritz, 2007). This questionnaire reflects four aspects most related to that of recovery, including psychological detachment from work, relaxation, mastery of non-work activities, and control, with a fairly high internal consistency, ranging from 0.79-0.85 (Sonntag & Fritz, 2007).

Lastly, objective vigilance is measured pre- and post-work shift in order to track vigilance and alertness over particular work shifts and fire-line deployments. The Psychomotor Vigilance Test (PVT) is a tool that is well validated within the literature as being related to poor sleep behaviour (Balkin et al., 2004). A multitude of studies have used this measure (Lim & Dinges, 2008) and the general conclusion is the same; the PVT is sensitive to measures of subjective fatigue, thus acting as an objective measure of fatigue (Lee et al., 2010; Lim & Dinges, 2008; Drummond et al., 2005). Furthermore, this test collects data in the form of the number of lapses (misses), reaction time in milliseconds, median reaction time, and errors of commission, variability in reaction times, and the slope of reciprocal reaction times across the run (measure of time on task effect) (Lim & Dinges, 2008).

1.9 Statement of the Problem

Fatigue and overexertion have been cited as the major causes of injuries of wildland firefighters in recent annual health and safety reports (Resources OMNRF, 2012-2014) provided by the OMNRF. However this finding is largely anecdotal and lacks objective evidence. *The key determinants of fatigue and their potential influence on injury occurrence are, for the moment, not clearly understood.* Therefore, the purpose of this study is to describe sleep behaviour and fatigue over specific work conditions in order to understand problematic areas of the workplace. A better understanding of the specific determinants of fatigue in this occupation will contribute to the development of strategies that will help mitigate injury risk and improve worker wellbeing.

1.10 Hypotheses

Hypotheses 1 (H1):

H1a: Sleep quantity and quality will be most compromised during high exertion deployments (i.e., Initial Attack)

H1b: Subjective ratings of fatigue will be highest during high exertion deployments (i.e., Initial Attack)

H1c: Subjective ratings of recovery will be lowest during high exertion deployments (i.e., Initial Attack)

H1d: Objective levels of alertness (reaction time) will be most compromised during high exertion deployments (i.e., Initial Attack)

Hypotheses 2: (H2)

H2a: Sleep quantity and quality will be most compromised for extended fire deployment work periods of greater than seven days

H2b: Subjective ratings of fatigue will be highest for extended fire deployment work periods of greater than seven days

H2c: Subjective ratings of recovery will be lowest for extended fire deployment work periods of greater than seven days

H2d: Objective levels of alertness (reaction time) will be most compromised for extended fire deployment work periods of greater than seven days

Hypotheses 3 (H3):

H3a: Sleep quantity and quality will be most compromised for extended (i.e., >12 hour shifts, with early start times <6 am and late end times >9 pm) individual fire-line shifts

H3b: Subjective ratings of fatigue will be highest for extended (i.e., >12 hour shifts, with early start times <6 am and late end times >9 pm) individual fire-line shifts

H3c: Subjective ratings of recovery will be lowest for extended (i.e., >12 hour shifts, with early start times <6 am and late end times >9 pm) individual fire-line shifts

H3d: Objective levels of alertness (reaction time) will be most compromised for extended (i.e., >12 hour shifts, with early start times <6 am and late end times >9 pm) individual fire-line shifts

1.11 References

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Chapter 2

2 Manuscript

The following section highlights a manuscript on the current study. This paper highlights all major results for the study and was submitted for publication to the *Journal of Occupational and Environmental Medicine* on April 28, 2017.

2.1 Title Page

A pilot study investigating sleep patterns amongst Ontario
wildland firefighters over a low-hazard fire season

Authors:

McGillis, Z., Dorman, S.C., Robertson, A., Larivière, M., Leduc, C., Eger, T., Oddson, B.
and Larivière, C.*

*Corresponding author

Céline Larivière PhD, RKin

School of Human Kinetics

Laurentian University

935 Ramsey Lake Road

Sudbury, ON

P3E 2B5

Tel: 705-675-1151 x1003

Fax: 705-675-4845

Email: clariviere@laurentian.ca

2.2 Abstract

Objective: there is a paucity of information regarding the sleep quality and quantity and fatigue levels of Canadian wildland firefighters while on deployments, and so the objective is to quantify these metrics within this occupation.

Methods: objective/subjective sleep and fatigue measures were collected using actigraphy and questionnaires during non-fire and fire deployments.

Results: total sleep time of less than six hours, sleep efficiency below 85%, and wake after sleep onset greater than 31 min were more frequently observed during high intensity, Initial Attack deployments. Sleep periods less than six hours were routinely observed in non-fire work periods, placing workers at risk of sleep debt. Self-reported morning fatigue scores were low-to-moderate and were best predicted by work during Initial Attack deployments.

Conclusions: the current study highlights the incidence of suboptimal sleep patterns in wildland firefighters during both non-fire and fire suppression work periods, but especially during high intensity, Initial Attack deployments.

2.3 Introduction:

Wildland firefighters in Ontario are called FireRangers, yet will be referenced as wildland firefighters throughout this paper, in accordance with the literature, globally. These wildland firefighters are a team of emergency responders that work within the Ontario Ministry of Natural Resources and Forestry (OMNRF) under the division of Aviation, Forest Fire, and Emergency Services (AFFES). During the Canadian fire season (April-October), these workers labour in harsh environmental conditions with a multitude of hazards, including: heat, smoke, poor terrain, and unpredictable weather (Aisbett, Wolkow, Sprajcer & Ferguson, 2012). Wildland firefighters are key members of the Canadian Fire Management Operation playing an important role in fire management. Their work schedule vary, depending on the severity of the fire season, but they can work up to 14 consecutive days (8-16 hours of service/day), with two days of travel at either end, before a minimum of two days rest is mandated (Resources OMNRF, 2011a). These periods of wildland firefighting are referred to as fire-line 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 (for fuel load, weather topography, fire behavior, hazards and valuable properties). Firefighters deployed to an Initial Attack are the first people to arrive 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 depends largely on fire severity, but Initial Attack fires can be the most personally intense deployments, due to the unpredictable nature of these fires (Heil, 2002; Ruby et al., 2002;

Cuddy & Ruby, 2011; Cuddy, Sol, Hailes & Ruby, 2015; Robertson et al., 2017; Aisbett et al., 2012; Ferguson, Smith, Browne & Rockloff, 2016; Wolkow, Aisbett, Ferguson, Reynolds & Main, 2016). 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 (throughout Canada) 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 stay at a centralized base camp, where upwards of one thousand 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 personally stressful, compared to Initial Attack deployments, due to more strategic and conservative fire suppression efforts (Robertson et al., 2017). When firefighters are not required on a fire line, they have scheduled work periods at their local Fire Management Headquarters (non-fire or Base), performing training, daily fitness, as well as rotating shifts ‘on alert’ for fire-line deployment.

The OMNRF has cited fatigue as a contributing factor to musculoskeletal and lost time injury (LTI) (Resources OMNRF, 2012-14); however, at the moment these claims are anecdotal in nature. Between 2004 and 2014, Ontario wildland firefighters accumulated a ten-year average of 4.46 LTIs per 100 workers as a result of slips/trips/falls, overexertion/fatigue and use of equipment/tools/machinery (Resources OMNRF, 2012-14). In comparison, the overall average LTI per 100 workers in the province of Ontario as reported in “*By the Numbers: 2013 WSIB Statistical Report*” has

declined from 1.88 in 2004 to 0.95 in 2013 (Workplace Safety and Insurance Board [WSIB], 2014).

Poor sleep increases fatigue and the risk of workplace injury (Dinges, 1995; Bunn, Slavova, Struttman & Browning, 2005; Patterson et al., 2011; Williamson et al., 2011). The sleep behaviors of Australian and American wildland firefighters have been investigated (i.e., Vincent et al., 2015; Vincent, Aisbett, Hall & Ferguson, 2016a; Vincent, Aisbett, Hall & Ferguson, 2016b; Cater et al., 2007; Budd et al., 1997; Aisbett & Nichols, 2007; Gaskill & Ruby, 2004). The subjective sleep behaviour of American wildland firefighters as assessed by Gaskill and Ruby (2004), revealed that the average sleep time was 7.02 ± 1.42 hours per night during fire-line work periods. This level is the threshold of what is considered good quality sleep (i.e., 7-9 hours), as required for adults to optimize daily performance (Hirshkowitz et al., 2015). Other studies have assessed sleep restriction (4 hours sleep opportunity/night) and effects on performance during simulated fire suppression tasks compared to control groups (8 hour sleep opportunity/night) in Australian wildland firefighters (Vincent et al., 2015; Cvirn et al., 2017). The results indicate that both sleep patterns were either adequate or had no effect on performance. A subsequent study with Australian wildland firefighters indicated that sleep quantity, measured objectively, is significantly lower when firefighters are exposed to poor sleep conditions (i.e., sleeping in tents), long work shifts (>14 hours), and early morning start times (Vincent et al., 2016a); without impacting subjective fatigue measures.

Successive days of sleep loss can lead to sleep debt, which is in turn associated with performance deficits, poor judgment, deflated mood and ill health (Dinges et al.,

1997; Banks & Dinges, 2007; Van Dongen, Rogers & Dinges, 2003a; Van Dongen et al., 2003b). Certain work characteristics of fire-line deployment may create situations where sleep loss is inevitable, thereby increasing fatigue and potentially, the risk of injury or ill health. 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 (Dembe, Erickson, Belbos & Banks, 2005; Caruso, 2006; Sallinen & Kecklund, 2010; Virtanen et al., 2009; Parkes, 2015, Vincent et al., 2016a; Vincent et al., 2016b; Akerstedt et al., 2002a; Akerstedt et al., 2002b), early shift start times (Vincent et al., 2016a; Akerstedt, Kecklund & Selen, 2010), and a reduced opportunity for quality sleep. To date no one has measured objective sleep quantity and quality in Canadian wildland firefighters, across different work deployments.

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). In order to more comprehensively gauge the levels of fatigue of these workers; subjective measures of fatigue and recovery were also collected. We expect that sleep quality and quantity would be sub-optimal, and that self-reported fatigue levels would be greater and self-reported recovery would be worse during Initial Attack compared to Project Fire deployments and Base work.

2.4 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 twenty-one participants (n=21). All participants provided written, informed consent prior to the start of data collection, and this study received ethics approval from the Laurentian University Research Ethics Board (see Appendix A).

Study design:

Participants met with researchers thrice: in the early, mid and late part of the fire season. During visit one, baseline measures were taken and the participants were shown how to use the study equipment. Measures included: age, height and mass, and the Short Form-36 question Health Survey (SF-36) (Ware, Snow, Kosinski, & Gandek, 1993). It should be noted that the height and mass variables were utilized in a parallel study (Robertson et al., 2017). At mid-season (visit two), the Job Stress Survey (JSS) (Spielberger & Vagg, 1994) was administered to assess job stress in the traditionally low-risk part of the fire season.

Participants were provided with a personalized bag, identified with their participant number, for transporting study devices, including: the w-ActiSleep-BT watch, log booklet (sleep log; morning fatigue & evening recovery questionnaires), iPod touch (Apple Inc. - Psychomotor Vigilance Test Application (Mind Metrics, Proactive Life

LLC)), Anker Astro Pro2 20000mAh Multi-Voltage external battery pack, and a BioHarness3 Heart Rate Variability monitor (used for a separate physiological, energy expenditure study – Robertson et al., 2017). These bags were approved by AFFES for carry. During visit three, the study equipment was collected and participants completed the Job Stress Survey for a second time. It should be noted that researchers collected the equipment periodically to extract data from the ActiSleep watches, replace log booklets, and charge all equipment, with equipment returned shortly thereafter.

During the fire season while working on fire-line deployments (Initial Attack and Project Fire) and when working at Fire Management Headquarters, participants were asked to collect personal data regarding three factors; outlined below: i) objective sleep data; ii) subjective fatigue/recovery data; and iii) objective fatigue data.

Objective Sleep Data: Participants were instructed to wear the w-ActiSleep-BT watches (ActiGraph Corporation, Pensacola, FL) before sleep periods each night on the dominant wrist (Ancoli-Israel et al., 2003). They were also asked to fill out sleep logs (date/time) each morning and evening specifying their time in bed (TIB) and time out of bed (TOB). This information was used to help assess sleep quantity and quality (Darwent, Lamond & Dawson, 2008). 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 (i.e., Berger et al., 2008). The ActiLife 6.11.5 data analysis software (ActiGraph Corporation, Pensacola, FL) 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), wake after sleep onset (WASO) (Table 2).

Subjective Fatigue/Recovery Data: Participants were asked to complete a daily, single item, subjective fatigue questionnaire in the morning (Van Hooff, Guerts, Kompier & Taris, 2007), and a sixteen-item, recovery questionnaire in the evening (Sonnentag & Fritz, 2007) (see Table 2).

Objective Vigilance Data: Each morning and evening, participants were instructed to complete a 5-minute version of the Psychomotor Vigilance Test (PVT) (on the iPod touch) (Dinges & Powell, 1985; Lamond et al., 2008). Overall average reaction time was the variable collected and the application date- and time-stamped the data collection period. The reaction times were then manually extracted from these outputs for further analyses.

Data analyses:

Data for the Health Survey (SF-36) were analyzed via compiling descriptive statistics on the Physical Component Score (PCS) and Mental Component Score (MCS). The Job Stress Survey scores were calculated and descriptive statistics for mid- and post-season administration are reported (Table 3). A paired-sample T-test was performed to identify differences in mid- and post-season job stress.

Data were analyzed using IBM SPSS (version 20.0). Deployment-specific dependent variables included: sleep measures (TST (min), SE (%), WASO (min)), morning subjective fatigue score, evening subjective recovery score, and morning and evening average reaction time (ms) (Table 2). Data were further assessed according to: i) combined Fire (Initial Attack/Project Fire combined), and ii) Project Fire only; and the

dependent variables were then analyzed according to: Consecutive Work Periods (CWP) (1-3 days, 4-7 days and >7 days), shift length (<12 hours, 12-13 hours, >13 hours), shift start (5-6 am, 6-7 am, 7-8 am, >8 am) and shift end (\leq 7 pm, 7-8 pm, 8-9 pm, >9 pm) on all fire deployments. Base data were excluded from this analysis as the shift characteristics were consistent and would not distribute across variable conditions (i.e., similar and pre-determined shift length, start, and end times).

Normality was assessed using the Shapiro-Wilk test. One-way ANOVAs (mean score) were performed for normally distributed data, whereas the Kruskal-Wallis H-Test (median score) was used when the data were not normally distributed. When significant differences were noted, post-hoc analyses were performed using Tukey's Test and Dunn's (1964) procedure 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.

Sleep debt was characterized across Base, Initial Attack and Project Fire deployments. These data were analyzed by determining the frequency of consecutive days where TST was less than six hours in each work condition, in order to estimate acute sleep debt. Lastly, we were interested in determining which of our sleep variables (TST (min), SE (%), and WASO (min)) collected either 24 hours or 48 hours prior on either Base, Initial Attack, or Project Fire deployments could best predict self-reported morning fatigue. This was accomplished by using a linear mixed model because of our sample size. The *p* value was set at <0.05.

Morning and evening PVT reaction time scores and evening recovery scores were also analyzed using a mixed model approach to understand the relationships with self-reported fatigue, if any.

Table 2: Deployment dependent variables and their definitions.

Variable	Definition
Sleep Efficiency (%)	Proportion of time spent asleep to time in bed (Total Sleep Time/Time in Bed)
Wake After Sleep Onset (mins)	Time awake throughout sleep period, after initial sleep onset
Total Sleep Time (min)	Total amount of time spent asleep
Time in Bed (min)	Total time in bed, including sleep period
Recovery Opportunity Time (hrs)	Period of time between reported shift end time and bed time
AM Subjective Fatigue	1-item questionnaire – “how fatigued do you currently feel” (1=no fatigue-10=extreme fatigue scale)*
PM Subjective Recovery	16-item questionnaire to understand subjective recovery on 4 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 x 4 scales x 1 no recovery = 16) and 80 (4 items x 4 scales x 5 full recovery = 80)**
AM/PM PVT (ms)	5-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
*Van Hooff et al., 2007	
** Sonnentag & Fritz, 2007	

2.5 Results:

Participant information:

All participants (n=23) were male, with a mean age of 29.9 ± 8.4 years (Range: 18-50 years) and were seasonal firefighters employed by the OMNRF. In total, 11 participants (28.4 ± 6.1 years; range 22-39) consistently collected actigraphy data, routinely completed their sleep log, their morning fatigue questionnaire and evening recovery inventory and completed their morning/evening psychomotor vigilance test; thus these participants were used for the analysis of the above variables.

The Health Survey (SF-36) was analyzed and described as: i) Physical Component Score of 54.2 ± 7.8 , and ii) Mental Component Score (MCS) of 54.7 ± 6.1 , indicating relatively high self-perceived health scores prior to study commencement (Ware et al., 1993). The Job Stress Survey scores were within normal limits as indicated by the T-score distribution (Table 3), highlighting normal-to-low perceived work stress, compared to normative data in the male clerical/skilled-maintenance sector (Spielberger & Vagg, 1994) (See Table 3).

Table 3: Baseline and post-season Job Stress Survey results.

		JS-X	JS-S	JS-F	JP-X	JP-S	JP-F	LS-X	LS-S	LS-F
Baseline (n=20)	Mean	46.7	45.2	51.5	48.0	45.1	52.9	45.8	45.8	47.5
	SD	6.2	8.0	7.4	5.6	9.4	7.1	7.1	7.3	8.3
	Minimum	39	34	40	40	30	43	38	31	38
	Maximum	62	63	67	62	65	70	62	60	68
Post-season (n=14)	Mean	49.6	45.0	55.1	48.6	44.5	53.6	50.1	46.5	53.2
	SD	7.7	9.8	7.5	6.3	9.4	5.9	8.5	9.9	8.4
	Minimum	38	26	43	39	29	44	39	27	40
	Maximum	66	66	69	66	65	64	71	64	72
JS=Job stress, JP = Job pressure subscale, LS=Lack of organizational support subscale, X=overall score, S=severity sub-score, F=frequency sub-score, Mean=T-score average, SD=standard deviation, Minimum=lowest obtained score, Maximum=highest obtained score										

Mid- and post-season job stress, analyzed via paired sample T-test, was significantly different for overall job stress ($t(13) = -2.915, p = 0.012$), with main effects from overall job stress frequency ($t(13) = -3.126, p = 0.008$). Lack of organizational support subscale produced significant differences ($t(13) = -4.791, p = 0.000$) with main effects produced via the frequency of events for this subscale ($t(13) = -4.971, p = 0.000$). No other significant differences were identified. These differences indicate that overall job stress was significantly different between mid- and post-season with higher reported stress in the post-season, due to the concepts under the Lack of Organizational Support subscale.

Deployment information:

Descriptive shift characteristics regarding Base work, Initial Attack and Project Fire deployments are reported in Table 4.

Table 4: Deployment type characteristics for Base, Initial Attack and Project Fire.

Deployment Type	Shift Length (hours)	Shift Start (hours - am)	Shift End (hours - pm)	Recovery Opportunity Time (hours)
Base	8.8 ± 0.9	10.2 ± 1.1	7.1 ± 0.3	4.8 ± 0.9
Initial Attack	13.3 ± 3.4	7.2 ± 2.0	9.2 ± 2.1	2.3 ± 2.0
Project Fire	12.5 ± 1.0	7.3 ± 0.8	7.9 ± 1.0	3.1 ± 1.2

Data are shown as mean ± SD
Number of shifts in each deployment category: Base (n=28), Initial Attack (n=15), Project Fire (n=106).

Actigraphy sleep data, according to deployment type:

Total sleep time (TST) and sleep efficiency (SE) were significantly different between the deployment types (Table 5). Initial Attack TST was significantly lower 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, 127.7]) and 86.2 minutes less sleep (95% CI [48.8, 123.5]) during Initial Attack fires than during Base work and during Project Fire deployment, respectively. For SE, Initial Attack fires had a significantly lower median SE than that observed for Project Fires ($p= 0.016$). Although wake after sleep onset (WASO) was not significantly different between deployment conditions, the values would be considered poor (>31 min), 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 7-9 hours for adults (see Table 6). Additionally, WASO was higher recommended standards (>31 minutes per sleep period). Finally, Initial Attack fires were the only type of work deployment with significantly disrupted sleep efficiency ($<85\%$) (Table 6).

Table 5: Sleep score distribution according to deployment type.

Variable	Work Condition	Mean±SD	Median	F-stat / χ^2	Sig.
TST (min)	B	371.6 ± 58.1	364.0	F= 15.221	<i>p</i> = 0.000
	IA	287.2 ± 69.3*	287.2		
	PF	373.4 ± 55.1	373.4		
SE (%)	B	85.7 ± 8.0	86.1	χ^2 = 8.178	<i>p</i> = 0.017
	IA	75.6 ± 19.2	79.0*		
	PF	87.6 ± 7.9	88.2		
WASO (min)	B	58.8 ± 33.9	58.0	χ^2 = 2.192	<i>n.s.</i>
	IA	92.8 ± 82.8	82.0		
	PF	51.4 ± 33.7	44.0		

B=Base, IA=Initial Attack, PF=Project Fire, TST=Total Sleep Time, SE=Sleep Efficiency, WASO=Wake After Sleep Onset, SD=Standard Deviation, Sig.=Significance, n.s.=not significant.
*Denotes significant differences

Table 6: Distribution of sleep measures (percentage) for each deployment type falling above (white) and below (shaded) good sleep quality and quantity threshold measures[†].

Deployment	SE (%)			WASO (mins)			TST (mins)		
	>90	85-90	<85	<5	5-30	>30	>420	360-420	<360
Base	32.1%	17.9%	50.0%	3.6%	21.4%	75.0%	14.3%	39.3%	46.4%
*Fire	39.6%	24.0%	36.4%	4.1%	24.8%	71.1%	16.5%	38.0%	45.5%
Initial Attack	13.3%	26.7%	60.0%	6.7%	6.7%	86.6%	0%	13.4%	86.6%
Project Fire	43.4%	23.6%	33.0%	3.8%	27.4%	68.8%	18.9%	41.5%	39.6%

*Includes both Initial Attack and Project Fire data.
[†]Threshold measures are 85% for sleep efficiency (SE), 30 min for wake after sleep onset (WASO), and 360 min for total sleep time (TST)

Actigraphy sleep data by consecutive work periods (CWP): 1-3 days, 4-7 days, and >7 days:

Overall fire deployment sleep data (combined Initial Attack and Project Fire) were analyzed by consecutive work periods (CWP) defined as short (1-3 days), medium (4-7 days), or long (> 7 days). TST (min) increased from short (1-3 days) to long (>7 days) ($p= 0.035$), by an increase of 37.0 minutes (95% CI [2.1, 71.9]) (Table 7). When analyzing the CWP sleep measures of Project Fires separately, there were no significant differences between work periods ($F(2, 103) = 1.633, (p= 0.200)$) suggesting that the Initial Attack data skewed the combined fire deployment data for the shorter CWPs. Furthermore, WASO (min) scores were consistently higher than the acceptable standard (i.e., >31 minutes) and SE measures were just above the threshold values of 85% for all three CWPs categories.

Table 7: Sleep quantity and quality for fire deployments according to CWP.

Sleep Measure	CWP Category	Mean \pm SD	Median	F-stat	Sig.	PF only – Mean \pm SD
TST (min)	1-3 days	344.3 \pm 83.4*	343.5	F = 3.492	<i>p</i> = 0.034	367.4 \pm 64.0
	4-7 days	356.9 \pm 49.3	352.0			364.6 \pm 46.9
	>7 days	381.3 \pm 57.5	381.0			385.1 \pm 56.0
SE (%)	1-3 days	85.7 \pm 15.3	85.7	F = 0.150	n.s.	90.1 \pm 6.7
	4-7 days	85.7 \pm 9.0	87.3			87.2 \pm 7.7
	>7 days	86.8 \pm 8.5	88.4			86.6 \pm 8.6
WASO (min)	1-3 days	55.5 \pm 60.6	45.5	F = 0.343	n.s.	40.1 \pm 28.1
	4-7 days	60.5 \pm 42.8	52.0			55.3 \pm 36.8
	>7 days	52.9 \pm 32.6	40.5			54.1 \pm 32.8
Sample size distribution: 1-3 days (n=30), 4-7 days (n=47), >7 days (n=44) CWP=Consecutive work period, PF=Project Fire, TST=total sleep time, SE=sleep efficiency, WASO=wake after sleep onset, SD=standard deviation, F-stat=F-statistic, Sig.=significance, n.s.=not significant *Denotes significant differences between 1-3 days and >7 days categories. Data displayed in the last column is for Project Fire only.						

Actigraphy sleep data, according to fire deployment shift characteristics

Overall fire deployment sleep data (Initial Attack and Project Fire) were analyzed according to shift characteristics, including shift length, shift start time, and shift end time. The shift length analysis revealed statistically significant differences in TST scores between the 12-13 hour and >13 hour shift (*p* = 0.038) categories (see Table 8). Lengthier shifts (>13 hours) resulted in shorter TST periods. However, analysis of Project Fire data, revealed no significant differences in TST between the shift length categories, further suggesting that Initial Attack data skewed the combined fire data.

For the shift start time analyses, TST was the lowest for the earliest shift start time of 5-6 am and this trend persisted even when Project Fire data were analyzed on their own. In particular, for combined Fire data, TST was 96.4 mins less when shifts started at

5-6 am compared to shifts starting at 6-7 am (95% CI [59.5, 133.4]). TST was 69.8 mins less when shifts started at 5-6 am, compared to shifts starting at 7-8 am (95% CI [33.6, 106.1]). For Project Fire data only, significant differences were still apparent, with 75.9 mins less TST when shifts started at 5-6 am compared to 6-7 am (95% CI [35.5, 116.4]). Of note, due to a low sample rate in the >8 am group, the analysis was re-run excluding this condition, and the results still produced significant differences in TST for both the combined Fire as well as the Project Fire analyses, between the three earlier start time conditions. This separate analysis revealed significant differences ($F(2, 110) = 22.820, P < .05$ ($p = 0.000$)) between 5-6 am and 6-7 am ($p = 0.000$) and 5-6 am and 7-8 am ($p = 0.000$). For Project Fire only ($F(2, 99) = 12.427, P < .05$ ($p = 0.000$)), significant differences were still identified between: 5-6 am and 6-7 am ($p = 0.000$); 5-6 am and 7-8 am ($p = 0.013$); as well as 6-7 am and 7-8 am shift starts ($p = 0.012$).

Lastly, TST was lowest when shift end time was latest. In particular, shift end times after 9 pm resulted in: 73.6 min less TST compared to shift end ≤ 7 pm (95% CI [26.3, 120.9], $p = 0.001$); 44.7 min less TST compared to shift end time 7-8 pm (95% CI [1.3, 88.1], $p = 0.041$); and 69.6 min less TST compared to shift end time between 8-9 pm (95% CI [22.6, 116.7], $p = 0.001$). These differences were not apparent when Project Fire data were subsequently analyzed on their own, once again indicating that Initial Attack data were possibly skewing the combined Fire data.

Table 8: Sleep quantity (TST) for fire deployment according to shift characteristics.

Sleep Var.	Analysis	Shift Categ.	n	Mean ± SD	Median	F-stat / χ^2	Sig.	PF only – Mean ± SD
TST (min)	Shift Length (hours)	<12 hours	16	343.8 ± 88.0	349.5	$\chi^2 = 7.269$	$p = 0.026$	380.7 ± 61.9
		12-13 hours	71	372.7 ± 53.0	366.0			375.3 ± 48.7
		>13 hours	31	348.2 ± 65.7 ⁺	341.0			364.0 ± 66.3
	Shift Start (am)	5-6 am	22	298.1 ± 64.8*	304.0	F = 16.151	$p = 0.000$	323.4 ± 46.3*
		6-7 am	43	394.5 ± 58.6	406.0			399.3 ± 57.3
		7-8 am	48	367.9 ± 45.3	364.5			367.9 ± 45.3
		>8 am	8	338.4 ± 42.8	350.0			355.0 ± 20.5
	Shift End (pm)	≤7 pm	27	385.1 ± 58.5	398.0	F = 6.742	$p = 0.000$	391.5 ± 54.1
		7-8 pm	46	356.2 ± 51.7	354.0			357.2 ± 52.0
		8-9 pm	28	381.2 ± 54.0	366.5			381.2 ± 55.0
		>9 pm	17	311.5 ± 80.7 [#]	309.0			378.4 ± 41.7
	⁺ difference between >13 hrs and 12-13 hrs [*] difference between 5-6 am and 6-7 am, 7-8 am (significant differences also noted for Project Fire data) [#] difference between >9 pm and all other shift end times TST=total sleep time, n=No. of data points, SD=standard deviation, F-stat=F-statistic (ANOVA), χ^2 = Chi-square (KW test), Sig.=significance. Categ.=category							

SE scores were lowest for shifts ending after 9 pm compared to those ending between 7-8 pm ($p = 0.047$) [$F = 2.702$, $p = 0.049$], (7.8% difference, 95% CI [0.1, 15.5]). However, no other statistically significant differences were noted for SE between shift characteristics. Nevertheless, it is notable that SE is generally above or near acceptable thresholds (i.e., 85%) regardless of shift length, start or end time (Table 9). WASO

measures were consistently higher than acceptable levels (> 31 min) even though no significant differences in WASO measures were observed according to the fire deployment shift characteristics (Table 9). Furthermore, Table 10 describes secondary variables associated with specific shift start conditions and provides insight into trends associated with shift start times during fire deployments.

Table 9: Sleep quality (SE, WASO) for fire deployments according to shift characteristics.

Analysis	Shift Category	Fire		Project Fire only	
		Mean \pm SD		Mean \pm SD	
		SE (%)	WASO (mins)	SE (%)	WASO (mins)
Shift Length (hours)	<12 hours	81.7 \pm 18.6	77.0 \pm 76.3	87.6 \pm 7.4	57.8 \pm 38.4
	12-13 hours	87.5 \pm 7.9	49.8 \pm 29.1	87.7 \pm 7.7	49.3 \pm 28.9
	>13 hours	84.5 \pm 10.3	64.9 \pm 49.5	86.3 \pm 8.8	59.2 \pm 43.4
Shift Start (am)	5-6 am	83.6 \pm 16.1	59.5 \pm 65.0	88.1 \pm 4.6	43.7 \pm 18.2
	6-7 am	86.6 \pm 8.3	60.7 \pm 38.5	87.4 \pm 7.9	58.3 \pm 38.9
	7-8 am	88.2 \pm 8.8	44.9 \pm 31.4	88.2 \pm 8.8	44.9 \pm 31.4
	>8 am	78.0 \pm 10.5	95.4 \pm 54.8	80.4 \pm 1.4	86.3 \pm 6.6
Shift End (pm)	\leq 7 pm	87.6 \pm 7.1	55.3 \pm 32.7	88.3 \pm 6.2	53.3 \pm 31.3
	7-8 pm	87.9 \pm 8.9	46.5 \pm 35.7	88.9 \pm 7.4	41.5 \pm 24.1
	8-9 pm	84.5 \pm 9.2	66.1 \pm 42.3	84.4 \pm 9.4	67.0 \pm 42.8
	>9 pm	80.1 \pm 18.0*	76.5 \pm 72.7	86.3 \pm 7.4	60.9 \pm 34.0
SE=Sleep Efficiency, WASO=Wake After Sleep Onset, SD=standard deviation, am=morning period, pm=evening period *Denotes significant differences between >9 pm and 7-8 pm					

Table 10: Shift start descriptive statistics for combined Fire deployments.

Fire Type	Shift Start Condition	Shift Length (hrs)	Shift End (pm)	Recovery Opportunity Time (hrs)
Fire	5-6 am	14.1±2.2	9.2±1.4	2.5±1.0
	6-7 am	12.3±1.3	7.3±1.0	2.7±1.5
	7-8 am	12.3±0.5	8.3±0.6	3.4±0.9
	>8 am	11.8±1.9	7.9±2.0	4.5±2.0
Project Fire	5-6 am	14.0±0.9	8.4±1.0	2.9±1.0
	6-7 am	12.2±1.1	7.2±0.9	2.7±1.5
	7-8 am	12.3±0.5	8.3±0.6	3.4±0.9
	>8 am	12.4±0.5	9.1±0.3	3.4±0.4
Initial Attack	5-6 am	14.3±3.6	10.6±0.7	1.8±0.6
	6-7 am	13.3±3.3	9.0±0.7	2.3±0.3
	*7-8 am	-	-	-
	>8 am	11.3±2.6	6.6±2.2	5.5±2.4
*No data available for this condition				

Sleep debt analysis:

Sleep debt was characterized across Base, Initial Attack and Project Fire deployments. These data were analyzed by determining the frequency of consecutive days where TST was less than six hours in each work condition, in order to estimate the occurrence of acute sleep debt. Figure 2 below highlights the high frequency of one day of sleep debt for all conditions. Interestingly, upwards of five and six days of consecutive sleep debt nights were encountered during the fire season for Base and Project Fire work, respectively. It was common to see four days of consecutive sleep debt, as viewed on five different occasions during Project Fire deployments.

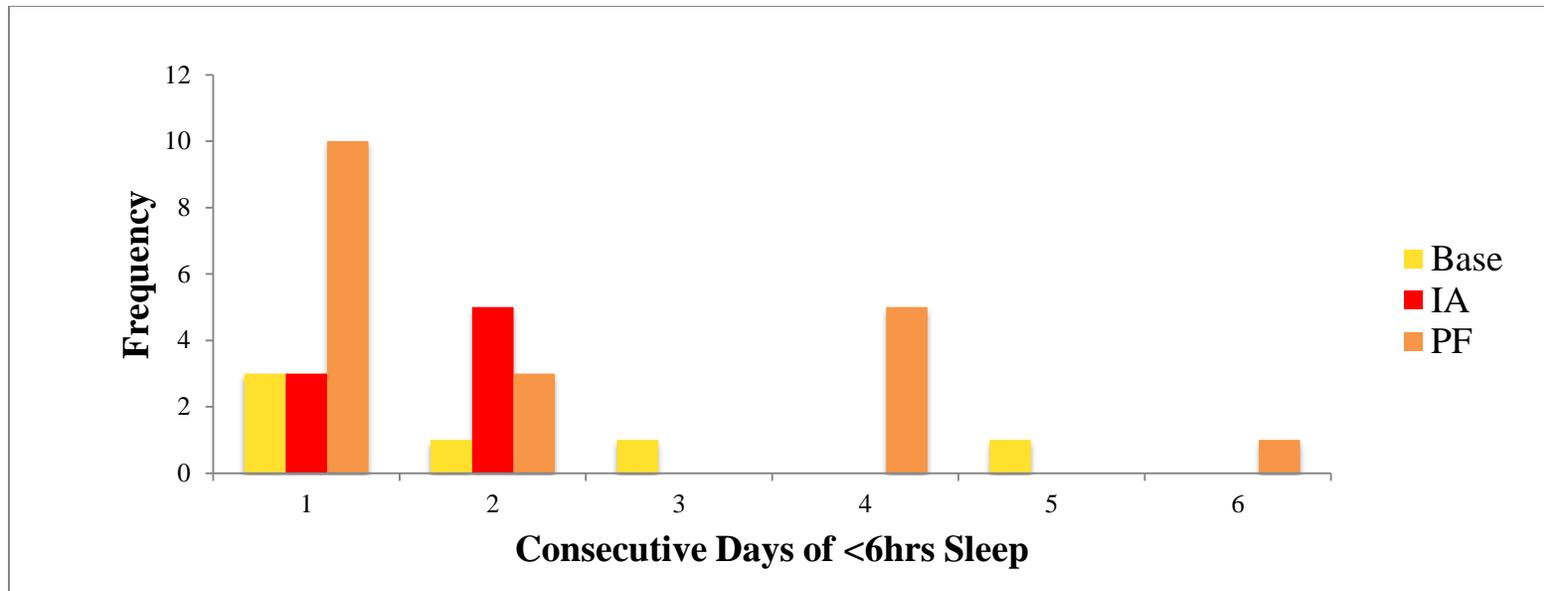


Figure 2: Frequency of consecutive days of sleep debt defined as less than six hours per night according to deployment type (Base (n=3), Initial Attack (IA) (n=5) and Project Fire (PF) (n=8)).

Psychomotor vigilance reaction time according to deployment type:

Psychomotor vigilance reaction time (PVT) data were collected to determine whether cognitive alertness in the morning and evening would differ according to the deployment types. PVT median scores during morning periods were significantly higher for Initial Attack (N=6, Med.=424.8, SD=51.3) compared to Project Fire (N=66, Med.=372.4, SD=51.1) ($\chi^2 = 8.097, p = 0.014$), but no difference was found in Base scores (N=19, Med.=385.7, SD=64.2). No significant differences were observed for evening reaction times for all work conditions, with Initial Attack (N=5, Mean=363.2, SD=34.7), Project Fire (N=63, Mean=381.1, SD=59.1), and Base (N=17, Mean=373.0, SD=53.7) scores all within normal limits (Figure 3). Of note, 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. Please see Appendix B for supplementary results on the PVT for fire deployments (CWPs and shift analyses).

It is important to note that these lapses were average reaction times, which is based on a five-minute test (standard of 30 trials). This indicates that average scores were greater than 500 ms, indicating multiple lapses within each of these average scores (decreased alertness/lapse in attention during these periods). This indicates that lapse frequency would be much higher with more sophisticated PVT platforms.

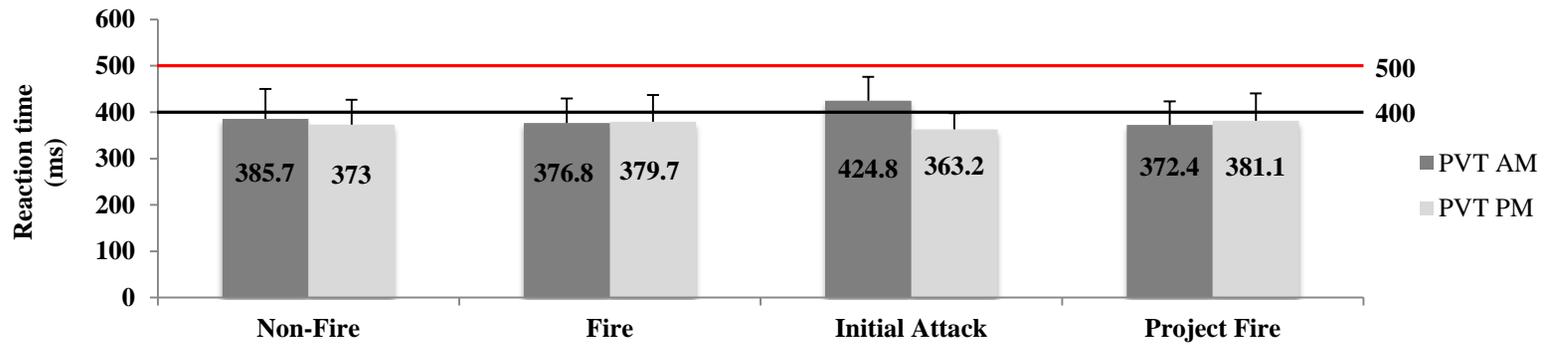


Figure 3: PVT reaction time scores according to shift type (non-fire (Base) and fire (Initial Attack and Project Fire)). Data are presented as mean \pm SD for reaction time during morning (AM) and evening (PM) work periods. The red line denotes a lapse in attention and the black line denotes a warning region.

Self-reported fatigue measures:

Self-reported fatigue (Table 11) was found to be significantly different between deployment types, with post hoc analyses revealing higher fatigue levels for Initial Attack compared to Base ($p= 0.006$). In terms of combined Fire data and deployment shift characteristics, self reported fatigue was highest for the 7-8 am shift start time and this was significantly higher compared to the 6-7 am start time ($p= 0.000$) (Table 11). The Project Fire analysis also indicated significant differences in self-reported fatigue between 5-6 am and 7-8 am ($p= 0.006$), 5-6 am and >8 am ($p= 0.026$), 6-7 am and 7-8 am ($p= 0.000$) and 6-7 am and > 8 am ($p= 0.012$), with 7-8 am and >8 am shifts incurring the highest reported fatigue. For shift end times, fatigue levels for combined Fire and Project Fire were highest for the later, 8-9 pm and >9 pm, shift end conditions [significant differences between ≤ 7 pm and 8-9 pm ($p= 0.000$), ≤ 7 pm and >9 pm ($p= 0.000$), 7-8 pm and 8-9 pm ($p= 0.001$), and 7-8 pm and >9 pm ($p= 0.000$) for combined Fire, and significant differences between ≤ 7 pm and 8-9 pm ($p= 0.000$), ≤ 7 pm and >9 pm ($p= 0.006$), 7-8 pm and 8-9 pm ($p= 0.001$), and 7-8 pm and >9 pm ($p= 0.032$) for Project Fire]. The majority of the self-reported fatigue scores were five or less thereby indicating that self-reported fatigue was generally considered low-to-moderate in this current study (Table 11).

Table 11: Self-reported fatigue measures according to deployment type and fire deployment shift characteristics.

Variable	Analysis	Category	N	Mean \pm SD	Median (PF)	χ^2	Sig.
Self-reported fatigue (scale 1-10) 1=no fatigue 10=extreme fatigue	Deployment Type	B	27	2.7 \pm 2.0	2.0	$\chi^2 = 10.054$	$p = 0.007$
		IA	15	4.3 \pm 1.6	5.0*		
		PF	103	3.5 \pm 1.8	3.0		
	CWP (days)	1-3 days	30	3.8 \pm 1.9	3.5	$\chi^2 = 2.405$	n.s.
		4-7 days	46	3.2 \pm 1.5	3.0		
		>7 days	42	3.8 \pm 2.1	4.0		
	Shift Length (hours)	<12 hours	16	4.0 \pm 1.6	4.0	$\chi^2 = 0.987$	n.s.
		12-13 hours	69	3.5 \pm 1.9	3.0		
		>13 hours	30	3.6 \pm 1.9	3.0		
	Shift Start (am)	5-6 am	21	3.5 \pm 1.8	3.0 (2.0)	$\chi^2 = 20.502$	$p = 0.000$
		6-7 am	42	2.7 \pm 1.7	2.0 (2.0)		
		7-8 am	47	4.3 \pm 1.6	5.0*+ (5.0)		
		>8 am	8	4.0 \pm 1.9	4.0 (5.5)		
	Shift End (pm)	≤ 7 pm	27	2.6 \pm 1.6	2.0	$\chi^2 = 34.561$	$p = 0.000$
		7-8 pm	44	3.0 \pm 1.5	3.0		
		8-9 pm	27	4.6 \pm 1.6	5.0*+		
>9 pm		17	5.1 \pm 1.5	5.0			

*Denotes significant difference
 +Project fire analysis also significantly different
 CWP=consecutive work period, B=Base, IA=Initial Attack, PF=Project Fire,
 SD=standard deviation, N=observations, χ^2 =chi-square (Kruskal-Wallis),
 Sig.=significance, n.s.=not significant

Additionally, we employed a linear mixed model analysis in an attempt to determine whether self-reported fatigue levels could be predicted by sleep quantity (TST), sleep quality (SE), sleep debt (defined as sleeping less than six hours) after one or more consecutive days, and the type of deployment (Fire or Base). The mixed effects regression analyses, using 120 observations from 11 participants, revealed that

deployment type, and being on fire deployment in particular, was predictive of higher reported fatigue levels the following morning ($Z= 3.12$, $p= 0.002$, 95% CI [0.441, 1.929]), with the largest impact for Initial Attack ($p= 0.07$). No linear relationships were noted between the morning fatigue scores and the recovery and reaction time scores recorded on the day prior.

Self-reported recovery measures:

Table 12: Self-reported recovery according to deployment type.

Variable	Deployment Type	N	Mean \pm SD	Median	ROT (hrs)	χ^2	Sig.
Self-Reported Recovery (16-80) 16=no recovery 80=complete recovery	B	27	54.2 \pm 9.9	51.0	4.8 \pm 0.9	$\chi^2 = 0.776$	n.s.
	IA	15	52.5 \pm 8.5	51.0	2.9 \pm 2.0		
	PF	103	51.0 \pm 8.4	52.0	3.1 \pm 1.2		
N=number of observations, SD=Standard deviation, ROT=Recovery opportunity time, χ^2 =Chi square (KW test), B=Base, IA=Initial Attack, PF=Project Fire, Sig.=significance, n.s.=not significant.							

According to Table 12, self-reported recovery was similar between the deployment types. All scores were above the mid-range of the scale thereby suggesting that participants perceived that they were adequately recovered. These recovery scores were also consistently reported regardless of the amount of recovery opportunity time (ROT) allocated per night during these work activities (Table 12). Please see Appendix B for supplementary results on the reported recovery for fire deployments (CWPs and shift analyses).

2.6 Discussion

This study employed objective methods to assess sleep as well as objective (alertness) and subjective methods to assess fatigue and recovery in a group of Canadian wildland firefighters during non-fire and fire deployments. Our findings affirm support for the integration of both objective and subjective measures in future wildland firefighting research (Van Hooff et al., 2007; Sonnentag & Fritz, 2007; Basner & Dinges, 2011; Marino et al., 2013; Smith, Browne, Armstrong & Ferguson, 2016). It was found that sleep quality and quantity, 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 deployments. It was also noted that between one-third and two-thirds of the sleep measures collected during all three deployment types (i.e., Base, Initial Attack, and Project Fires) fell outside the optimal ranges recommended for young adults (Ohayon, Carskadon, Guilleminault & Vitiello, 2004; Girschik, Fritschi, Heyworth & Waters, 2012; Hirshkowitz et al., 2015).

Sleep parameters during non-fire and fire deployments:

In the current investigation, sleep measures on Initial Attack deployments seemed to be worse compared to Base and Project Fire deployments. In particular, two-thirds of the SE observations collected for Initial Attack deployments fell below the recommended threshold of 85% for SE (Ohayon et al., 2004; Girschik et al., 2012). In addition, the average TST for Initial Attack deployments was well below recommendations for young adults (4.8 ± 1.2 hours compared to 7-9 hours; Hirshkowitz et al., 2015). A previous study on American wildland firefighters indicated that these workers accumulated 7.02 ± 1.42

hours of sleep per night (based on 276 nights between 47 subjects) when performing random duty assignments, but it is worth noting that these measures were self-reported and that the fire and non-fire duties were not clearly outlined (Gaskill & Ruby, 2004). Interestingly, WASO scores in the current investigation were not different between deployment types; however, a meaningful percentage of the observations fell above the recommended 31 min threshold regardless of deployment type (Ohayon et al., 2004; Girschik et al., 2012), which indicates poor quality sleep in general. These results could be due to a number of factors (i.e., sleep conditions, non-productive rumination, etc.) that were not identified in this specific study; this should be investigated in future studies.

Acute sleep deprivation caused by low sleep duration and poor sleep quality can have immediate effects on an individual, such as decreased alertness, impaired cognitive ability and psychological stress (Dinges et al., 1997; Banks & Dinges, 2007; Cuddy et al., 2015; Wolkow et al., 2016). Furthermore, chronic sleep deprivation can lead to higher rates of mortality and increased health-related problems (Van Dongen et al., 2003b). In our sample of firefighters, TST of less than six hours were observed at a high frequency for all three work conditions (i.e., Initial Attack, Project Fire and Base) indicating that our participants were at risk of sleep debt. Upwards of five consecutive nights of potential sleep debt was accumulated during Base work periods, one to two nights of sleep debt during Initial Attack and upwards of six nights during Project Fire deployment (See Figure 2). These results indicate that some firefighters in this study are accumulating sleep debt for upwards of six consecutive days, which has been previously identified as problematic in terms of performance and health (Van Dongen et al., 2003b; Banks & Dinges, 2007). 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 [CIFFC], 2014). Contextually, results may underestimate the impact of sleep debt as data were collected during a low-hazard fire season.

Interestingly, Van Dongen and colleagues (2003a) discuss inter-individual differences in the relationship between sleep debt and performance deficits. In the current study, our participants were fairly homogenous in terms of their overall health status and were mostly young, male adults. We nevertheless attempted to link sleep profiles and PVT average reaction time scores of these firefighters, but found that the participants performed reasonably well and similarly on the PVT reaction time test irrespective of the deployment type or time of day (i.e., morning versus evening). In other words, sleep debt did not appear to negatively impact performance on a simple PVT reaction time test. PVT scores have been recently shown to correlate reasonably well with a fatigue scale administered to moderately sleep-deprived volunteer firefighters undergoing simulated firefighting work in high temperature conditions (Ferguson et al., 2016). Still, our finding does not rule out the possibility that the suboptimal sleep profiles of our participants could impact performance on more complex fatigue/sleep loss-sensitive psychomotor vigilance test variables (Basner & Dinges, 2011).

Half of the SE measures recorded for Base work in the current investigation were also below the 85% SE cut-off and TST (6.2 ± 1.0 hours) was generally lower than what is recommended for young adults (Hirshkowitz et al., 2015) and marginally lower than what was reported in Vincent et al. (2016a) for non-fire activity work periods (7.0 ± 0.9 hours). This was somewhat surprising given that firefighters working at the Base are 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 non-work obligations (i.e., demands from family/friends, personal conflicts, etc.) and low social activity (Fritz & Sonnentag, 2005; Zijlstra & Sonnentag, 2006). 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 wellbeing prior to lengthy fire deployments (Dinges et al., 1997, Scott, McNaughton & Polman, 2006). Our findings suggest that attention should be given to sleep behaviors during Base work and that interventions should include the promotion of good sleep hygiene to maximize recovery opportunities.

Association between work shift parameters and sleep quantity and quality:

The literature is fairly consistent regarding long work hours and increased employee risk for sleep deprivation, sleepiness, and poor sleep behaviour (Caruso et al., 2006; Sallinen & Kecklund, 2010; Virtanen et al., 2009; Parkes, 2015). There is also research indicating a higher risk of injury with long working hours; with self-reported sleep duration as an independent, yet additive factor, increasing the risk of injury (Lombardi, Folkard, Willetts & Smith, 2010). Similarly, Waage, Pallesen, Moen and Bjorvatn (2013) 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 behaviour. The SE scores in the current study did decline as the work period lengthened, which is in line with the results of Waage and colleagues (2013). However,

the current investigation indicates a slight increase in TST from short to long CWPs, with consistently high WASO scores. The longer work periods (greater than seven days) in the current study were primarily Project Fire deployments and the increase in TST may reflect an environmental adaptation of the firefighters during this generally less intense work deployment. It is worth noting that a large proportion of the recorded sleep behaviours fell below recommended guidelines for all work conditions (Ohayon et al., 2005; Girschik et al., 2012; Hirshkowitz et al., 2015). Future studies should assess the 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 sub-optimal sleep behaviour and to ascertain any correlations with injury rates.

Initial Attack deployments in the current study characteristically had extended shift lengths, late shift end times and earlier morning start times; these factors would be expected to impact the timing and duration of sleep periods, which have been identified as determinants of sleep outcomes (Akerstedt et al., 2010, Jay, Aisbett, Sprajcer & Ferguson, 2015, Vincent et al., 2016a). Our overall sleep measures during fire deployments did not appear to be appreciably different according to shift length, but early shift start times were associated with the worst SE measures. Others have noted that early morning shift start times are not typically associated with worse sleep quality (Akerstedt et al., 2010); rather they are associated with a decline in sleep duration due to maladjusted bed times. In the current study, sleep duration was significantly lower for shifts starting between 5-6 am. Furthermore, shifts beginning prior to 6 am in this analysis had later shift end times (>9pm) and lengthy shifts (>14 hrs) the day before as

early shift start times are typically encountered during more severe fire conditions. Accordingly, the recovery opportunity time the night prior to 5-6 am start times was typically lower than for all other shift start conditions and, as mentioned, this combination of shift characteristics is typically encountered when fire suppression is at a high-alert phase. In the current study, sleep duration for shifts starting prior to 6 am was at least 70 minutes and 45 minutes lower for combined Fire and Project Fire conditions, respectively. This indicates that regardless of the type of fire deployment, earlier shift start times are associated with a decrease in TST; similar results were obtained by Vincent and colleagues (2016a). 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 advisable whenever possible to consider the shift length and the sleep duration opportunity the night prior in 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 (Vincent et al., 2016a).

Association between work intensity, opportunities for recovery and sleep quantity and quality:

Other than the shift characteristics, we postulate that the suboptimal sleep measures, particularly on Initial Attack, could be related to the physically demanding and high-intensity fire suppression activities accomplished during these deployments as well as the unpredictable and harsh conditions routinely encountered during this type of deployment (Robertson et al., 2017). This is in line with previous studies reporting that

prolonged, intense and hectic work periods predict poor sleep and higher risk of fatigue (Akerstedt et al., 2002a; Akerstedt et al., 2002b) and not surprisingly, the self-reported morning fatigue measures in this investigation were best predicted by the type of deployment (i.e., Initial Attack). Vincent and colleagues (2016a; 2016b) also reported higher subjective fatigue rating scores during fire versus non-fire periods. Interestingly however, they found sleep efficiencies for non-fire periods ($88.1\% \pm 6.8$) and fire ($88.8\% \pm 5.4$) deployments were above the 85% recommended threshold and that TST was lower for fire versus non-fire deployments (Vincent et al., 2016a). Fire deployments in Vincent and group (2016a) were not further dichotomized into Initial Attack and Project Fire, which limit comparison. Taken together, the results from this analysis underline that Initial Attack deployments were associated with the worst sleep quality compared to the other deployment types. It is worth noting that the sleeping conditions according to the various deployment types in the current investigation were not systematically monitored. Accordingly, a combination of sleep hygiene training, fatigue awareness, schedule adaptation and further research on the specifics of fire suppression sleep conditions (see Vincent et al., 2016a) may help optimize sleep behaviour and possibly result in a lower risk of fatigue and fatigue-related injury.

A closer look at recovery opportunity time and self-reported recovery suggests that the firefighters in the current 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

sub-optimal sleep measures, yet the scores obtained for all deployment types were within the mid range of the perceived recovery scale. Of note, Querstret and Copley (2012) have reported that long hours, highly strenuous work and long work periods lead to individuals ruminating, or thinking, about work during evening recovery periods which can cause psychophysiological arousal that is counterintuitive to the recovery process. Furthermore, affective rumination (arousal that remains high and non-conducive to recovery) has been associated with poor sleep (Querstret & Copley, 2012). 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. Unfortunately, the characteristics of wildland firefighting (i.e., on site for 14 days sleeping in the outdoors) are not conditions typically studied with regards to the concept of psychological detachment from work, given that most occupations allow the individual to return home after work. This poses a unique situation where physically these workers do not leave work, yet mentally they need to disengage to promote recovery. Strategies that are currently being explored in the literature, that may be useful in this type of work environment, may be that of mindfulness-based interventions for recovery from work (Hulsheger, Feinholdt, & Nubold, 2015; Querstret, Copley & Fife-Schaw, 2016). Findings from these interventions reveal that mindfulness-based training can help relieve strain and affective rumination, while

promoting good sleep behaviour. Utilizing such an intervention would be a good future direction for research into emergency operations such as this.

Fatigue as a risk factor for injury within the wildland firefighter profession:

There is evidence that firefighters have a high rate of injury during fire suppression and related activities and that fatigue is an underlying concern for this occupation (Resources OMNRF, 2012-14; Britton, Lynch, Torner & Peek-Asa, 2013; Gordon and Lariviere, 2014). Other organizations worldwide have also identified fatigue as a challenge in wildland firefighting (Aisbett et al., 2007; Vincent et al., 2016a; Smith et al., 2016). Within the profession of firefighting and other workforces, there is evidence linking poor sleep, worker fatigue and workplace injury-risk (Akerstedt et al., 2002a; Akerstedt et al., 2002b; Swaen, Van Amelsvoort, Bültmann & Kant, 2003; Dinges, 1995; Williamson et al., 2011). 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 current 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. We were unable to further correlate the fatigue data with the lost-time injury data for the 2014 fire season because our sample size was too small and because those injury data were not yet available at the time of writing this manuscript. In a future study, it may be possible to retrospectively analyze injury rate data from previous fire suppression periods and to determine whether the injuries were more prevalent during

Initial Attack deployments given our current findings that workers during these work periods experienced the worst sleep patterns and highest self-reported fatigue scores.

A larger sample size is required to understand whether subjective reporting of fatigue could be utilized to understand when wildland firefighters require breaks or if they should be pulled off the fire line. In relation to this, Smith and colleagues (2016) 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 and fatigue symptom awareness and quite possibly an optimization of the safety culture of the wildland firefighting profession would need to be considered. It is interesting to note that although workplace sleep health programs may not improve sleep behaviors, it may mitigate injury rates as demonstrated in a recent study of structural firefighters (Sullivan et al., 2016). In this case, self-reported sleep and sleepiness were unchanged post-intervention, but firefighters who attended education sessions of this particular workplace sleep health program were less likely to file injury reports compared to peers who did not attend the classes (Sullivan et al., 2016). It is also worth noting that sleep health education programs have the greatest impact when they are led by experts compared to other methods of delivery such as online or ‘train-the-trainer’ (Barger et al., 2016).

The research on fatigue management in the workplace has expanded in the past decade, and there have been multiple methods proposed for mitigating the effects of fatigue in various occupational settings (Dawson & McCulloch, 2005; Dawson, Chapman & Thomas, 2012; Williamson & Friswell, 2013). However, 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 (i.e., out-of-control bush fires and danger to inhabited communities). Nevertheless, there are possible ways to help optimize sleep opportunity for wildland firefighters, especially during Project Fire suppression work, including good design of work hours and fatigue and sleep hygiene education (Caldwell, Caldwell & Schmidt, 2008; Caldwell, 2012; Williamson & Friswell, 2013). Good design of work hours would include later shift start times ($\geq 7\text{am}$ – i.e., Yeung, Sletten & Rajaratnam, 2011) and more time between shifts (≥ 12 hours) when possible. During Project Fire deployments, these guidelines may be easier to implement rather than during 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 (commonly due to long shifts and early shift start/late end times) as much as possible in order to reduce performance deficits and fatigue-related errors in judgment. Fatigue mitigation training programs are not ideal for managing/eliminating fatigue compared to decreased work hours and increased (and *quality*) 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 (Caldwell, 2012; Lerman et al., 2012; Davy, 2014; Randolph, 2015).

2.7 Limitations and Conclusions

A few limitations should be noted for the current 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. Second, the 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 non-work 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 prior to the fire season in order to gauge the effects of wildland firefighting work periods on sleep behaviour. Fourth, there were a low number of observations for Initial Attack and Base work, relative to Project Fire deployments, as well as inconsistency in collection from the participants. In order to determine the factors that best predict fatigue in these workers, larger participant numbers would also be required and more complete data collection of all variables from participants would be essential. Finally, due to the low sample size and the fact that 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 to other occupations and it is reported anecdotally that fatigue is a likely risk factor (Resources OMNRF, 2012-14). Fatigue risk management systems tailored to wildland firefighters should be evidenced-based. Accordingly, the current study analyzed the sleep behaviour

and subjective fatigue of wildland firefighters in order to quantify potential areas contributing to fatigue. 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 behaviour out of the three conditions and this should be considered an area for targeted intervention. Sleep behaviour at the Base was unexpectedly poor; therefore, better sleep hygiene practices should be promoted during this work period to avoid sleep debt prior to fire deployments. It is recommended that the impact of shift start and shift 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.

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CHAPTER 3

3 General Discussion

3.1 Summary of Hypotheses for the Current Study

The first set of hypotheses (H1) postulated that sleep behaviour (H1a) and fatigue (H1b) would be significantly worsened while on high exertion deployments (i.e., Initial Attack; these hypotheses were accepted. However, self-perceived recovery (H1c) was not lower during higher intensity deployments; this hypothesis was rejected. Objective alertness (PVT test measures, H1d) was compromised during these high intensity deployments, but this was only indicated during morning scores; therefore, this hypothesis was accepted for morning alertness only.

The second set of hypotheses (H2) suggested that sleep behaviour (H2a), self-reported fatigue (H2b), self-reported recovery (H2c) and objective alertness (H2d) would be compromised during extended consecutive work periods on the fire-line. These hypotheses were rejected, as extended work periods did not negatively impact any of the outcome measures.

The third set of hypotheses (H3) tested whether sleep behaviour (H3a), self-reported fatigue (H3b), self-reported recovery (H3c), and objective alertness (H3d) would be negatively impacted by lengthy fire-line shifts characterized by early shift start times, and late shift end times. Early shift start times (5-6 am) negatively impacted sleep behaviour regardless of type of fire suppression. Further, late shift end times (>9 pm) resulted in poor sleep behaviour; this hypothesis was accepted. Self-reported fatigue (H3b) and recovery (H3c) as well as objective alertness (H3d) were not compromised by shift length; these hypotheses were therefore rejected.

3.2 WHO Healthy Workplace Model: Context of Wildland Firefighting

The World Health Organization developed a Healthy Workplace Model for occupational researchers and industry partners to create sustainable and safe workplace environments (reviewed in Kortum, 2014). This model is an integrated and holistic approach to creating safe work environments and it encompasses four avenues thought to cover all dimensions of worker health and wellbeing (World Health Organization [WHO], 2010; Kortum, 2014). In order for this model to be generalizable, it has been created as a flexible and general framework, thus allowing organizations to address their own needs through a tailored approach within the four avenues. Furthermore, this model is modernized in that it allows both management and front-line workers to work in synergy to foster an integrated and holistic view of all aspects of worker health and wellbeing. The four avenues are as follows:

1. *“Health and safety concerns in the physical environment;*
2. *Health, safety and well being concerns in the psychosocial work environment including organization of work and workplace culture;*
3. *Personal health resources (available choices) in the workplace provided by the employer; and*
4. *Ways of participating in the community to improve the health of workers, their families, and other members of the community”* (Kortum, 2014, p. 154-155)

In this regard, the four avenues could be utilized to direct research particularly related to the physical and psychosocial work environments which, based on the findings of other wildland firefighting agencies (e.g., Aisbett & Nichols, 2007; Vincent, Aisbett, Hall & Ferguson, 2016), would be suitable avenues to conduct objective research. In the context of the physical and psychosocial work environments for wildland firefighters, research is available for both of these avenues, with the majority from Australia, and some in America. In terms of Australian-based research; heat, smoke, intensity and

duration of work, and strain/stress have all been examined during real and simulated wildland firefighting activity (Budd et al., 1997; Budd, 2001; Aisbett & Nichols, 2007; Aisbett, Wolkow, Sprajcer & Ferguson, 2012; Larsen, Snow, & Aisbett, 2015; Vincent et al., 2017), and this research indicates that these stressors are commonplace for this occupation. Specific physical workplace stressors reported for American wildland firefighters include; smoke, intensity of work and heat (Heil, 2002; Ruby et al, 2002; Cuddy & Ruby, 2011; Cuddy, Sol, Hailes & Ruby, 2015). In terms of psychosocial research, interesting results have been published in Canadian wildland firefighters, in which personality and job stress have been correlated with workplace injury (Gordon & Larivière, 2014). These researchers found that non-lost time injury (i.e., first aid only) was related to older workers scoring high on neuroticism and low in openness on the NEO Personality Survey, while high job stress was related to lost-time injury. Of note, more experienced workers were less likely to incur lost-time injury. Other aspects related to the psychosocial determinants of health in the firefighting profession (urban and wildland) have been recently reviewed (Larivière, Kerekes & Valcheff, 2016).

In recent years, focus has shifted to the development of a safe culture for hazardous occupations such as wildland firefighting. This research, conducted in the United States, has focused on organizational culture and social pressures to reporting safety issues (Lewis, Hall & Black, 2011), safety climate/culture and differences between hierarchy of command (Black & McBride, 2013), the adaptation of safety rules and how to communicate these rules (Jahn, 2016), as well as research on bridging the gap between that of safety research and implementation of these policies into everyday practice (Adams, Butler, Brown, Wright & Black, 2017). Furthermore, reports have also surfaced

in terms of the implementation of various wellness programs in wildland firefighting. This research has focused on identifying variables involved in developing critical leadership (Lewis, 2013; Waldron & Ebbeck, 2015), as well as the implementation of mindfulness programs into wildland firefighting operations (Lewis, 2013) in order to promote leadership development and a subsequent healthy working culture. This research would fall under the second avenue in the WHO Healthy Workplace Model, namely with the work safety culture.

In terms of the current research, wildland firefighters working for the Ontario Ministry of Natural Resources and Forestry (OMNRF) under the division of Aviation, Forest Fire, and Emergency Services (AFFES) can take advantage of the WHO Healthy Workplace Model to maximize worker wellbeing. These firefighters endure 14-day fire-line deployments, lengthy work hours, high physical intensity, and harsh physical and mental work environments (Resources OMNRF, 2011a; Robertson et al., 2017). Furthermore, internal reports have documented high injury rates that are thought to be attributable to fatigue and overexertion. With injury rates as high as 4.46 lost time injuries per 100 workers (11-year average, 2004-14; Resources OMNRF 2012-14) as compared to the WSIB average of 1.38 lost time injuries per 100 workers (10-year average, 2004-2013, average of all industries; Workplace Safety and Insurance Board [WSIB], 2014), it is clear that this occupation requires evidence-based intervention to promote health and safety awareness.

3.3 Main Objectives of Current Study and Summary of Main Findings

Given the large body of evidence linking fatigue to sleep behaviour (see Chapter 1), the current study sought to assess objective sleep behaviour and fatigue (alertness) and subjective fatigue/recovery in a group of wildland firefighters during both non-fire and fire-line deployment conditions. To our knowledge, there is no previous research on sleep behaviour and fatigue for Canadian wildland firefighters.

In general, Initial Attack deployments were associated with lengthy shifts, early starts, late shift end times and thus less recovery time available each evening. Decreased sleep duration and quality, as well as increased reported fatigue were also noted for this deployment type. These results were not surprising as this type of fire suppression is known to be of high-intensity requiring increased energy expenditure (Robertson et al., 2017), and is characterized by shift characteristics that are more likely to interfere with the natural sleep process. Project Fire deployments involved lengthier consecutive work periods (i.e., 14 days) and consistent shifts (12 hours on/12 hours off) and were typically out of province due to the low-hazard fire season in Ontario. Although better sleep behaviours were noted for Project Fire, the results still indicate lower than recommended sleep quantity and quality (Hirshkowitz et al., 2015). Furthermore, sleep behaviour during non-fire work at the Fire Management Headquarters was below recommended levels even though sleep was usually in the home environment and workdays were consistently eight hours in length. Overall, sleep behaviour was generally suboptimal in all work conditions (Hirshkowitz et al., 2015; Ohayon, Carskadon, Guilleminault & Vitiello, 2004; Girschik, Fritschi, Heyworth & Waters, 2012). It is also worth noting that the data for the current study were collected in a relatively low-hazard fire season with

the “*lowest number of fires and 9th least amount of hectares (ha) burned since 1960*” (Canadian Interagency Forest Fire Centre [CIFFC], 2014, p. 11). We would therefore postulate that fatigue levels and sleep behaviours would be more compromised during high-hazard fire seasons. However, this notion would need to be confirmed with further research.

3.4 Targeted Interventions for Wildland Firefighting

The results of the current study suggest that suboptimal sleep behaviours may be contributing to fatigue and possibly increasing injury-risk. Overall, sleep in this sample was found to be below recommended thresholds and the presence of consecutive days of sleep debt is a concerning finding for both fire and non-fire work periods. It was found that shift characteristics such as long work hours, working later into the evening and starting shifts prior to 6 am were typically associated with worse sleep quantity and quality. However, even when looking at recovery opportunity time during evening periods, there was no apparent association with better sleep even though these longer periods of recovery time could be utilized for optimal sleep attainment. This would lead to an issue of potentially self-selected poor sleep behaviour (i.e., opting for late bed times regardless of start time). On the other hand, the sleeping conditions and environment may hinder sleep behaviour regardless of time offered for recovery between work shifts. This would be a targeted intervention and would need to be more understood in the context of these firefighters.

Not surprisingly, a prescription for reduced work hours would be a reasonable intervention in certain situations (i.e., Project Fire deployments over Initial Attack),

however this would need to be carefully implemented. Altering shift parameters to maximize homeostatic sleep processes and to mitigate fatigue may be a difficult intervention to implement due to the critical nature of the job and because the unpredictable fire behaviour can require extensive work hours.

Given the potential limitations on work schedule intervention, safety strategies could target recovery opportunity times (i.e., time between shifts) for both non-fire (pre-deployment preparation) and fire-line deployment, and could include: i) stress reduction techniques, ii) sleep hygiene practice and education, and iii) implementation of fatigue countermeasures with fatigue-risk management systems.

Firstly, given that poor sleep behaviour was observed regardless of recovery opportunity time allocated, this would indicate that the extra time to unwind and prepare for sleep periods did not prove beneficial in this sample. In this context, *affective rumination*, which is a psychophysiological arousal that is non-conducive to recovery, may be compromising sleep (Querstret & Cropley, 2012). Affective rumination can be caused by work-related stress, high workload, and inability to psychologically detach from work during non-work periods (Akerstedt et al., 2004; Querstret & Cropley, 2012). Although not directly measured in the current study, affective rumination may have factored into the poor sleep behaviour given that, while on fire-line deployment the non-work environment was not physically separable from the work environment for upwards of 14 days.

In order to combat affective rumination related to work, mindfulness-based stress reduction techniques and meditation training for improved sleep quality, task performance and psychological detachment from work have been recently explored

(Hulsheger et al., 2014; Hulsheger, Feinholdt, & Nubold, 2015; Querstret, Cropley & Fife-Schaw, 2016; Hafenbrack, 2017). It should be noted that this type of intervention is different than that of the mindful-leadership programs explored earlier (i.e., Lewis, 2013). To our knowledge these mindfulness-based interventions are non-existent in the wildland firefighting occupation.

Hulsheger and colleagues (2014) discuss the role of mindfulness in the context of recovery for promoting sleep quality and psychological detachment from work. Simply put, mindfulness is largely about paying attention to internal (i.e., thoughts) and external (i.e., sounds) stimuli (Brown, Ryan & Creswell, 2007, Hulsheger et al., 2014) with a nonjudgmental attitude, typically through meditation (not always required) (Dane, 2011; Hafenbrack, 2017). The result is self-regulation of thoughts and improved wellbeing in terms of situational awareness and acceptance (Howell, Digdon, & Buro, 2010), and fostering stress reduction and positive sleep behaviour. Hafenbrack (2017) highlights that on-the-spot mindfulness to reduce stress is effective under the following three prerequisite conditions; i) employees must be aware they are in a problem situation, ii) mindfulness intervention is readily available, and iii) employees must actually engage in the meditation. It is suggested that this technique be used in situations where critical decisions and alertness are not required and thus would be optimally used during non-work periods for wildland firefighters. Similarly, Querstret and colleagues (2016) have investigated the effectiveness of an internet-based mindfulness intervention (8-week online course) on various organizations associated with the University of Surrey as a low-cost initiative to improve occupational health and found that this intervention lowered fatigue and work-related rumination, as well as improved sleep quality. Furthermore,

reduced workplace injury and medical costs in an urban firefighter workplace have been linked to various stress management interventions and healthy lifestyle courses (Kuehl et al., 2013). This is a low-cost program that may be generalizable to other occupations, with the benefit of providing tools and strategies for workplace stress reduction and possible reduction of affective rumination. In general, the evidence regarding the effectiveness of mindfulness-based interventions in the workplace on improved sleep is still scarce (Winbush, Gross & Kreitzer, 2007; Hulsheger et al., 2014), but this avenue may be worth pursuing given the limitations on work-hour modification and sleeping arrangements in wildland firefighting. Interventions of this nature may provide low-cost tools for wildland firefighters to utilize in the field to aid in psychological detachment from work and improve sleep quality and duration.

Secondly, to our knowledge, no sleep hygiene programs have been explored and developed with wildland firefighters in any organization. Previous wildland firefighter sleep research (reviewed in Chapter 2) has discussed recommendations to optimize sleep behaviour, such as modified shift start times and better sleeping conditions (i.e., Vincent et al., 2016). With relatively recent findings regarding poor sleep behaviour in wildland firefighters (Gaskill & Ruby, 2004; Aisbett & Nichols, 2007; Vincent et al., 2016), including the current study, it is clear that sleep education programs and interventions to help firefighters obtain better sleep are warranted. Many interventions developed for occupational use have been holistic approaches to general worker health promotion (Feltner et al., 2016; Anger et al., 2015; Cooklin, Joss, Husser & Oldenburg, 2016; Poston, Haddock, Jahnke, Jitnarin & Day, 2013). However, these do not consider sleep

behaviour specifically. Understandably, few studies have targeted sleep hygiene, as this is a less explored topic in health and safety.

Sleep hygiene can include a range of factors, such as: avoiding stimulants prior to sleep periods, regular exercise, stress reduction and sleep timing regularity (Irish, Kline, Gunn, Buysse & Hall, 2015). Utilizing sleep hygiene factors, Steffen and colleagues (2015) report the outcome of a workplace healthy sleep program in which members of a worksite wellness center underwent an eight-week healthy sleep program (e.g., dealing with sleep problems and knowledge of sleep issues/tools for optimizing sleep) and reported a significant improvement in sleep behaviour post-intervention. Similarly, Burton and colleagues (2016) evaluated a financial services corporation-based sleep education program (webinars and intranet-based resources) and again found improved reporting of sleep in terms of duration and quality. In another study, Barger and colleagues (2016) determined the efficacy of a sleep program delivered to eight fire departments using three methodologies: expert-led, train-the-trainer, and online. They revealed that all programs were beneficial, but that expert-led program delivery was the best mode of knowledge dissemination in terms of participation rates. Furthermore, Sullivan and colleagues (2016) analyzed the impact of a sleep health education and sleep disorders screening program in urban firefighters on sleep and injury. Interestingly, self-reported sleep quantity/quality was not significantly different, but those who had the education and screening treatment were 24% less likely to file an injury.

In recent years, the topic of sleep hygiene education has been integrated into management education initiatives (Barnes, 2011; Caldwell, 2012; Barnes, Schouten, and van de Veen, 2016). Understandably, it has been proposed that managers and leaders of

organizations understand the importance of sleep on workplace safety and productivity and understand the negative performance consequences associated with sleep deprivation and/or disturbances in the workplace setting (Barnes, Schouten, & van de Veen, 2016). In the context of wildland firefighters, these sleep education programs could theoretically be tailored to the specific job demands and conditions encountered by these workers during fire-line deployments. However, these programs must be championed by managers and leaders in order to promote continuous awareness and education of sleep hygiene. Furthermore, collaboration between regional wildland firefighting agencies, including management, leaders and front-line workers, can facilitate the successful implementation of sleep hygiene education and interventions to reduce sleep-related fatigue as well as potential injury-risk.

Thirdly, fatigue countermeasures and fatigue risk management systems are being proposed to mitigate fatigue and aid in the development of a safe and educated organization. The main contributor to fatigue in the workplace is the disruption of sleep behaviour (circadian and homeostatic processes), which is typically from shift misalignment affecting the sleep-wake process (Williamson & Friswell, 2013; Satterfield & Van Dongen, 2013), resulting in reduced alertness (Lehrer, 2015; Satterfield & Van Dongen, 2013). It is well documented in the literature that reduced alertness, which can be objectively measured (a standard for measuring fatigue), is thought to cause attentional lapses and is suggested to be a key contributor to fatigue-related accidents (Lim & Dinges, 2008; Williamson et al., 2011; Satterfield & Van Dongen, 2013; Lehrer, 2015; Ferguson, Smith, Browne & Rockloff, 2016). Thus, fatigue countermeasures have been identified and tested in various occupational settings. Given the high prevalence of

poor sleep behaviour in the current study, these countermeasures could be implemented into wildland firefighting operations for optimal fatigue risk management.

Fatigue interventions are not ‘one-size fits all’ and any intervention needs to address the unique needs of the operation in question, balance overall cost strain and benefits, transition easily into the current operational framework and also be sustainable by encouraging active participation from all levels of the organization (Schutte, 2009; Schutte 2010; Williamson & Friswell, 2013; Phillips, 2016). From this perspective, current fatigue countermeasures could be tailored and implemented based on the needs and limitations of wildland firefighting operations.

Currently, the fatigue countermeasures most applicable to wildland firefighting would include proper sleep (i.e., conditions, hygiene, alertness management) (Dawson & McCulloch, 2005; Caldwell, Caldwell, & Schmidt, 2008; Williamson & Friswell, 2013; Satterfield & Van Dongen, 2013; Comperatore, Ng, & Carvalhais, 2015; Phillips, 2016), optimal shift scheduling (i.e., length, work hours, and timing of shift with respect to prior sleep-wake history) (Williamson & Friswell, 2013; Satterfield & Van Dongen, 2013; Comperatore, Ng, & Carvalhais, 2015; Phillips, 2016), and fatigue education/awareness programs (Schutte, 2010; Dawson, Mayger, Thomas & Thompson, 2015; Phillips, 2016). Not surprisingly, sleep remains at the core of these fatigue countermeasures and is therefore a core feature of all fatigue risk management systems (discussed below).

Fatigue countermeasure strategies have been proposed to be either preventive or operational (mitigating already present fatigue symptoms) (Satterfield & Van Dongen, 2013). Preventing fatigue involves sleep and sleep influencers, such as planned napping (Gillberg, Kecklund, Axelsson, & Akerstedt, 1996; Brooks & Lack, 2006; Purnell, Feyer

& Herbison, 2002), strategic melatonin use (Dijk & Lockley, 2002; Satterfield & Van Dongen, 2013), and other factors affecting sleep hygiene (e.g., diet and substance abuse) (Schutte, 2010; Barnes, Schouten, and van de Veen, 2016). Unfortunately, proper sleep is not always possible due to both work and non-work constraints, and hence operational countermeasures can be utilized, with proposed methods such as strategic caffeine administration (Snel & Lorist, 2011; Satterfield & Van Dongen, 2013), prescription stimulants (e.g., Modafinil – Caldwell & Caldwell, 2005; however ethical and legal considerations must be met (Caldwell, 2011)), and ergonomic adjustment of the sleep environment (e.g., noise, ambient temperature, light exposure, and use of a mattress) (McCallum et al., 2003; Comperatore, Ng, & Carvalhais, 2015; Vincent et al., 2016). These factors are important to consider in managing fatigue before it occurs as well as to mitigate fatigue when good sleep is not possible.

Earlier fatigue-risk management solutions would typically focus on prescription of work hours as a primary defense. However, this defense system is not always reasonable, particularly for safety-critical operations, as it restricts operational flexibility (Dawson & McCulloch, 2005). Thus multilayered models have surfaced with foundations based on the “Swiss cheese” model proposed by Reason (2000), indicating that occupational fatigue safety defenses have “holes” and when accidents occur it is due to the chain of events lining up these holes. Dawson and McCulloch (2005) developed a strong fatigue management system based on this theory, with multiple layers of defense preceding a fatigue-related accident and with prior sleep-wake situated at the core of this model (Figure 4).

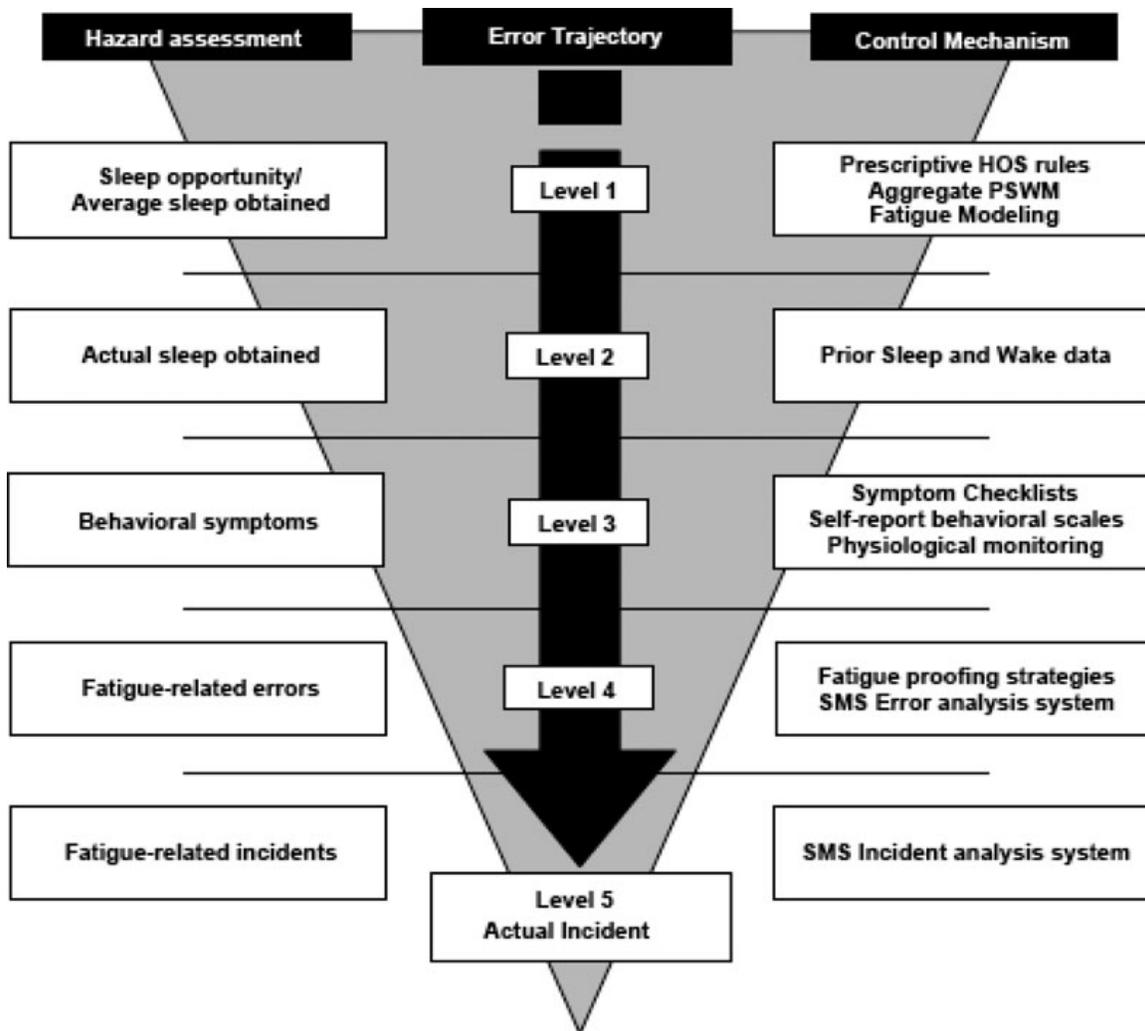


Figure 4: Fatigue risk management trajectory with the multilevel “Swiss cheese” model foundation, indicating prior sleep-wake history as the core of the error trajectory. Obtained from Sleep Medicine Reviews, vol. 9, Dawson, D., and McCulloch, K., Managing fatigue: It’s about sleep, p. 369, 2005, with permission from Elsevier.

However, research has inherently moved to more sophisticated approaches with attempts at predicting alertness via biomathematical models of fatigue, which is unsurprising due to the demand for automated and simple fatigue scoring sought by industry (Dawson Noy, Harma, Akerstedt, & Belenky, 2011). These systems attempt to predict fatigue-risk, in the context of reduced alertness, with that of prior sleep-wake behaviour, time of day

and shift timing/duration as components in model algorithms (Dawson et al., 2011; Lehrer, 2015). It is clear that operational strains (e.g., schedules) affecting sleep behaviour are at the core of these models and thus, a functional field-tested model could be of interest to future wildland firefighting operations.

In line with the current study, the Sleep, Activity, Fatigue and Task Effectiveness (SAFTE) biomathematical model, which uses actigraphy (or self-report) for sleep-wake periods and prior shift duration/timing to predict neurobehavioural performance (via predicting average psychomotor vigilance speed; an objective measure of fatigue (Hursh et al., 2004)), is considered one of the more advanced and holistic models to date, based on a review of the literature. However, depending on the type of work tasks being performed (e.g., monotonous or complex) or the type of work environment (e.g., stimulating versus calming), this prediction may or may not have the capacity to identify true performance on the task (Hursh et al., 2004). Still, the use of this type of model tends to be the direction in which fatigue management is currently trending (Dawson et al., 2011), and with increased use and research, the more valid, systematic and generalizable they will become. At the current time, few models are actually utilized in industry and many are too simplistic to incorporate into dynamic work environments (Dawson et al., 2011), and so this technology may not yet be reliable for detecting alertness, or fatigue, within a multidimensional safety-critical operation. It is stated that these models are “*not yet optimally tuned to map chronic or task-specific fatigue risk*” (Lehrer, 2015, p.195) as they do not account for inter-individual differences or internal/external factors influencing fatigue (e.g., *internal*-physiological function, demographics; *external*-task demands, environment). Furthermore, they lack empirical

data on actual intended use, effectiveness of fatigue-prediction, and how they may be further improved (Lehrer, 2015). However, if these models are used, even at the most basic level, to identify sleep opportunity and generate an average level of fatigue-related risk above specific organization-based thresholds (i.e., higher threshold for critical operations; Dawson and Zee, 2005; Dawson et al., 2011) for groups of employees, then they can be beneficial in fatigue management, if the limitations are acknowledged (see Dawson et al., 2011).

In this context, Andrew Lehrer (2015) proposes an integrated approach to current biomathematical fatigue models by adhering to the “Swiss cheese” model framework (Reason, 2000) in that fatigue defenses must be multilayered or holistic with several fatigue-risk factors, rather than just estimations of sleep and shift information, in order to effectively predict fatigue and injury risk. This integrated model has been termed the eight-state model (for complete review see Lehrer (2015)). Generally, the eight-state model includes internal factors (physiological drivers, performance traits/practices, health and wellness profiles and demographics) and external factors (schedule dynamics, task demands, socioeconomic dimension, environmental variables). To understand the complexity of this model relative to previous models, sleep (circadian effect and homeostatic pressure) would be classified under physiological drivers, representing one aspect of the eight-state model framework. It is known that fatigue is multidimensional and thus it is appropriate for models to become more complex in order to be valid, efficient and reliable tools for operational use (Lehrer, 2015). In the context of wildland firefighting, specifically automated and individualized devices would be of particular use and could help track fitness-for-duty based on sleep-wake history, shift dynamics, as well

as the other factors related to fatigue (i.e., Lehrer, 2015). However, as stated these models may be implemented at the most basic level to provide insight into possible alertness decrements, as long as they are used with the limitations acknowledged (i.e., not individualized and task-specific insensitivity).

3.5 Recommendations:

Based on the findings presented in the current study, it would be recommended to target sleep behaviour as a significant determinant of fatigue and to use a broad approach to engage and sensitize wildland firefighting management, leaders, and front-line workers. Suboptimal sleep and fatigue could be mitigated by: i) implementing sleep hygiene and fatigue-mitigation strategies (such as: tracking sleep-wake history with shift modification, mandatory sleep education sessions/training, injection of fatigue awareness within fire-line crew, etc.) that foster continuous and sustainable awareness that is integrated within the safety culture of this workplace setting, and ii) creating a safe climate for voicing fatigue and vigilance issues, which would be reinforced through educated and mindful leadership as well as continued reinforcement through actionable awareness (i.e., leading by example).

In terms of more specific recommendations, it would be suggested to i) monitor Initial Attack sleep-wake patterns along with shift timing and duration, and to limit consecutive extreme shifts to a few days at most to avoid serious performance deficits, ii) promote good sleep hygiene at the Base, with awareness of pre-deployment sleep debt as high-risk behaviour, iii) consider flexible shift start times while on fire deployment to avoid decreased sleep opportunities, whenever possible, and iv) intervene with sleep

conditions on fire-line deployment to promote optimal sleep, including avoidance of light, noise, and high or low temperatures, as well as optimizing sleep area (i.e., mattress, pillows, etc.).

3.6 Future Directions:

Certain aspects of this particular workplace were identified as being problematic in terms of sleep behaviour (i.e., shift duration, timing of shifts and type of work) and would be areas to target in future research. In terms of future direction, research could target:

1. Interventions for the *sleep environment* on fire-line deployments; this research would identify current conditions (i.e., temperature, noise, and lodgings) and then possible avenues for optimization, as well as analysis of these avenues. Ideally, it would be important to discern where self-selected poor sleep behaviour may be occurring more often versus when the work/sleep environment dictates the poor sleep behaviour. This separation may identify where either sleep hygiene/awareness versus when sleep environment modification may be warranted. Fatigue countermeasures and sleep hygiene techniques discussed earlier could be good starting points for this research.
2. Interventions for *sleep and fatigue education and awareness*; this participatory research could engage management, leaders and front-line workers to develop a tailored education program and conduct a program evaluation to determine the effects on safety climate and culture and on overall sleep and fatigue behaviour.

3. *Comprehensive analysis of sleep behaviour, fatigue and injury rate in this occupation.* This could take the form of a retrospective study to correlate sleep behaviour, fatigue perception and injury prevalence. Other variables of interest in this regard would include age and work experience in relation to sleep, fatigue and injury. It is well known that as we age, sleep behaviour tends to change and this could contribute to different trends in fatigue and injury-risk. Further, experience in the workplace may be a predictor of safer work behaviour and could be essential in understanding the dynamics of this particular workforce regarding sleep behaviour, fatigue and performance during fire line deployment. This type of research would enhance knowledge on safety-critical occupations by correlating sleep behaviour/fatigue and injury rates.

3.7 References:

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Appendices

Appendix A: Research Ethics Board Certificate

APPROVAL FOR CONDUCTING RESEARCH INVOLVING HUMAN SUBJECTS

Research Ethics Board – Laurentian University

This letter confirms that the research project identified below has successfully passed the ethics review by the Laurentian University Research Ethics Board (REB). Your ethics approval date, other milestone dates, and any special conditions for your project are indicated below.

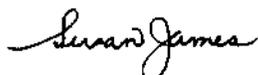
TYPE OF APPROVAL / New X / Modifications to project / Time extension	
Name of Principal Investigator and school/department	Ayden Robertson, Zach McGillis (SHK) Sandra Dorman, Céline Boudreau-Larivière (SHK)
Title of Project	A multi-disciplinary approach assessing factors contributing to fatigue, to mitigate injury in wildland fire-fighters
REB file number	2013-07-08
Date of original approval of project	August 18, 2013
Date of approval of project modifications or extension (if applicable)	
Final/Interim report due on	September 30, 2015
Conditions placed on project	Please add the LU toll free number for your contact - it is the same number as for the REB – you can add in your extension if you would like to differentiate it from the REB number. Final report due on September 30, 2015

During the course of your research, no deviations from, or changes to, the protocol, recruitment or consent forms may be initiated without prior written approval from the REB. If you wish to modify your research project, please refer to the Research Ethics website to complete the appropriate [REB form](#).

All projects must submit a report to REB at least once per year. If involvement with human participants continues for longer than one year (e.g. you have not completed the objectives of the study and have not yet terminated contact with the participants, except for feedback of final results to participants), you must request an extension using the appropriate [REB form](#).

In all cases, please ensure that your research complies with [Tri-Council Policy Statement \(TCPS\)](#). Also please quote your REB file number on all future correspondence with the REB office.

Congratulations and best of luck in conducting your research.



Susan James, Chair
Laurentian University Research Ethics Board

Appendix B: Supplementary Results; Recovery and Alertness

The following section provides supplemental information on morning and evening reaction time scores as well as evening reported recovery for fire deployments. These factors are analyzed according to: Consecutive Work Periods (Table 13), Shift Length (Table 14), Shift Start (Table 15) and Shift End (Table 16). These data were not included in the manuscript and thus presented in this section.

Table 13: PVT reaction time and self-reported recovery for fire deployment CWP.

Measure	CWP Category	N	Median	χ^2	Significance	Median – PF only
AM Reaction Time (ms)	1-3 days	21	371.0	$\chi^2=0.984$	<i>n.s.</i>	369.5
	4-7 days	25	373.0			370.5
	>7 days	26	365.5			365.5
PM Reaction Time (ms)	1-3 days	20	364.5	$\chi^2=0.579$	<i>n.s.</i>	358.0
	4-7 days	25	365.0			365.0
	>7 days	23	381.0			381.0
PM Reported Recovery (scale=16- 80)	1-3 days	30	51.5	$\chi^2=0.121$	<i>n.s.</i>	53.0
	4-7 days	46	52.5			53.0
	>7 days	42	51.5			51.0

CWP=Consecutive Work Period, N=sample size, PF=Project Fire, AM=morning test, PM=evening test, χ^2 =Chi Square, n.s.=not significant
Data displayed in the last column is for Project Fire data only.

Table 14: PVT reaction time and self-reported recovery for fire deployment shift length analysis.

Measure	Shift Length Category	N	Median	χ^2	Significance	Median – PF only
AM Reaction Time (ms)	<12 hours	9	389.0	$\chi^2=3.226$	n.s.	388.0
	12-13 hours	43	368.0			368.0
	>13 hours	20	371.0			371.0
PM Reaction Time (ms)	<12 hours	6	371.5	$\chi^2=0.385$	n.s.	392.0
	12-13 hours	45	377.0			377.0
	>13 hours	17	363.0			362.5
PM Reported Recovery (16-80)	<12 hours	16	50.5	$\chi^2=1.885$	n.s.	52.0
	12-13 hours	69	52.0			52.5
	>13 hours	30	53.0			53.0

N=sample size, PF=Project Fire, AM=morning test, PM=evening test, χ^2 =Chi Square, n.s.=not significant
Data displayed in the last column is for Project Fire data only.

Table 15: PVT reaction time and self-reported recovery for fire deployment shift start analysis.

Measure	Shift Start Category	N	Median	χ^2	Significance	Median – PF only
AM Reaction Time (ms)	5-6 am	11	383.0	$\chi^2=9.346$	$p=0.025$	371.0
	6-7 am	32	371.5			371.0
	7-8 am*	23	364.0			364.0
	>8 am*	6	412.0			395.5
PM Reaction Time (ms)	5-6 am	12	363.5	$\chi^2=8.305$	$p=0.040$	363.5
	6-7 am*	29	377.0			377.0
	7-8 am	23	381.0			381.0
	>8 am*	4	318.5			318.0
PM Reported Recovery (16-80)	5-6 am	21	53.0	$\chi^2=11.561$	$p=0.009$	53.0
	6-7 am*	42	49.0			49.0 ⁺
	7-8 am*	47	57.0			57.0 ⁺
	>8 am	8	50.5			44.5

N=sample size, PF=Project Fire, AM=morning test, PM=evening test, χ^2 =Chi Square, *Indicates significant differences for Fire analysis
⁺Indicates significant differences for PF analysis
Data displayed in the last column is for Project Fire data only.

Brief Summary:

AM Reaction Time: significant differences should not be expanded any further provided the difference in sample size as noted above.

PM Reaction Time: significant differences should not be expanded any further provided the difference in sample size as noted above.

PM Reported Recovery: significant differences were identified between the 6-7 am shift start and 7-8 am shift start for all fire data combined. The scores are still both within moderate reported recovery levels regardless of the statistical differences. No clear pattern is discernible. PF only analysis revealed similar results provided that most of the data for both analyses were PF data ($\chi^2(3) = 14.874, p = .002$).

Table 16: PVT reaction time and reported recovery for fire deployment shift end analysis.

Measure	Shift End Category	N	Median	χ^2	Significance	Median – PF only
AM Reaction Time (ms)	≤7 pm	18	383.0	$\chi^2=4.329$	n.s.	383.0
	7-8 pm	28	365.5			363.5
	8-9 pm	17	373.0			372.5
	>9 pm	9	383.0			358.0
PM Reaction Time (ms)	≤7 pm	18	376.0	$\chi^2=4.808$	n.s.	376.0
	7-8 pm	30	382.5			383.0
	8-9 pm	12	327.0			328.0
	>9 pm	8	357.0			356.0
PM Reported Recovery (16-80)	≤7 pm*	27	47.0	$\chi^2=35.697$	p=0.000	47.0 ⁺
	7-8 pm*	44	57.0			57.0 ⁺
	8-9 pm*	27	49.0			49.0 ⁺
	>9 pm*	17	48.0			42.0 ⁺

N=sample size, PF=Project Fire, AM=morning test, PM=evening test, χ^2 =Chi Square,
 *Indicates significant differences for Fire analysis
⁺Indicates significant differences for PF analysis
 Data displayed in the last column is for Project Fire data only.

Brief Summary:

PM Reported Recovery: significant differences were identified between the 7-8 pm shift end time and all other shift end times (≤7 pm and 7-8 pm (p= .000), 7-8 pm and 8-9 pm (p= .000), and 7-8 pm and > 9 pm (p= .002)). There is a trend (excluding the early shift end) indicating that later shift end times impeded perceived recovery.

For PF analysis, similar results were indicated with significant differences identified between the 7-8 pm shift end time and all other shift end times (≤7 pm and 7-8 pm (p= .000), 7-8 pm and 8-9 pm (p= .000), and 7-8 pm and > 9 pm (p= .000)); ($\chi^2(3) = 43.495, p = .000$).