

**A novel approach to understanding cognitive fatigue and sleep deprivation in Canadian
wildland firefighters**

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A novel approach to understanding cognitive fatigue and sleep deprivation in Canadian wildland firefighters

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Abstract

Wildland firefighters are subject to prolonged and irregular shifts which can have detrimental effects on sleep and increase fatigue. Fatigue and sleep deprivation can reduce information-processing resulting in slower reaction times, poor decision-making, situational awareness, and hazard recognition. At present, current research on fatigue and sleep in firefighters is lacking and limited to laboratory studies. The main goal of this study was to provide insight and understanding into the impact the current wildland firefighting schedule has on the emergence of cognitive fatigue in an effort to guide future interventions that aim to improve occupational health and safety amongst wildland firefighters. This study aimed to objectively and subjectively measure sleep quantity, quality and fatigue throughout a 17-day firefighting deployment amongst firefighters in British Columbia, Canada during the fire season. During the deployment, 39 firefighters' sleep was assessed using wrist actigraphy and subjective questionnaires. Fatigue was assessed using a cognitive performance test known as the psychomotor vigilance test. Our analysis revealed that sleep quantity was suboptimal during both fire and non-fire days. Total sleep time and sleep efficiency was less on fire days compared to non-fire days. Firefighters reported being significantly sleepier towards the end of their 14-day deployment. Our results also demonstrated that firefighters continued to report high levels of sleepiness and poor quality of sleep throughout their rest days immediately following their work deployment.

Firefighters performed significantly poorer on cognitive performance tests and reported significantly higher levels of fatigue and decreased alertness near the end of their 14-day work deployment. Our results provide valuable insight into the development of fatigue across a 14-day work schedule and into the 3-day rest period for wildland firefighters. Our study highlights that

firefighters may still be fatigued, sleep deprived and inadequately rested prior to their work deployment. Fire agencies and researchers should target future interventions and studies that aim to improve and manage sleep and fatigue during firefighters' work and rest days.

Lay Summary

The aim of the proposed research study was to improve our understanding of the relationship between occupational risk factors of fatigue and sleep deprivation in wildland firefighters.

Firefighters continue to have a disproportionately high level of workplace injuries owing to a physically and psychologically demanding occupation in harsh working environments that can influence cognitive impairment. Given the high risks associated with fighting fires and the desire to maximize worker safety, we worked with the B.C. Wildfire Service (BCWS) to assess and describe fatigue amongst firefighters in a novel 17-day field-based study. This study made two important contributions. First, it provided an understanding of the relationship between determinants of fatigue and cognitive impairment in a forest firefighting environment in Canada. Second, the results from this study have the potential to guide future interventions to reduce fatigue and improve occupational health and safety in the workplace.

Preface

The research presented in chapter 3 was conducted at the Cougar Creek Fire, Boston Bar, BC and the Teslinden Fire, Oliver, BC using methods approved by UBC's Clinical Research Ethics Board (H15-01191). A manuscript detailing this work is in the process of preparation. This work was conducted in collaboration with Dr. Darren Warburton, Dr. Shannon Bredin, Dr. Hugh Davies, Todd Nessman, Bradley Hansen, Leah Meanwell, Ben Hives, Amy Sparrow and Matt Godbeer. Dr. Warburton was the senior investigator. I was responsible for all major areas of study design, concept formation, data collection and data analysis. Todd Nessman was involved in recruiting the BCWS firefighting teams and coordinating the research locations. Dr. Bredin was involved with study design and concept formation. Dr. Davies was involved with study design and concept formation. Bradley Hansen, Leah Meanwell, Ben Hives, Amy Sparrow and Matt Godbeer were involved in data collection.

The research presented in chapter 4 was conducted at the Cougar Creek Fire, Boston Bar, BC and the Teslinden Fire, Oliver, BC using methods approved by UBC's Clinical Research Ethics Board (H15-01191). A manuscript detailing this work is in the process of preparation. This work was conducted in collaboration with Dr. Darren Warburton, Dr. Shannon Bredin, Dr. Hugh Davies, Todd Nessman, Bradley Hansen, Leah Meanwell, Ben Hives, Amy Sparrow and Matt Godbeer. Dr. Warburton was the senior investigator. I was responsible for all major areas of study design, concept formation, data collection and data analysis. Todd Nessman was involved in recruiting the BCWS firefighting teams and coordinating the research locations. Dr. Bredin was involved with study design and concept formation. Dr. Davies was involved with study design and concept formation. Bradley Hansen, Leah Meanwell, Ben Hives, Amy Sparrow and

Matt Godbeer were involved in data collection.

The research presented in chapter 5 was conducted at the Cougar Creek Fire, Boston Bar, BC and the Teslinden Fire, Oliver, BC using methods approved by UBC's Clinical Research Ethics Board (H15-01191). Data analysis occurred while in Boston, Massachusetts, USA with Circadian Software. A manuscript detailing this work is in the process of preparation. This work was conducted in collaboration with Dr. Darren Warburton, Dr. Shannon Bredin, Dr. Hugh Davies, Todd Nessman, Bradley Hansen, Leah Meanwell, Ben Hives, Amy Sparrow, Matt Godbeer, and Cameron Kenyon. Dr. Warburton was the senior investigator. I was responsible for all major areas of study design, concept formation, data collection and data analysis. Todd Nessman was involved in recruiting the BCWS firefighting teams and coordinating the research locations. Dr. Bredin was involved with study design and concept formation. Dr. Davies was involved with study design and concept formation. Bradley Hansen, Leah Meanwell, Ben Hives, Amy Sparrow and Matt Godbeer were involved in data collection. Cameron Kenyon was involved with analysis support.

The research and results of this study are presented in two separate chapters. In chapter three the results from the fatigue measures are presented and in chapter four the results of the sleep measures are presented.

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List of Abbreviations

BAC	Blood Alcohol Concentration
BCWS	British Columbia Wildfire Service
B.C.	British Columbia
CAS	Circadian Alertness Simulator
FF	Firefighter
FRMS	Fatigue Risk Management System
IA	Initial Attack
MT	Management Team
OHS	Occupational Health and Safety
PSG	Polysomnography
PVT	Psychomotor Vigilance Test
RT	Reaction Time
SCN	Suprachiasmatic Nuclei
SE	Sleep Efficiency
SL	Sleep Latency
TST	Total Sleep Time
VAS	Visual Analogue Scale
WASO	Wake After Sleep Onset

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1700 days later and the list is long....

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Dedication

To my brothers, sister, mom and dad.

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and all my career endeavors

Chapter 1: Introduction

1.1 Wildfires in British Columbia

The province of British Columbia (B.C.) is one of the most diverse geographical regions in all of Canada, spectacular rich forests and wildlands spread over nearly 94 million hectares of rugged coastline, mountainous terrain and rolling grasslands (Province of British Columbia, 2018a). However, each year nearly 2000 wildfires will burn in B.C. (Province of British Columbia, 2018a). Wildfires destroy millions of acres of land, cost billions of dollars in suppression and threaten communities across Canada (Province of British Columbia, 2018a). A serious concern to fire agencies both in B.C. and globally is that climate change will increase wildfire frequency, duration, and severity of large and uncontrollable wildland fires (Westerling et al., 2006; Albertson et al., 2010; Province of British Columbia, 2018a).

1.2 Structure and Overview of Firefighting in British Columbia

Since its formation in 1912, the British Columbia Wildfire Service (BCWS) has been tasked with managing wildfires in the province of B.C. (Province of British Columbia, 2018b). The BCWS employees over 1600 people, which include seasonal firefighters and support staff, as well as full time officers, fire managers and senior leaders in wildfire management (Province of British Columbia, 2018b).

The province of British Columbia is divided into 6 regional fire centers, as seen in Figure 1. These fire centers are: 1) Cariboo, 2) Coastal, 3) Kamloops, 4) Northwest, 5) Prince George, and 6) Southeast. Each fire center is responsible for wildfire management within its boundaries (Province of British Columbia, 2018c). The Provincial Wildfire Coordination Centre (Kamloops) and the BCWS Headquarters (Victoria) oversee and coordinate all province-wide wildfire functions (Province of British Columbia, 2018c).



Figure 1: Regional Fire Centers in British Columbia. By permission from BCWS

There are currently four different types of fire crews within the BCWS:

- 1- Initial attack (IA) crews: These crews operate as part of a 3-person crew and usually are the first on scene to a new wildfire. They are responsible for initiating fire suppression efforts which may include setting up water pumps, hose suppression, and digging fire guards. The majority of fires in B.C. are responded to by IA crews.

- 2- Rapattack crews- With difficult to access fires for vehicles or landing areas for helicopters, a rapattack crew will rappel from a helicopter adjacent to the fire to take immediate action. There are 12 rapattack crews made up of 3 firefighters each in B.C.

- 3- Parattack crews- Parattack crews parachute from fixed-wing aircraft, this allows for more personnel and equipment to be deployed. Parattack crews range from 3-12 firefighters each.

- 4- Unit crews- When fires grow to a size that requires firefighters beyond the initial suppression, unit crews consisting of 20 firefighters will be deployed. Unit crews establish pump and hose lines, dig fire guards, and remove and burn fuel from the fire's path. For fires which require a high level of response for extended period of time, firefighters will stay at temporary camps. These fire deployments are known as project fires. Currently there are nearly 30 unit crews across the 6 fire centers in B.C.

The BCWS has nearly 1,100 firefighters who respond to fires from April to October each year across B.C. and Canada (Province of British Columbia, 2018c). Wildland firefighters in B.C. are typically seasonal employees, many of which are university students (Province of British Columbia, 2018c). Firefighters in B.C. are physically fit, highly trained and skilled individuals who are considered some of the best firefighters in the world (Province of British Columbia, 2018c). In order to be considered for a firefighting position individuals need to successfully complete the WFX-FIT (Province of British Columbia, 2018c; Gumieniak et al., 2018). The WFX-FIT is valid job-related physical performance standard used to determine whether an individual possesses the physical capabilities to meet the rigorous demands while fighting wildland fires (Gumieniak et al., 2018).

Wildland firefighting duties largely depends on the unit the firefighter is assigned to. Initial attack crews are responsible for initiating fire suppression efforts and fire duties usually involves high intensity work (Rodriguez-Marroyo et al., 2011; McGillis et al., 2017). This work may include water hose suppression, falling trees for helicopter pads, digging fire lines and setting up base camp (Province of British Columbia, 2018c). When a large fire requires more extensive fire management, as mentioned previously, it is known as a project fire (Province of British Columbia, 2018c). The level of work is less physically intense during a project fire and firefighters usually spend their days establishing pump and hose lines, digging fire guards, extinguishing hot spots (Province of British Columbia, 2018c).

1.2.1 B.C. Firefighter Schedules and Deployments

Any BCWS employee, or temporary statutory hire employee, involved in fireline and support operations can currently work up to a maximum of 14 consecutive duty days, or 17 cumulative duty days in a 27/28-day period (Province of British Columbia, 2018c). Duty days includes all days where overtime is incurred. Minimum rest requirements are either: 1) 3 days off, 2) 2 days off + 2 regular days. A regular day is considered a day of regularly scheduled work with no standby or overtime. No standby or fireline duties are allowed until rest requirements are met. All employees are required to have a minimum of one of the following in a 31-day period: 1) 3 days off and at least 2 of these days must be consecutive, 2) 2 days off + 2 regular days consecutively.

Fire deployments will vary depending on the severity of the fire. Confronted with an average of 2,000 wildfires each year, highly trained crews are successful in containing 94% of all wildfires in B.C. by 10am the following day (Province of British Columbia, 2018b). However, when larger fires threaten public safety and property or grow beyond initial attack resources, temporary fire camps are constructed. During project fires it is common for fire crews to work 12-16 hours a day for up to 14 consecutive days (Province of British Columbia, 2018c).

At each project fire, in addition to firefighters', the BCWS will also assemble a management team (MT). These management teams are made up of senior BCWS staff, foresters, air attack specialists, pay-roll clerks and fire operation specialists all with previous firefighting experience (Province of British Columbia, 2018b). Management teams must also follow the operational

work standards listed above (Province of British Columbia, 2018b). The BCWS MT's are tasked with not only coordinating and organizing all fire operations but are responsible for the health and safety of all individuals at the project fire as well as the surrounding public.

1.2.2 Risks and Injury Rates in Wildland Firefighting

Wildland firefighters in B.C. and around the world face a number of occupational and environmental risks in their daily course of work (Aisbett et al., 2012; Britton et al., 2013; Purchio, 2017). These risks include extended and irregular shifts, restricted and disrupted sleep, smoke inhalation, high ambient temperatures, and physical and mental stress (Cater et al., 2007; Aisbett et al., 2012; Vincent et al., 2016; McGillis et al., 2017). This routine exposure to a myriad of stressors for up to 14 consecutive days and volatile working environment make firefighters highly vulnerable to fatigue and fatigue related injuries (Aisbett et al., 2012; Britton et al., 2013; Purchio, 2017; McGillis et al., 2017). Although wildland firefighters have an increased risk to injury owing to a physically and psychologically demanding occupation, few studies have been published on injuries related to fatigue in wildland firefighters (Britton et al., 2013; McGillis et al., 2017).

Workplace accidents in which fatigue is a likely factor are often difficult to investigate and currently many organizations, including the BCWS, do not have a protocol in place to investigate whether common firefighter injuries such as slips/trips/falls and overexertion can be attributable to fatigue. A study conducted by Britton et al. (2013) looked at non-fatal injuries amongst US wildland firefighters from 2003 to 2007 and suggested that slips/trips/falls were the leading

cause of injury. More recently, Purchio (2017) demonstrated that sprains/strains accounted for 40% of injuries amongst 250 US firefighters between 2012-2017. Research has demonstrated that fatigue and sleep deprivation can be a contributing factor to decreased postural control and falls, and therefore may be playing an important role in these mechanisms of injury amongst firefighters (Gomez et al., 2008).

In B.C., and across Canada, data on firefighting injuries remains limited (McGillis et al., 2017). During the 2013 fire season in B.C. there were 144 reported injuries, of those 67 (46%) were reported as a strain/overexertion injuries (Province of British Columbia, 2018d). Of more serious accidents in 2013 where time off was required, strain and overexertion accounted for 55% of all B.C. firefighter injuries (Province of British Columbia, 2018d). Langlois (2012) measured the health and safety in Aboriginal firefighting crews in B.C. and identified overexertion and strain as the second most common type of injury amongst B.C. firefighters, second only to falls. Given the lack of available data on injuries amongst B.C. forest firefighters, Langlois conducted a review of WorkSafeBC statistics from similar emergency occupations (firefighters, police, and search and rescue) and demonstrated again that overexertion and strain were the leading cause of injury, days lost, and claim costs in the province of BC (Langlois, 2012).

In a 5-year period (2008-2012) the BCWS's lost time injury rate was approximately 3.5 persons per 100 workers (Province of British Columbia, 2018d). This is higher in comparison to the rest of BC, 2.3 persons per 100 workers, but lower than the average amongst Ontario firefighters, 4.46 persons per 100 workers (WorkSafeBC, 2015; Workplace Safety and Insurance Board Ontario, 2018). It is evident overexertion and strain injuries are common in forest firefighters

(Province of British Columbia, 2018d; Langlois, 2012; Britton et al., 2013; Purchio, 2017), yet the role of fatigue is undetermined and very few studies have measured fatigue amongst firefighting in the field (Vincent et al., 2016; Smith et al., 2016; McGillis et al., 2017).

1.3 Defining Fatigue

Fatigue is a common, almost universal feature of modern life that affects all humans bound by the laws of physiology (Williamson et al., 2011). Fatigue can be defined as a physiological state of diminished mental and physical performance capacity caused by sleep deprivation or inadequate rest from prolonged work or activities that can impair a worker's alertness and ability to safely operate and perform their duties (Lerman et al., 2012; Gander et al., 2011). The literature distinguishes between acute and chronic fatigue (Dawson et al. 2011; Gander et al. 2011). Acute fatigue will occur when there is inadequate time to rest and recover from a work period (Dawson et al. 2011; Gander et al. 2011). Chronic fatigue occurs when there is insufficient recovery from acute fatigue over time (Dawson et al. 2011; Gander et al. 2011). Fatigue can be further differentiated into physical and mental (cognitive) fatigue (Dawson et al. 2011; Satterfield & Van Dongen, 2013). Physical fatigue is a loss of maximal force-generating capacity during muscular activity which can be brought on by high-energy consumption (Shen et al., 2006). Whereas cognitive fatigue is a state of weariness related to reduced motivation (Shen et al., 2006). In occupational settings, cognitive fatigue usually results from irregular work schedules and work demands (Satterfield & Van Dongen, 2013). The focus of this research is on cognitive fatigue.

In some literature, cognitive fatigue is referred to as sleepiness (Lerman et al., 2012; Satterfield & Van Dongen, 2013), however, sleepiness and fatigue are actually two different states.

Sleepiness is the tendency to fall asleep and fatigue is the body's response to sleep loss or to prolonged physical or mental exertion (Lerman et al., 2012). For instance, fatigue may be reduced by sedentary activity or rest without sleeping, whereas sleepiness and the propensity to sleep would be exacerbated by sedentary activity or rest (Akerstedt & Wright, 2009). It is important to distinguish between the two.

Fatigue is a complex interaction of physiological, cognitive and emotional factors (Satterfield & Van Dongen, 2013). An extensive body of scientific research over the past 30 years has established that multiple factors interact to determine the state of physiological alertness of an individual at any moment in time, for instance when a workplace accident occurs (Durmer & Dinges, 2009; Lerman et al., 2012; Williamson & Friswell, 2013). An exhaustive discussion of all these factors is beyond the scope of this paper but the factors of fatigue are listed below (Lerman et al., 2012):

- 1) Length of prior wakefulness (homeostatic pressure for sleep)
- 2) Prior sleep-wake history
 - a. Duration of the most recent consolidated sleep period
 - b. Quality of sleep in the most recent sleep period
 - c. Cumulative effects of the pattern of sleep and wakefulness over the last week
- 3) Time of day according to the individuals own circadian phase

- 4) Time on task
- 5) Workload (level of physical and mental stimulation of the required task)
- 6) Environmental factors and stimulation (light, noise, temperature)
- 7) Age and underlying medical conditions

Understanding the factors that interact to cause fatigue will assist fire agencies in managing the occupational risks of fatigue in the workplace.

1.4 Identifying Fatigue as an Occupational Hazard

Fatigue is an increasing health and safety problem in our society (Williamson et al., 2011; Dinges, 1995; Rosekind et al., 2010). Fatigue has been implicated as a contributing factor in many occupational accidents and injuries as people who are fatigued are less likely to perform safe actions in the workplace (Dinges, 1995; Philip et al., 2001; Williamson et al., 2011).

Cognitive fatigue degrades reaction time, impairs judgment, memory and vigilance, reduces attention span, and increases distractibility (Dinges, 1995; Durmer & Dinges, 2009; Williamson & Friswell, 2013). Fatigue raises the risk of attentional failures, sleep attacks, falling asleep at the wheel and motor vehicle crashes (Anderson and Horne, 2006; Durmer & Dinges, 2009; Williamson et al., 2011). Cognitive fatigue has further been shown to impact decision making and hazard recognition (Dinges, 1995; Lerman et al., 2012) which may have serious implications in safety-critical environments such as firefighting.

The consequences of fatigue in real-world settings have been widely documented with increased accident rates, higher operating costs and increased worker turnover (Dinges, 1995; Dembe et al., 2005; Rosekind et al., 2010; Williamson et al., 2011). In fact, fatigue and sleep deprivation costs US businesses an estimated \$150 billion per year in absenteeism, workplace accidents, and lost productivity (Institute of Medicine, 2006). These consequences are particularly evident in operations that conduct shift work (Akerstedt & Wright, 2009; Williamson et al., 2011; Wright et al., 2013; Short et al., 2015). Traditionally in an occupational setting, shift-work is defined as work that occurs outside 7 am and 6 pm or work that includes extended shifts, >8 hours or >7 consecutive days (Lerman et al., 2012). Shift workers are at an increased risk of neurocognitive deficits (decrease reaction times and alertness) and workplace accidents (Folkard & Akerstedt, 2004; Akerstedt & Wright, 2009; Williamson et al., 2011).

The development of fatigue in the workplace is multifactorial and complex (Lerman et al., 2012; Williamson & Friswell, 2013). For management, workplace fatigue can be a difficult operational challenge to manage compared to many other hazards since it is influenced by factors that often extend beyond the workplace and control of the employer (Lerman et al., 2012). A direct link between fatigue and a workplace accident is often difficult to demonstrate due to these many casual factors (Satterfield & Van Dongen, 2013). It is important that we continue to understand and identify the interaction of factors that influence and contribute to fatigue in the workplace to ensure the safety and well-being of workers.

1.5 Fatigue in Wildland Firefighting

Owing to a physically and psychologically demanding occupation, irregular work schedule, harsh environmental conditions, and disrupted sleep patterns, fatigue is a serious occupational hazard amongst wildland firefighters (Aisbett et al., 2012; Cater et al., 2007; Vincent et al., 2016). Wildland firefighters continue to have a disproportionate amount of workplace injuries in which fatigue is a likely factor (Britton et al., 2013; Purchio, 2017).

Firefighters in B.C. routinely have lengthy work weeks (>100 hours), lengthy work days (>12 hours) and regularly work 14 consecutive shifts. Working such extended shifts with little rest between work periods has resulted in reduced opportunity for wildland firefighters to obtain adequate sleep (Gaskill and Ruby, 2004; Cater et al., 2007; Vincent et al., 2016; McGillis et al., 2017). Studies from Australia (Cater et al., 2007; Vincent et al., 2016), US (Gaskill and Ruby, 2004), and Canada (McGillis et al., 2017) have all demonstrated that firefighters obtain between 3-7 hours of sleep a night during wildfire deployments. Firefighters also are expected to sleep in temporary fire camps that are smoky, hot, and loud and these factors will impact the quality of their sleep and increase their risk of developing cognitive fatigue (Aisbett et al., 2012).

Prolonged work following truncated sleep is associated with compounded degradations in cognitive performance (Ferguson et al., 2011; Smith et al., 2016). Firefighting involves a large cognitive demand including assessing emergency situation scenarios, executing critical decisions, situational awareness of surroundings and hazards and making split second decisions in extreme and unpredictable fire situations (Ferguson et al., 2011; Williams-Bell et al., 2017).

Cognitive fatigue may have serious consequences to firefighter's safety during deployment (Vincent et al., 2018). At present, current research on cognitive fatigue in wildland firefighters is lacking (Vincent et al., 2018). Research is often limited to laboratory studies (Ferguson et al., 2016; Smith et al., 2016) and to our knowledge only one study has been conducted in the field (McGillis et al., 2017). Insightful data for fire agencies on the development of cognitive fatigue is needed. This is particularly salient for Canada where firefighters routinely work upwards of 16 hours a day for 14 consecutive days and fatigue is a serious occupational risk.

1.6 Measuring Fatigue in the Workplace

Fatigue is an area of major occupational concern but can often be difficult to measure in the field given that it changes as function of time and is experienced and reported differently amongst individuals (Williamson et al., 2011; De Vries et al., 2003; Satterfield & Van Dongen, 2013). There is no standard way to assess fatigue, however fatigue should be measured objectively as well as subjectively (De Vries et al., 2003; Ferguson et al., 2016; Lerman et al., 2012). For instance, when objective measures of performance decrease, subjectively people should identify that they feel tired or fatigued (Lerman et al., 2012). Contrary, fatigued individuals are poor at assessing their own levels of fatigue with subjective reports and therefore objective measures are important (De Vries et al., 2003; Lerman et al., 2012). At current, neurobehavioral assays, such as the Psychomotor Vigilance Test (PVT) are the gold standard objective measure of cognitive performance (Ferguson et al., 2016; Basner et al., 2011). Subjective ways to assess fatigue include questionnaires and visual analogue scales (VAS).

1.6.1 Objective Fatigue Measures

The PVT, a simple reaction time (RT) test, is the most widely used performance measure in studies of sleep loss and fatigue in the field and has consistently been shown to be sensitive to increasingly levels of fatigue (Ferguson et al., 2016; Lamond et al., 2005). The PVT stimuli occur at random intervals and therefore measures vigilant attention (Basner et al., 2011). The PVT is more than just a simple RT as it relies on a stimulus and RT but also depends on sampling many responses to stimuli that appear at random inter-stimulus intervals (ISI) over a period of 10 minutes, which represent the vigilance aspect of the test (Basner et al., 2011). While longer tests are commonly used in the laboratory, validated 5-minute versions are often used during time constraints and have been found to be as sensitive to fatigue as the full version (Lamond et al., 2005). The two PVT performance metrics used in this study are number of lapses (RT >355ms) (Basner et al., 2011) and the median RT (milliseconds) of the trial (Lamond et al., 2005) as they are the most widely published PVT metrics.

1.6.2 Subjective Fatigue Measures

It is important to assess subjective levels of fatigue in occupational settings as they have been shown to reliably signal elevated fatigue before performance is impaired to the point of error (Ferguson et al., 2016). Considerable research has gone into single item visual analogue scales (VAS) to ensure they are highly reliable in capturing the subjective nature of fatigue (Lee et al., 1991). Visual analogue scales are easy to administer, easy for participants to see and use few words to minimize the possibility of different interpretations with little bias. Visual analogue

scales are a blank 100-mm line which begin with a question, “mark with a vertical line how Fatigued you feel right now”, this will be anchored with, “not at all fatigued” (0), to “extremely fatigued” (100). An advantage of using the VAS is that the data is obtained as continuous intervals, therefore can be normally distributed (Lee et al., 1991).

1.7 What is Sleep?

Sleep is a naturally occurring basic requirement and restorative behaviour for all living things. Sleep serves critical roles in brain functions including neurobehavioural, cognitive and safety related performance (Van Dongen et al., 2003; Belenky et al., 2003; Lim and Dinges, 2010), memory consolidation (Tononi & Cirelli, 2014), mood regulation (Minkel et al., 2012), nociception (Edwards et al., 2008) and clearance of brain metabolites (Mendelsohn and Larrick, 2013). Sleep is also critically involved in systematic physiology, including metabolism (Magee & Hale, 2012), appetite regulation (Spiegel et al., 2004), immune and hormone function (Prather et al., 2012) and cardiovascular systems (Yeo et al., 2013). The sleep-wake cycle is regulated in the body by a two-process model of sleep regulation (Van Dongen & Dinges, 2003; Durmer & Dinges, 2005). The two processes in the model, the circadian process (process C) and the homeostatic process (process S), interact to determine the timing and quality of sleep and the stability of waking neurocognitive function (Van Dongen & Dinges, 2003; Durmer & Dinges, 2005; Akerstedt & Wright, 2009).

Process C is driven by the brains endogenous biological clock located in the Suprachiasmatic Nuclei (SCN) of the hypothalamus (Van Dongen & Dinges, 2003). The SCN is synchronized to

the day/night cycle through external clues such as light exposure, body temperature, cortisol, and melatonin (Czeisler & Gooley, 2007). This endogenous circadian clock is a major determinant of the timing and internal architecture of sleep in humans (Khalsa et al., 2002; Dijk and Lockley, 2002). From a circadian perspective, cognition and performance is optimal during the internal biological day and sleep is optimal during the internal biological night (Akerstedt & Wright, 2009).

Process S represents the pressure for sleep that increases during wakefulness (Durmer & Dinges, 2005; Boivin & Boudreau, 2014). When this pressure increases above a certain threshold, sleep is triggered (Durmer & Dinges, 2005). After sleep is achieved, this pressure dissipates exponentially (Durmer & Dinges, 2005). Higher homeostatic sleep drive results in impaired cognition, increased sleepiness and increased propensity for sleep (Van Dongen & Dinges, 2003; Akerstedt & Wright, 2009).

1.8 Consequences of Inadequate Sleep

Fatigue is biologically regulated over time as a function of the two primary biological processes of sleep, the homeostatic and circadian process (Satterfield & Van Dongen, 2013). The principal cause underlying operational risks due to fatigue is a misalignment of these neurobiological processes (Satterfield & Van Dongen, 2013; Durmer & Dinges; 2005). When misalignment occurs, fatigue can have serious performance decrements and cognitive deterioration during tasks of sustained attention or vigilance (Satterfield & Van Dongen, 2013).

Without sleep, alertness and neurocognitive performance exhibit a steady deterioration (Czeisler & Gooley, 2007). Spontaneous sleepiness and the ability to sleep vary markedly with circadian phase and biological time of day and interact with the homeostatic process to regulate sleep propensity, daytime alertness and neurocognitive performance (Van Dongen & Dinges, 2003; Durmer & Dinges, 2005; Czeisler & Gooley, 2007). Multiple factors influence the ability to sustain effective waking neurocognitive performance (Van Dongen et al., 2003; Lim & Dinges, 2008; Scheer et al., 2008). These include biological time of day, the length of prior wakefulness, nightly sleep duration, and the time of the last sleep episode (Van Dongen et al., 2003; Lim & Dinges, 2008; Lerman et al., 2012; Boivin & Boudreau, 2014). The effect of these four factors can create an imposing biological force that can overpower a worker's ability to remain awake and attentive while at work (Van Dongen et al., 2003; Lim & Dinges, 2008; Satterfield & Van Dongen, 2013). This can lead to impaired neurocognitive performance, including memory consolidation, and deterioration of waking performance marked by increased rates of attentional failures (Van Dongen & Dinges, 2003; Durmer & Dinges, 2005; Czeisler & Gooley, 2007). These consequences are particularly evident while attempting to sustain attention for a continuous duration of time (e.g., for 10-20 minutes or more) (Van Dongen et al., 2003; Lockley et al., 2004; Durmer & Dinges, 2005). Sleep-related performance decrements can lead to impaired job performance and higher rates of errors, accidents and injuries (Akerstedt & Wright, 2009; Williamson et al., 2011; Satterfield & Van Dongen, 2013; Boivin & Boudreau, 2014).

As a society, we continue to sleep less (Rand, 2017; Watson et al., 2015). A recent report suggested that Canadians between the ages of 18 and 64 slept on average 7.2 hours a night (Statistics Canada, 2017). In the same report, 33% of Canadians report sleeping less than 7 hours

a night and as a country we are sleeping 1 hour less a night than in 2005 (Statistics Canada, 2017). Evidence suggests 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; Watson et al., 2015).

When inadequate sleep is obtained, sleep deprivation occurs. Sleep deprivation can be either acute or chronic (Dinges et al., 1997). Acute sleep deprivation usually occurs when individuals only are able to get 1-6 hours of sleep a night (Santhi et al., 2007). Chronic sleep deprivation is the result of consecutive days of less than 6 hours of sleep a night (Dinges et al., 1997). Total sleep deprivation, 24 hours of sustained wakefulness, is the most dangerous and has been shown to greatly impair neurobehavioural reaction time performance to an extent that is comparable to a level of 0.10 % blood alcohol concentration (BAC) (Dawson & Reid, 1997; Williamson & Feyer, 2000). Acute sleep deprivation is usually alleviated by recovery sleep, however, chronic sleep deprivation results in cumulative adverse effects on cognitive performance (Cohen et al., 2010; Van Dongen et al., 2003). Multiple studies (Van Dongen et al., 2003; Belenky et al., 2003) have demonstrated the ability to sustain attention, maintain cognitive performance and prevent attentional failures deteriorates when sleep is chronically restricted to fewer than 7 hours a night for a week or longer. Measures of performance were actually worsened with each successive day that insufficient sleep was obtained (<7 hours a night) (Van Dongen et al., 2003). When an individual was chronically (>7 days) exposed to a schedule that only afforded 5-6 hours of sleep a night they were not able to reverse the neurobehavioural performance decrements when given the opportunity to sleep 10-12 hours (Van Dongen et al., 2003). In fact, two weeks of six hours of time in bed per night was equivalent to the same neurobehavioral impairment as 24 hours of

wakefulness (Van Dongen et al., 2003), or a BAC of 0.10% (Dawson & Reid, 1997; Williamson & Feyer, 2000). Chronic sleep deprivation also leads to an increased probability of experiencing lapses of attention and falling asleep involuntarily in inappropriate or dangerous situations (Dawson & McCulloch, 2005). The effects of sleep deprivation are not overcome with a single night's sleep but can carry over several days so even if subsequent work was scheduled during an appropriate circadian phase (day time), the probability of falling asleep while working is still markedly increased after chronic sleep deprivation (Van Dongen et al., 2003; Banks, 2007; Cohen et al., 2010).

Instead of slowing response times to preserve accuracy, research has demonstrated that sleep-deprived participants increase speed at the expense of making more mistakes and take greater risks (Horowitz et al., 2003; McKenna et al., 2007). Sleep deprivation also greatly increases the probability of missing signals in one's visual field and can result in micro-sleep episodes (involuntary sleep episodes < 15 seconds long) which are attentional failures that can have catastrophic consequences in an occupational setting (Barger et al., 2006; Lockley et al., 2004). Sleep deprived participants exposed to brief balance perturbations have been reported to experience near falls in the laboratory, leading to the conclusion that sleep deprivation may be a contributing factor to decreased postural control and falls (Patel et al., 2008).

When sleep is disrupted, sleep deprivation can significantly impair neurocognitive performance, decision making, memory, reaction time and contributes to an increase risk of a workplace injury attributable to fatigue (Dinges, 1995; Williamson et al., 2011; Satterfield & Van Dongen, 2013).

1.9 Sleep Deprivation in Wildland Firefighters

As wildfires can often last days, weeks, or even months, firefighters are required to work extended shifts which may degrade the quality and quantity of their sleep (Aisbett et al., 2012; Rodriquez-Marroyo et al., 2011). As we have seen, B.C. firefighters currently work 14 consecutive days and upwards of 16 hours a day and such work arrangements can result in firefighters becoming sleep-restricted. In a Canadian study conducted by McGillis et al. (2017) firefighters total sleep time during wildfire suppression was 6.2 hours. Early subjective reports from Australian wildland firefighters suggested that firefighters only slept 3-6 hours during deployment (Cater et al., 2007). A more recent study conducted in Australia by Vincent et al. (2016) demonstrated that firefighters only obtained 6.1 hours of sleep during wildfire deployment. These levels are lower than what is the recommended sleep duration (7 to 9 hours) for adults to optimize daily performance (Hirshkowitz et al., 2015). As we have seen above, truncated sleep is known to increase fatigue and the risk of workplace injuries (Dinges, 1995; Akerstedt et al., 2002; Williamson et al., 2011). Current research examining firefighters' sleep during multiday wildfire suppression is lacking. To the authors knowledge, only one study in Australia (Vincent et al., 2016) and one study in Canada (McGillis et al., 2017) have used activity monitors to objectively examine firefighters' sleep behaviour during wildfire suppression (Vincent et al., 2016; McGillis et al., 2017). Of note, in Australia firefighting shifts are <5 days compared to in Canada where they can last upwards of 14 days (Cater et al., 2007). Research, particularly amongst Canadian firefighters where shifts are considerably longer, is needed to determine how certain operational and environmental factors may affect sleep quantity during deployments.

Sleep quality has also been investigated in the field amongst wildland firefighters (Vincent et al., 2016; McGillis et al., 2017). An Australian study (Vincent et al., 2016) found that there was no difference in subjective sleep quality between days suppressing wildfire and non-fire days. However, in a study conducted by McGillis et al. (2017) amongst Canadian wildland firefighters it was found that firefighters had measures of poor sleep quality during deployment days. Poor sleep quality can have immediate effects on an individual such as decreased alertness and impaired cognitive ability (Dinges et al., 1997). Sleep and the impact of restricted sleep is a significant and potentially modifiable factor impacting operational performance (Vincent et al., 2016; McGillis et al., 2017). Again given the existing lack of research, especially in Canada, on sleep quality of firefighters during deployment further studies should look at understanding the factors that influence sleep during fire days in effort to better understand the risk of sleep deprivation in firefighters.

1.10 Measuring Sleep in the Workplace

Sleep can be measured with three primary methods: polysomnography, activity monitoring, and self-reported measures. The gold standard for measuring sleep is polysomnography (PSG) (De Souza et al., 2003). Polysomnography is difficult in remote firefighting locations so sleep can also be measured objectively using wrist actigraphy. Similar to measures of fatigue in the workplace, in order to achieve accurate sleep values we need detailed subjective documentation of about sleep periods.

1.10.1 Objective Sleep Measures

Wrist actigraphs provide an objective, non-invasive method to monitor and collect data generated by validated algorithms that distinguish sleep from wakefulness (Ancoli-Israel et al., 2003). Activity monitors indirectly assess sleep and can collect data continuously for long periods of time and have been validated against the gold standard PSG (Signal et al., 2005).

1.10.2 Subjective Sleep Measures

Subjective sleep assessments are obtained through sleep logs and should be used in conjunction with objective activity monitoring (Vincent et al., 2018). The accuracy of objective sleep assessments can be improved when used in conjunction with sleep logs as it provides the researcher with detailed information about the start and end of the sleep periods (Vincent et al., 2018). Subjective sleep assessments also allow researchers to obtain important information on the quality of sleep. Sleep quality is usually obtained by asking participants to provide numerical ratings of perceived sleep and is an important consideration when assessing sleep and fatigue (Signal et al., 2005).

1.11 Bio-Mathematical Models of Fatigue of Fatigue in the Workplace

An often source of fatigue is the work schedule itself (Baulk et al., 2009). A schedule defines the time in which a worker can have opportunity for sleep (Lerman et al., 2012). It is common for wildland firefighters to work extended shifts (upwards of 16 hours a day), have early morning start

times (5 and 6 am), late shift end times (>9pm) and little time between successive shifts (< 8 hrs) (McGillis et al., 2017; Vincent et al., 2016; Cater et al., 2007; Gaskill & Ruby, 2004). Although such work shift parameters are known to increase the risk of fatigue (Caruso et al., 2006; Ferguson et al., 2012; Boivin & Boudreau, 2014), they can sometimes be unavoidable in emergency situations such as firefighting.

Bio-mathematical models of fatigue are becoming a useful tool for industry as they can assist decision-making at the organizational level about the fatigue associated with different patterns of work (Lerman et al., 2012; Dawson et al., 2011). Models are used to estimate the effects of duty scheduling on the level of worker fatigue in an attempt to predict the risk of impairment of different working patterns (Lerman et al., 2012; Dawson et al., 2011). Interactive models of fatigue can also be used as an education tool to identify scheduling practices which are known to contribute to fatigue and sleep deprivation (Dawson et al., 2011).

To our knowledge, no forest firefighting schedule has yet to have been assessed using a validated bio-mathematical model of fatigue. Therefore, we aim to both generate a fatigue risk score of a typical BCWS firefighting deployment cycle (17 days) and work with the BCWS organization to identify, understand, and manage work shift parameters that may be contributing to fatigue amongst firefighters. To achieve this, we will be using the validated Circadian Alertness Simulator (CAS) model of fatigue (Moore-ede et al., 2004).

1.12 Circadian Alertness Simulator (CAS) Model of Fatigue

Our bio-mathematical fatigue risk assessment was conducted using the proprietary Circadian Alertness Simulator (CAS) (Moore-edé et al., 2004; Circadian, 2018). The circadian alertness simulator is based on circadian and sleep physiology and uses a three-process model which combines: homeostatic factors (build-up of sleepiness from extended wakefulness), circadian factors (the phase of the human biological clock and its adjustment to time zones or night work) and sleep inertia (the transitory impairment of alertness on arousal from sleep depending on circadian phase, length of sleep, and level of prior sleep deprivation) to convert on-duty and rest data from schedule work patterns into a fatigue risk score (Moore-edé et al., 2004; Circadian, 2018). The circadian alertness simulator generates a score (0-100) into three fatigue levels:

- 1) Green Zone- Low Fatigue Risk 0- 30
- 2) Yellow Zone- Average Fatigue Risk 31- 60
- 3) Red Zone- High Fatigue Risk 61- 1000

The circadian alertness simulator uses circadian sleep physiology to estimate the duration, timing and quality of sleep for each sleep opportunity before, during, and after any given duty rest schedule (Moore-edé et al., 2004; Circadian, 2018) The CAS model is one of the longest operationally used fatigue models, with a 20 year validated record of reducing errors, incidents, and injuries in FRMS applications (Circadian, 2018). The CAS model has been validated against work/rest and accident data from the trucking industry (Circadian, 2018).

Chapter 2: Objectives and Hypothesis

The objective of the research study was to improve our understanding of the relationship between working prolonged and irregular shifts and the development of cognitive and subjective fatigue amongst B.C. forest firefighters. To our knowledge there are no studies investigating fatigue in B.C. forest firefighters; our aim was to provide valuable insight into the impact the BCWS 14-day work schedule had on the fatigue and sleep patterns of B.C. firefighters. This study also aimed to highlight important work shift parameters (shift start times, shift duration, and time between shifts) that are known to increase the risk of fatigue and workplace injuries during a 14-day deployment and to investigate whether fatigue and sleep patterns differed between firefighters and management personnel. The aim of the research was to provide valuable insight for fire agencies across Canada and internationally and guide future interventions to reduce fatigue and improve occupational health and safety in the workplace.

2.1 Aims

The specific aims of this thesis were:

- 1- To assess and quantify the development of objective and subjective levels of fatigue amongst B.C. wildland firefighters over a 17-day work cycle.
- 2- To understand the impact in which a 17-day work cycle has on B.C. wildland firefighters' sleep quantity and quality.

- 3- To evaluate and highlight shift characteristics (start times, shift length, time between shifts) and to fatigue model the current BCWS firefighting schedule.
- 4- To understand if BCWS management firefighters were at an increased risk of fatigue and shortened sleep during the 17-day deployment compared to unit crew firefighters.

2.2 Hypothesis

The hypotheses for the study were:

2.2.1 Hypothesis for Aim #1

Measures of cognitive and subjective fatigue will significantly increase with consecutive days worked as measured using the psychomotor vigilance test and a visual analogue scale of fatigue.

2.2.2 Hypothesis for Aim #2

Sleep will become increasingly disrupted and shortened throughout the progression of the work deployment, resulting in significant increases in subjective reports of sleepiness as measured using a visual analogue scale for sleepiness.

2.2.3 Hypothesis for Aim #3

The current BCWS firefighting schedule will generate a high risk fatigue score using the CAS bio-mathematical model of fatigue.

2.2.4 Hypothesis for Aim #4

Fatigue and sleep quantity will be most compromised amongst the BCWS management team compared to the BCWS unit crew firefighter group.

Chapter 3: Fatigue in Firefighting

3.1 Introduction

Forest firefighters have an increased risk to fatigue owing to a physically and psychologically demanding occupation, irregular work schedule, harsh environmental conditions, and disrupted sleep patterns (Vincent et al., 2016; Smith et al., 2016; McGillis et al., 2017). Forest firefighting involves a large cognitive demand in which firefighters assess extreme and unpredictable fire situations, make split second decisions, execute critical decisions and need to maintain situational awareness of surroundings and hazards (Vincent et al, 2018). Fatigue has been shown to lead to poor decision making, decreased reaction time, situational awareness and hazard recognition (Williamson et al., 2011; Satterfield & Van Dongen, 2013). Firefighters continue to have a disproportionate amount of workplace injuries, in which fatigue may be a contributing factor (Britton et al., 2013 & Purchio, 2017). Although fatigue is a central concept in occupational health and shift work research (Williamson et al., 2011; Lerman et al., 2012; Dawson et al., 2005), few studies have objectively measured the development of cognitive fatigue amongst forest firefighters (McGillis et al., 2017; Ferguson et al., 2016; Smith et al., 2016). The study conducted by McGillis et al. (2017), to our knowledge was the first study amongst Canadian firefighters. However, this research was conducted in Ontario during a particularly low fire season and crews did not often work >7 consecutive days (McGillis et al. 2017). In B.C. the terrain can be extreme and averages over 1,600 fires a summer where crews often are required to work 14 days straight, 13-14 hours a day (Province of British Columbia, 2018c). Our project is one of the first large scale field studies conducted in Canada to provide

objective evidence to assess the development of fatigue amongst B.C. firefighters during a 17-day work cycle.

3.2 Methods

3.2.1 Participant Recruitment

In the summer of 2015, with the assistance of the BCWS, 25 BCWS wildland firefighters were recruited from the Cougar Creek Fire (Boston Bar, B.C.) and 15 from the Teslinden Fire (Oliver, B.C.) for a total of 40 participants. Of the 40 participants, 30 were BCWS type-1 unit crew firefighters (FF) and 10 were from a BCWS management team (MT) supervising and overseeing the fire operations at the Teslinden Fire. Fire crews and management team members were notified by the BCWS of the research study with a letter of intent (Appendix B) immediately before deployment. Interested participants were invited to attend an information session upon arrival and briefed by lead investigator Andrew Jeklin (AJ). Only one participant, a MT member, withdraw from the study as they were transferred to another fire, resulting in a final sample of 39 participants (FF= 30; MT= 9; Female = 13; Male = 26). All participants were expected to commit to 17-days of testing, 14 during deployment and 3 during the rest period. All participants provided written, informed consent prior to the initiation of testing and the study was approved from the University of British Columbia human ethics board.

3.2.2 Objective Fatigue Measures

Psychomotor Vigilance Test (PVT) data was collected using E-prime software (Version 3.0) on an Asus tablet. A validated 5-minute version (Lamond et al., 2005) was used due to the time constraint of testing in the field. Participants entered their ID number and performed PVT tests immediately following their shift during fire days (1-14). Data was time and date stamped and manually extracted from E-prime to Microsoft excel by lead investigator AJ and further analyzed. PVT variables used in this study were median reaction time (RT) (milliseconds) and lapses: which was classified as a RT >355 milliseconds (Basner et al., 2010).

3.2.3 Subjective Fatigue Measures

Participants were asked to report their daily subjective levels of fatigue, alertness and how strenuous they perceived each deployment day on a 100-mm visual analog scale line. The value ranged from 0 mm (not at all fatigued, strenuous and alert) to 100 mm (extremely fatigued, alert, and strenuous). Each subjective measure was done during the testing session immediately following a shift. Scores were manually measured by AJ and then extracted for analysis. Participants were expected to continue to record these measures during their rest days with the VAS scales provided.

3.2.4 Procedure

Researchers recruited participants at two project fires organized by the BCWS. Data was continuously collected each day throughout a 17-day work deployment. The first fourteen days were “active fire line days” and the next 3 were “recovery days”. Researchers met the participants on day 1 and recorded baseline measures and showed participants how to use the equipment (tablets). Baseline measures included; age, height, weight, and a brief work-history questionnaire (see Appendix A). Subsequent testing sessions involved daily PVT and subjective measures of fatigue (VAS) immediately following each shift. Testing times could not be standardized for participants due to variability in the scheduling each day. As firefighters spent their recovery days not at a central location, equipment constraints limited us to continue measuring PVT during rest days. Participants were however provided with subsequent VAS scales that allowed for subjective measures of fatigue to be recorded during rest days. Visual analogue scales were then securely mailed (prepaid envelopes) to researchers at the University of British Columbia.

3.2.5 Statistical Analysis

The association between group (firefighter vs. management) and time (consecutive days worked, 1-17) was tested with a linear mixed model for repeated measurements. Results were assessed for both a significant 2-way interaction between group and time and a significant main effect of time, $p < 0.05$. Post-hoc analysis were performed using Tukey’s test with a Bonferroni correction for multiple comparisons to identify which days significantly were different. Subsequently, the

main effect of time was analyzed with the data separated by group (firefighter and management). The same post-hoc analysis as above was conducted to identify differences between days. Mauchly's Test of Sphericity ($p > 0.05$) was used and when the assumption was not met, the p-value from the Greenhouse-Geisser was recorded. Before the analysis, the data was assessed by Shapiro-Wilk's test of normality ($p > .05$) and normally distributed. All data are reported with mean (M) \pm standard deviation (SD).

Psychomotor vigilance test data, median RT (milliseconds) and number of lapses (scores >355 milliseconds), were manually extracted from E-Prime software and scores were averaged for each participant each day using Microsoft Excel. Means were compared in the linear mixed model as in classical analysis of variance models. Daily VAS scores of fatigue, alertness and strenuous duty days for each participant was inputted in the linear mixed model. All data is reported as mean (M) \pm SD, unless otherwise stated. Descriptive statistics of patient demographics and previous work experience were collected with a workplace questionnaire (appendix A) and analysis was separated based on group (firefighters & management). An independent sample T-test was used to identify differences. All statistical analyses were carried out using IBM SPSS (version 20.0).

3.3 Results

Participant Information:

There were a total of 39 participants in the study (FF= 30, MT= 9) and 13 were female (FF= 10, MT= 3). The mean age of participants was 30.4 ± 11.6 (range: 19 to 58 years) and all were employed by the BCWS as either type-1 firefighters or part of a BCWS management team. There was an expected significant difference ($p = .004$) in firefighting experience between FF ($M = 4.2 \pm 4.6$ yrs) and MT ($M = 18.2 \pm 10.1$ yrs) and a difference in previous 2015 multi-day (>7 day) deployments between FF ($M = 4.2 \pm 1.1$) and MT ($M = 4.4 \pm 1.2$), $p = 0.002$. All participants were healthy and there was no report of existing sleep disorders.

Table 1- Characteristics of Firefighters (FF) and Management Team (MT)

Variable	Group		p-value
	FF (n=30)	MT (n=9)	
Age (yrs.)	24.6 ± 4.8	48.1 ± 6.3	$p = .0005^*$
Height (cm)	180.4 ± 8.6	173.1 ± 10.5	$p = .02^*$
Weight (kg)	84.4 ± 12.6	87.4 ± 18.8	$p = .65$
BMI (kg/m^2)	25.9 ± 3.2	29.1 ± 5.2	$p = .06^*$
Waist circumference (cm)	86.5 ± 9.9	99.2 ± 13.9	$p = .02^*$
Firefighting experience (years)	4.1 ± 4.6	18.2 ± 10.1	$p = .004^*$
Number of 2015 multi-day deployments	4.2 ± 1.1	4.4 ± 1.2	$p = .002^*$

* = $p < .05$

3.3.1 Objective Fatigue Measures

PVT Median Reaction Time:

PVT median reaction times were significantly slower amongst management team members ($M=305.9 \pm 35.8$ ms) then firefighters ($M= 260.9 \pm 28.6$ ms), $p = < .0005$, during deployment. There was a significant interaction for time and group, ($F(7, 263), = 3100, p= <.0005, \eta_p^2= .145, \epsilon = .547$) and an overall significant main effect of time, ($F(7, 263), = 3306, p = <.0005, \eta_p^2 = .153, \epsilon = .547$). Post-hoc analysis revealed that there was no significant difference in cognitive performance scores between day 1 ($M= 291.3 \pm 40.5$ ms) and day 14 ($M = 287.4 \pm 43.1$ ms), $p= 1.00$, as seen in figure 1. There was a significant difference amongst PVT scores on days 3 ($M= 281.0 \pm 32.7$ ms), 4 ($M= 275.2 \pm 34.9$ ms), and 6 ($M= 279.1 \pm 33.4$ ms) compared to day 13 ($M= 300.0 \pm 42.5$ ms), $p = .018, <.0005, <.0005$, respectively; figure 1.

Separate analysis of groups indicated the main effect of time on PVT median RT was significant for the firefighter group, $F(6, 192) = 2015, p < .0005, \eta_p^2 = .126, \epsilon = .511$. Post-hoc analysis indicated again there was no significant differences in cognitive performance between days 1 (264.1 ± 30.4 ms) and day 14 (269.4 ± 34.7), $p= 1.000$, as seen in figure 1. There were significant differences in PVT scores between day 4 ($M= 252.0 \pm 28$ ms) and days 11 ($M= 267.8 \pm 26.7$ ms) and 12 ($M= 265.9 \pm 26.9$ ms), $p = .007, \text{ and } .013$, respectively. There was also a significant difference between day 5 (253.4 ± 29.7 ms) and days 11 ($M=267.8 \pm 26.7$ ms) and 13 ($M=267.1 \pm 32$ ms), $p= .031 \text{ and } .025$, indicating poorer cognitive performance later in deployment.

Our results also demonstrated a significant main effect for time on PVT median RT in the management group, $F(4, 32) = 6260, p = .002, \eta_p^2 = .406, \epsilon = .314$. There was no statistical difference between day 1 ($M = 318.6 \pm 43.1$ ms) and day 14 ($M = 305.4 \pm 57.7$ ms), $p = 1.000$. Post hoc analysis revealed significant differences between day 4 ($M = 298.4 \pm 32.7$ ms) and day 13 ($M = 332.7 \pm 32.0$ ms), $p = .004$ and between days 6 ($M = 294.5 \pm 28.7$ ms) and 7 ($M = 285.4 \pm 31.5$) compared to day 13 ($M = 332.7 \pm 33.7$ ms), $p = .002$ and $.003$.

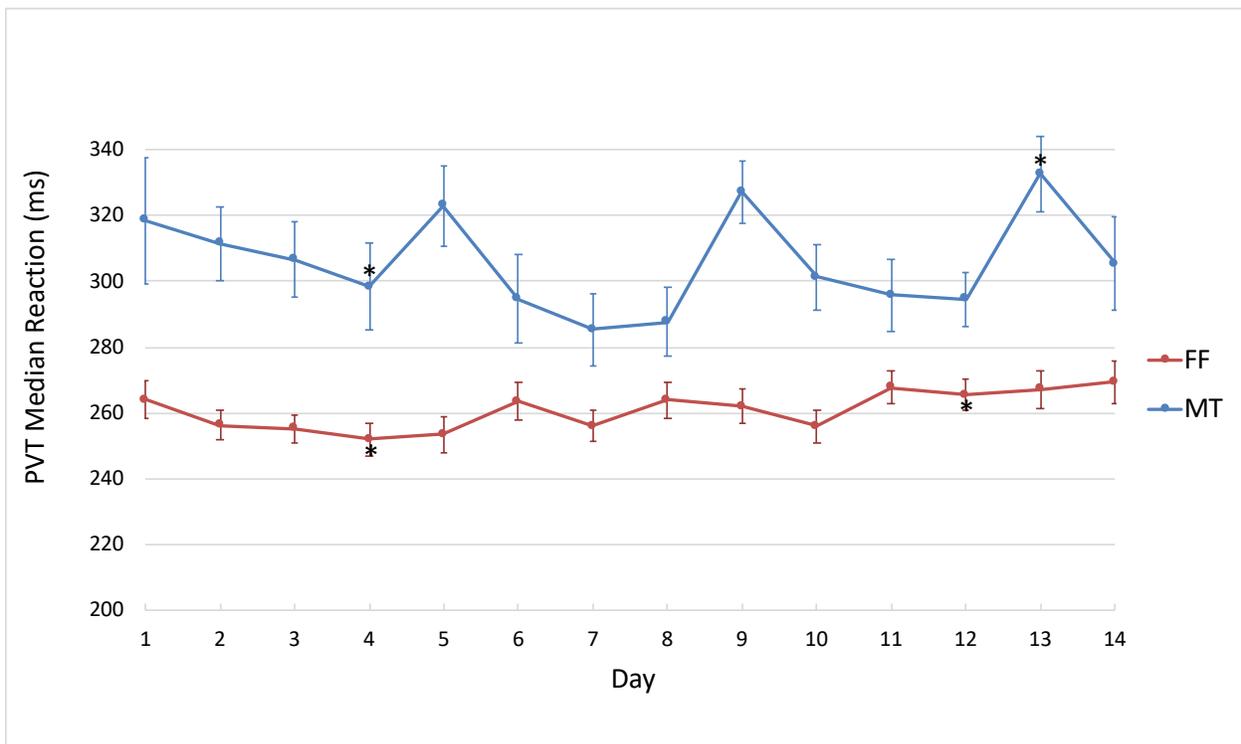


Figure 2: PVT Median Reaction Time During Deployment: Red line indicates firefighters PVT response time and blue line represents management team. * indicates significant difference between days, $p < .05$

PVT Lapses:

The average number of PVT lapses was significantly higher amongst management (N=174, M=1.38 ± 1.4) than firefighters (N=277, M= .662 ± 1.0), p= .012, during the deployment. There was no significant interaction for time and group, (F (8, 303), = 1.7, p= .288, η_p^2 = .032, ϵ = .630) but there was a significant overall main effect for time, (F (8, 303), = 3.7, p = .009, η_p^2 = .066, ϵ = .630). Post hoc analysis for the overall group revealed that day 13 (N=51, M= 1.7 ± 1.3) had significantly more PVT lapses than days 1 (N=26, M= .822, ± 1.4), 2 (N=27, M=.839, ± .83), and 3 (N=24, M=.750, ± 1.0) p= .002, .003, and .0005 respectively, as seen in figure 2.

Separate analysis of groups and PVT lapses did not reveal a significant main effect of time for firefighters, (F (6, 193), = 2.1, p= .259, η_p^2 = .043, ϵ = .512) or management, F (3,30), = 10.4, p= .152, η_p^2 = .186, ϵ = .512) during the 14 day work period.

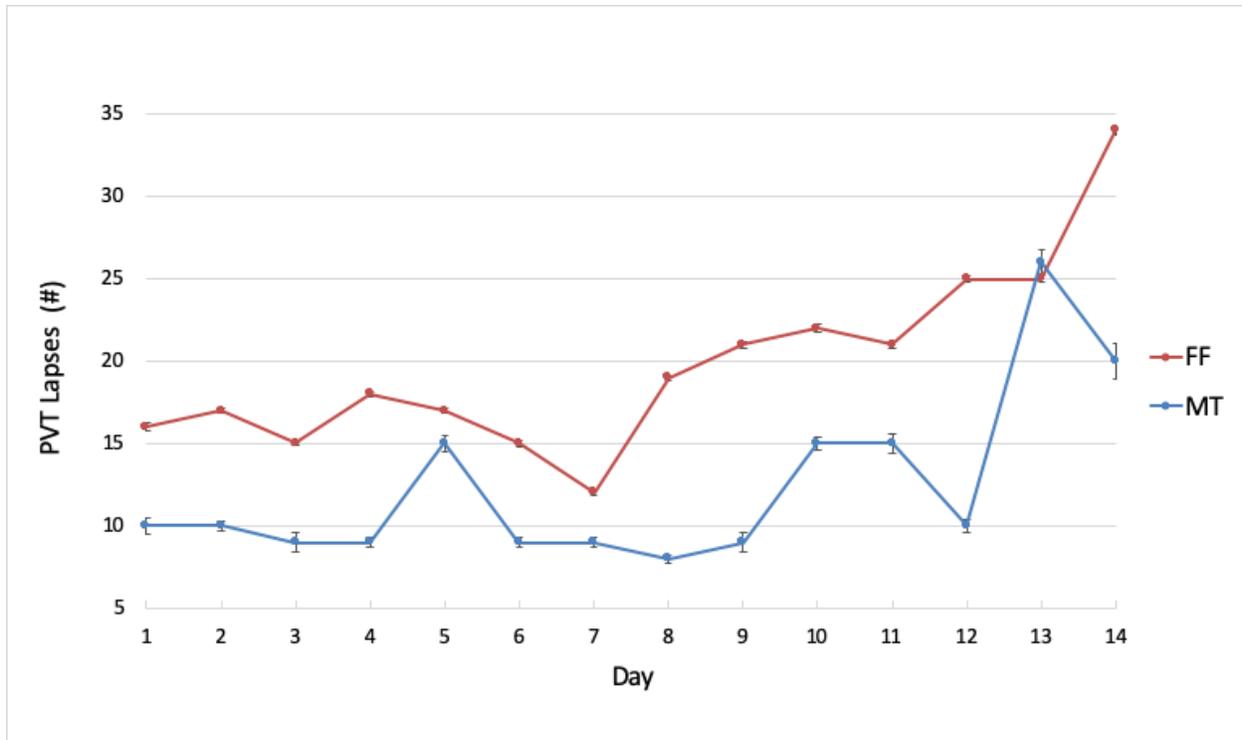


Figure 3: PVT Lapses During Deployment: Red line indicates number of PVT lapses (>355 ms) for firefighters and blue line represents number of PVT lapses (>355 ms) for the management team.

3.3.2 Subjective Fatigue Measures

VAS-Fatigue:

Self-reported fatigue was not statistically different between firefighters ($M= 5.0 \pm 2.1$ mm) and management ($M= 4.6 \pm 2.0$ mm) during deployment, $p = .270$. Our data did not demonstrate a significant interaction between time and group, $F(8, 298), = 9.2, p = .235, \eta_p^2 = .034, \epsilon = .504$), for subjective fatigue but there was an overall main effect of time, $F(8, 298), = 33.7, p < .0005, \eta_p^2 = .115, \epsilon = .504$. Post hoc analysis revealed that subjective fatigue was significantly higher for

participants during days 7 ($M= 5.6 \pm 1.6$ mm), 11 ($M= 5.7 \pm 1.9$ mm), and 13 ($M= 6.1 \pm 1.9$ mm) compared to day 1 ($M= 3.9 \pm 2.3$ mm), $p= .040$, $.029$, and $.002$ respectively. Day 13 ($M=6.1 \pm 1.9$ mm) had significantly higher levels of self-reported fatigue than each of the first 5 days of deployment, indicating that with consecutive days worked participants reported significantly higher levels of fatigue.

During separate analysis of groups, our results demonstrated a significant main effect of time on subjective fatigue for firefighters, $F(8, 240) = 28.2$, $p < .0005$, $\eta_p^2 = .117$, $\epsilon = .517$). There was no significant difference between day 1 ($M= 4.2 \pm 2.3$ mm) and day 14 ($M= 5.2 \pm 2.3$ mm), $p= 1.000$, but there was a significant increase in self-reported fatigue on day 13 ($M=6.0 \pm 1.9$ mm) compared to days 3 ($M=4.2 \pm 2.2$ mm) and 5 ($M=4.1 \pm 2.2$ mm), $p= .033$ and $.011$ respectively. The results also showed a significant increase in self-reported fatigue on Day 16 ($M=6.3 \pm 2.2$ mm) compared to day 5 ($M= 4.1 \pm 2.2$ mm), $p= .025$, indicating self-reported fatigue levels did not improve during the rest period. Although not significant, the results showed a trend, where self-reported fatigue was higher on day 16 ($M= 6.3 \pm 2.2$ mm) than day 13 ($M=6.0 \pm 1.9$ mm).

There was a significant main effect of time on self-reported fatigue amongst the management group, $F(3,22) = 59.0$, $p= .035$, $\eta_p^2 = .310$, $\epsilon = .165$. Post-hoc analysis demonstrated that there was a significant increase in fatigue on day 13 ($M=6.2 \pm 1.9$ mm) compared to day 1 ($M=3.1 \pm 2.1$ mm), $p = .019$. Similar to the firefighter group, there was a trend of an increase in subjective fatigue during day 17 ($M= 4.7 \pm 2.3$ mm) compared to day 1 ($M= 3.1 \pm 2.1$ mm) and day 2 ($M= 2.59 \pm 1.9$ mm) $p= 1.000$, 1.000 . These results indicate there was potentially inadequate rest

following a deployment as the management team were more fatigued after a 3-day rest period with no firefighting duties compared to the beginning of their shift.

VAS-Alert:

Self-reported levels of alertness were not significantly different between the firefighter ($M=5.5 \pm 2.0$ mm) and management ($M=5.7 \pm 1.8$ mm), $p= .507$, groups during the deployment. There was no significant interaction for time and group ($F(9, 346)= 8.0$, $p= .213$, $\eta_p^2= .035$, $\epsilon = .585$) but there was an overall main effect of time and alertness, $F(9, 346), =20.5$, $p= < .0005$, $\eta_p^2= .085$, $\epsilon = .585$. Post hoc analysis demonstrated that alertness was significantly lower on day 13 ($M=4.2 \pm 1.9$ mm) compared to days 1 ($M= 6.8 \pm 1.9$ mm) and 2 ($M=6.5 \pm 1.9$ mm), $p= <.0005$ and $.001$ respectively. There was a trend, although not significant, towards decreasing alertness on days 14 ($M= 5.0 \pm 2.1$ mm) and 17 ($M= 5.5 \pm 2.1$ mm) compared to day 1 ($M= 6.8 \pm 1.9$ mm) indicating that participants became less alert with consecutive days worked, yet did not report their levels of alertness improving after 3 days rest.

Analysis of the separate groups, showed a significant main effect of time on subjective alertness, $F(9, 254), =17$, $p=.007$, $\eta_p^2= .082$, $\epsilon = .549$, amongst firefighters. Post hoc analysis did not reveal a difference in alertness between day 1 ($M= 6.2 \pm 2.0$ mm) and day 14 ($M=4.9 \pm 2.2$), $p= 1.000$, but there was a significant decrease in alertness from day 3 ($M=6.5 \pm 1.2$ mm) compared to days 10 ($M=5.0 \pm 1.9$ mm) and 13 ($M=4.7 \pm 1.8$ mm), $p= .005$ and $.003$ respectively. There was trend towards reporting a decrease in alertness on day 17 ($M= 5.4 \pm 2.2$ mm) compared to day 1 ($M= 6.2 \pm 2.0$ mm).

The results demonstrated that the management group also showed a significant main effect of time on alertness during the deployment, $F(4,33), =30.6, p=.041, \eta_p^2 = .258, \epsilon = .260$. Post hoc analysis revealed a significant decrease in reported levels of alertness from days 1 (7.2 ± 1.5 mm) and 2 (7.4 ± 1.5) to day 13 ($M=3.8 \pm 1.8$ mm), $p=.011$ and $p= .049$ respectively. Management also showed a trend emerging towards a decrease in alertness on day 17 (6.0 ± 1.8 mm) compared to day 1 (7.2 ± 1.5 mm).

VAS-Strenuous:

Firefighters ($M=3.9 \pm 2.4$ mm) reported significantly higher levels of strenuous activity than management ($M= 3.0 \pm 1.8$ mm), $p=.012$ during fire-line days. Our results demonstrated a significant interaction for time and group, ($F(8, 312), =20.8, p= .027, \eta_p^2 = .055, \epsilon = .528$) and a main effect of time, $F(8, 312), = 64.6, p<.0005, \eta_p^2 = .154, \epsilon = .528$. Post hoc analysis demonstrated that the group found days 7 ($M= 4.7 \pm 2.2$ mm) and 11 ($M= 5.0 \pm 2.3$ mm) significantly more strenuous than day 1 ($M= 2.8 \pm 2.6$ mm). However, the group also found days 2 (4.3 ± 2.7 mm) and 3 ($M= 4.1 \pm 2.7$ mm) significantly more strenuous than day 14 ($M= 1.4 \pm 1.4$ mm).

During separate analysis of groups our results demonstrated a significant main effect of time and perceived strenuous activity for firefighters, $F(10, 223), = 122, p= <.0005, \eta_p^2= .264, \epsilon = .480$. Post hoc analysis demonstrated that firefighters self-reported that day 1 ($M=4.5 \pm 2.4$ mm) was a significantly more strenuous fire-line day then compared to day 14 ($M=1.6 \pm 1.5$ mm), $p=$

<.0005. Firefighters also perceived that days 2 (5.4 ± 2.5 mm), 3 ($M=4.0 \pm 2.7$ mm) and 4 ($M=4.4 \pm 2.7$ mm) were significantly more strenuous fireline days compared to days 13 ($M=1.7 \pm 2.3$ mm) and 14 ($M=1.6 \pm 1.5$ mm).

Our analysis also demonstrated that there was a significant main effect of time on perceived strenuous duties within the management group, $F(4, 40)= 37.2$, $p= .005$, $\eta_p^2= .330$, $\epsilon= .313$, during the deployment. Post-hoc analysis revealed that management found day 10 ($M= 4.3 \pm 1.4$ mm) significantly more strenuous than day 1 ($M= 1.1 \pm 0.8$ mm). Management also found days 4 ($M= 3.9 \pm 1.8$ mm) and 11 ($M= 4.6 \pm 1.8$ mm) significantly more strenuous than day 14 (1.2 ± 1.2 mm).

Table 2 - Fatigue Variables for Firefighters (FF) and Management Team (MT) During a 17-Day Firefighting Deployment

	<u>Overall (N=39)</u>		<u>FF (n=30)</u>		<u>MT (n=9)</u>	
	Mean	SD	Mean	SD	Mean	SD
PVT Median RT (ms)	271.3	36.3	260.9*	28.6	305.9	35.8
PVT Lapses (N=total #)	0.8 (N=451)	1.2	0.6 (N=277)*	1.0	1.3 (N=174)	1.4
VAS-Fatigue (mm)	4.9	2.2	5.1	2.1	4.62	2.0
VAS-Alert (mm)	5.5	2.0	5.5	1.9	5.67	1.8
VAS-Strenous (mm)	3.7	2.7	3.9*	2.4	3.04	1.8

*Significant ($p < .05$) difference between Firefighter (FF) and Management (MT) group

3.4 Discussion

The aim of this study was to investigate the impact that the current BCWS firefighting schedule has on subjective and objective levels of fatigue under the various occupational and environmental stressors of forest firefighting. The main finding of our study was that BCWS firefighters performed poorer on cognitive performance tests and reported significantly higher levels of fatigue and decreased alertness with increasing days on deployment. Our results indicate measures of objective and subjective fatigue increase with successive days worked.

Neurobehavioral testing of forest firefighters has only been conducted in one field study (McGillis et al., 2017) and two firefighting simulations (Ferguson et al., 2016; Smith et al., 2016). To our knowledge, this is the first study to objectively monitor fatigue for 14 consecutive days in the field and to measure fatigue in both firefighter and management groups. Smith et al. (2016) demonstrated in the laboratory that in the absence of sleep restriction, PVT scores declined across 4 consecutive 12-h shifts, suggesting that even without additional stressors, the nature and duration of firefighting tasks during wildfire suppression will impair cognitive performance (Smith et al., 2016; Vincent et al., 2018). Further, when firefighters were sleep restricted, which is common in multi-day deployments, they had even poorer cognitive performance compared to controls (Smith et al., 2016). Our study demonstrated that firefighters who worked 14 consecutive 12-h shifts reported significantly greater fatigue and had poorer cognitive performance on sustained attention and vigilance tasks as measured by the PVT by their 13th deployment day compared to early in their deployment (day 3). Although we did see a

significant increase of lapses in attention (measured on PVT) from day 1 (N=26) to day 13(N=51) several of our variables indicated that firefighters potentially were entering the deployment previously fatigued or inadequately rested. For instance, PVT median scores were notably higher on day 1 than day 14, participants reported the first two days to be significantly more strenuous than later deployment days, and several participants self-reported higher levels of fatigue and decreased alertness during rest days than deployment days. One possible reason for this could be that total sleep time for participants during the 3-day rest period was only 6.9 hr \pm 89.2 min, which is below the considered optimal sleep duration (7-9 hours) (Hirshkowitz et al., 2015). It is difficult to elucidate whether the rest period was inadequate as it was not known how firefighters optimized their 3 day rest period prior to the study but future research should explore multiple deployments in an effort to understand the impact the current 17-day schedule is having on the development and recovery of fatigue in firefighters. Self-reported fatigue as expected was notably low on day 1 but participants had notably poor cognitive performance scores. Fatigued individuals often are not able to recognize their fatigue or predict their cognitive performance on PVT (Lerman et al., 2012). It remains to be determined if and how firefighters optimize their recovery opportunity time, particularly during a high-fire season in which this study took place. Fire agencies will want to target the results of this study, which suggest potentially inadequate rest and poor sleep hygiene, with interventions strategies on the importance of acquiring adequate rest and sleep during rest periods.

Multi-day deployments and long hours have been shown to lead to cognitive impairment and increase the risk of workplace accidents (Dembe et al., 2005; Williamson et al., 2011; Folkard et al., 2005). For instance, relative to 8 h duty periods, 12 h duty periods are associated with a

27.5% increase in risk of workplace injury (Folkard et al., 2005). In an effort to determine the aspects of cognitive performance critical in wildland firefighting performance, Ferguson et al. (2011) conducted focus groups with wildland firefighters in a simulation study. Vigilance, concentration, decision-making, and maintaining awareness of critical cues in the environment while concurrently focusing on the primary task were identified as key cognitive elements of wildland firefighting (Ferguson et al., 2011). Our results indicate worsening neurocognitive performance on critical cognitive tasks identified by Ferguson et al. (2011) such as vigilance and maintaining awareness. It is important to note that our study used a 5-min PVT, rather than the standard 10-min version. Although the reduced length has been shown to affect results, it has been noted that the 5 min version is validated in time-constrained experimental scenarios (Loh et al., 2004). We also acknowledge that using PVT median RT has been criticized as an outcome measure due to its susceptibility to outliers and all median and mean RT should be log transformed (Basner & Dinges, 2011). We acknowledge this as a potential limitation in our study, however, it should be noted that median RT is the second most published PVT outcome metric in the literature (Basner & Dinges, 2011).

Firefighters had significantly more lapses in attention and slower reaction times later in the shift, indicating they were becoming increasingly fatigued with consecutive days worked. The overall PVT scores in our study ($M = 271.3 \pm 36.3$ ms) were notably lower than the PVT scores ($M = 372.4 \pm 51.1$) from the base camp in the other firefighting field study conducted in Canada (McGillis et al., 2017). One possible reason for the differences in PVT scores amongst firefighters could be that total sleep time (TST) was 381.0 ± 57.5 min in the McGillis et al. (2017) study and 408.6 ± 49.2 minutes during fire line days in our study, a significant difference

of 27.2 minutes. The study conducted by McGillis et al. (2017) demonstrated even further cognitive impairment amongst firefighters when shifts lasted > 7 days on PVT (M= 381 ± 57.5 ms).

The impact of successive shifts on cognitive performance is currently lacking in wildland firefighting (Vincent et al., 2018) but research in health care (Geiger-Brown et al., 2012) and shift work settings (Jay et al., 2008; Folkard et al., 2005) demonstrate worsening neurocognitive functioning after working successive prolonged shifts. Worsening cognitive functioning is a serious concern in firefighting given that firefighting involves a large cognitive demand and situational awareness of surroundings is very important (Williams-Bell et al. 2017). The results of our study imply that the relationship between consecutive days worked, workload, objective performance and subjective fatigue are complex and that further research is required.

A major finding of our study, which has important implications for fire agencies and organizations that evaluate existing policies on scheduling, was that subjective measures of fatigue, alertness and perceived strenuous days got worse with consecutive days worked but did not return to baseline following a 3-day rest period. Participants actually had higher levels of self reported fatigue and decreased alertness during their rest period compared to their fire line days. In a study conducted by Vincent et al. (2016) they demonstrated that subjective fatigue was higher amongst firefighters on fire days compared to non-fire days. Of note, firefighters in this study only worked a maximum of 5-7 consecutive days and 11:36 hours on average. On average, firefighters in our study worked > 13 hours a day for 14 consecutive days and perhaps a 3-day rest period is not adequate as levels of subjective fatigue do not decrease. A major limitation of

this study was that sufficient equipment was not available to continue measuring PVT performance during rest days and we suggest that future research evaluate objective fatigue during the rest period.

The current study is to our knowledge the first to investigate the impact of fatigue in a group of management personnel. As highlighted above, project fires in BC are managed by a team of 10 BCWS employees with extensive knowledge and education in firefighting and forestry. Given their expectations to ensure the safety of all site personnel and executing critical decisions in unprecedented emergency situations understanding fatigue and cognitive impairment in this group is important to fire agencies and organizations. Our study demonstrated that when compared to firefighters, management had significantly poorer cognitive performance, as measured by slower daily reaction times and increased number of attentional lapses when compared to firefighters. Previous research in other shift work environments has demonstrated that older aged workers (35-49 and 50-58) when compared to younger workers (25-34) had a greater decline in performance on median RT and increased amount of PVT lapses with successive days worked (Bonnefond et al., 2006). It is suggested that aging decreases shiftwork tolerance and after the age of 40 to 50 years, sleep becomes fragmented which may consequently lead to poorer cognitive performance (Van Dongen et al., 2003; Bonnefond et al., 2006). Management personnel reported significantly higher levels of fatigue and decreased alertness with increasing days on deployment but these levels were not significantly different than firefighters. The management group found from the middle of deployment (day 6-8) onwards to be the most strenuous duty days while firefighters reported the first half of deployment (days 1-8) to be the most strenuous. We postulate that management may not be experiencing as high levels of

fatigue entering a new deployment as firefighters as they may better manage their rest periods. For instance, they reported lower levels of subjective fatigue (4.6 ± 2.4 mm) compared to firefighters ($M= 5.3 \pm 2.3$ mm) during their rest period and slept on average 40 minutes longer each night. Our findings do suggest though that levels of fatigue and decreased alertness were still higher throughout the rest period than at the beginning of the deployment for management personnel indicating that again the rest period may not be adequate for recovery from the previous 14 day work period. Further research is required, with larger sample size, in this important group of firefighters to understand the impact of long work schedules on the development of fatigue.

Chapter 4: Sleep in Firefighting

4.1 Introduction

The possible real world consequences of sleep deprivation in the workplace has been widely documented (Dinges, 1995; Folkard et al., 2005; Akerstedt & Wright, 2009; Williamson et al., 2011). Sleep can be negatively impacted by a range of operational and environmental factors during shift work (Akerstedt & Wright, 2005; Williamson & Friswell 2013). Wildland firefighters continue to routinely face many of these operational factors (extended and irregular shifts, early shift start times, and little time between successive shifts) and environmental factors (noise, smoke, heat, and temporary sleeping locations) during deployment that can seriously impact the quantity and quality of their sleep (Aisbett et al., 2012; Vincent et al., 2016). Working 12-16 hours a shift, common for B.C. firefighters, results in a decreased total sleep time (Williamson & Friswell, 2013; Vincent et al., 2016; McGillis et al., 2017). Successive days of sleep loss can result in chronic sleep deprivation that is associated with neurocognitive performance deficits, poor judgment, poor hazard recognition, and ill health (Harrison & Horne, 2000; Van Dongen et al., 2003; Durmer & Dinges, 2005). To our knowledge, there has only been one study that has investigated the effects of long firefighting deployments (>7 days) on sleep quantity and quality (McGillis et al., 2017). Their data was collected during a low-hazard firefighting season in Ontario and therefore may not reflect the sleep patterns encountered during a high-hazard fire season which is common in B.C. With the severity and incidence of wildfires expected to increase in B.C. wildland firefighters will continue to be expected to work long

extended shifts in difficult and dangerous environments and this study will be the first to measure their sleep quantity and quality.

This study will also be the first to our knowledge to investigate the effects of sleep in a wildfire management team. Understanding sleep patterns in this group is significant given the large responsibility these teams have managing project fires and that aging is associated with difficulty initiating and maintaining sleep (Mander et al., 2017). With age sleep becomes more fragmented and therefore there is an increase in nightly awakenings and a reduction in restorative slow wave sleep (Mander et al., 2017; Suzuki et al., 2017). It is important that we work to understand the quality of objective and subjective sleep in this group of firefighters.

4.2 Methods

4.2.1 Participant Recruitment

The same participants and information briefing session was held as described in section 3.2.2

4.2.2 Objective Sleep Measures

Participants were required to wear an activity monitor on their dominant wrist before bed each night. Actigraph data was saved in 60-second epochs and data was manually extracted from the actigraphs to ActiLife 6.11.5 data analysis software (Actigraph Corporation, Pensacola, FL). The

following actigraph variables, as seen in table 3, were used for analysis in the study: total sleep time (TST), wake after sleep onset (WASO), sleep efficiency (SE), and sleep latency (SL).

Table 3 - Definition of Sleep Variables

Total Sleep Time (min)	Total amount of time asleep (min)
Sleep Efficiency (%)	The proportion of time spent asleep while in bed (total sleep time/time in bed)
Wake After Sleep Onset (min)	Time awake throughout sleep period, after initial sleep onset
Sleep Latency (min)	Length of time taken to fall asleep (from lights out)

4.2.3 Subjective Sleep Measures

Firefighters were expected to complete a customized work diary during both fire and rest days. Information was recorded on time in bed (lights out) and time out of bed (Appendix C). This information was used in conjunction with objective sleep data to help improve the accuracy of the assessment of sleep quantity. Participants were also asked to provide a daily subjective sleep quality score each morning using a 5- point Likert scale where 1 = “Very Poor”, 2 = “Poor”, 3 = “Average”, 4 = “Good”, 5 = “Very Good”.

Wildland firefighters were asked to complete a Visual Analogue Scale for sleepiness (VAS- Sleepiness) each day immediately following work during the testing sessions. Firefighters rated their sleepiness on a 100-mm line. The value ranged from 0 mm (not at all sleepy) to 100 mm

(extremely sleepy). The lead investigator (AJ) measured and recorded measurements for each day.

4.2.4 Procedure

Data on quality and quantity of sleep was continuously collected each day throughout the 17-day work deployment. Days 1-14 were active fire line days and days 14-17 were recovery days.

Researchers met the participants on day 1 and recorded baseline measures and showed them how to use the study equipment, ActiGraph wGT3X-BT sleep watches and individual sleep logs.

Each participant was then given a bag, identified with their individual study number, that contained their equipment. Participants were also provided a pre-paid mailing envelope to return the study equipment after day 17, as rest days are off site. Due to the risk of damage on the fire line, actigraphs were instructed to be worn as soon as participants arrived back to fire camp but continuously during rest days. Daily sleep logs were collected by the research team each day to ensure they were properly completed.

4.2.5 Statistical Analysis

The association between group (firefighter vs. management) and time (consecutive days worked (1-17)) for sleep variables were tested with a linear mixed model for repeated measurements.

Results were assessed for both a significant 2-way interaction between group and time and a significant main effect of time, $p < 0.05$. Post-hoc analysis were performed using Tukey's test with a Bonferroni correction for multiple comparisons to identify which days were different.

Subsequently, the main effect of time was analyzed with the data separated by group (firefighter & management). Post-hoc analysis was then again performed using Tukey's test with a Bonferroni correction for multiple comparisons to identify which days were. Mauchly's Test of Sphericity ($p > 0.05$) was used, when the assumption was not met, the p-value from the Greenhouse-Geisser was recorded. Before the analysis, the data was assessed by Shapiro-Wilk's test of normality ($p > .05$) and normally distributed. All data are reported with mean (M) \pm standard deviation (SD).

Total Sleep Time (TST (min)), Sleep Efficiency (SE (%)), Wake After Sleep Onset (WASO (min)), and Sleep Latency (SL (min)) were extracted from Actigraph software and used in the linear mixed model analysis. Data is reported as mean (M) \pm SD and time is reported as hh:mm, unless otherwise stated. Visual analogue scale (VAS) scores of sleepiness (millimeters) and sleep quality (1-5) were measured each consecutive day and the scores were then used in the linear mixed model of analysis. Data is reported as mean (M) \pm SD. All statistical analyses were carried out using IBM SPSS (version 20.0).

4.3 Results

Participant information is the same as section 3.1

4.3.1 Objective Sleep Measures

Total Sleep Time (TST):

Total sleep time (TST) during the 17-day deployment was not significantly different between firefighters ($M= 399.3 \pm 57.5$ minutes) and management ($M=396.8 \pm 46.2$ minutes), $p = .829$. There was no significant interaction between time and group ($F(6, 232), = 13066, p = .078, \eta_p^2 = .049, \varepsilon = .392$) or a main effect of time, $F(6, 232), 14465, p = .051, \eta_p^2 = .054, \varepsilon = .392$. Total sleep time was not significantly different on day 1 (390.6 ± 36.3 minutes) compared to day 17 (426.3 ± 72.7 minutes), $p = 1.000$. Participants average TST during rest days was 415.0 ± 89.2 minutes, nearly 20.0 minutes more than during fire days $M = 395.2 \pm 50.2$ minutes.

When analyzed separately, there was not a significant main effect for time and total sleep time for the firefighter group, $F(5, 164), = 10769, p = .270, \eta_p^2 = .042, \varepsilon = .355$. Post hoc analysis did not reveal a significant difference between day 1 ($M= 394.5 \pm 37.0$ minutes) and day 14 (382.7 ± 73.9 minutes), $p= 1.000$. There was also no significant difference between day 1 ($M= 394.5 \pm 37.0$ minutes) and day 17 ($M=425.7 \pm 75.9$ minutes). The average TST during fire line days for firefighters was to 397.3 ± 49.2 minutes compared 408.6 ± 96.2 minutes during rest days.

There was a significant main effect for time and TST in the management group, $F(4, 33), = 2294, p= .016, \eta_p^2 = .306, \varepsilon = .256$. Post hoc analysis revealed that TST was significantly less on day 1 ($M= 377.7 \pm 32.6$ minutes) compared to day 15 ($M= 447.4 \pm 18.5$ minutes), $p= .008$. Total sleep time was lower on day 1 ($M= 377.7 \pm 32.6$ minutes) compared to day 14 ($M=437.8 \pm 78.7$

minutes) and day 17 ($M= 428.3 \pm 66.5$ minutes). Total sleep time during rest days for management was 436.5 ± 41.9 minutes compared to 388.3 ± 47.0 minutes during fire days.

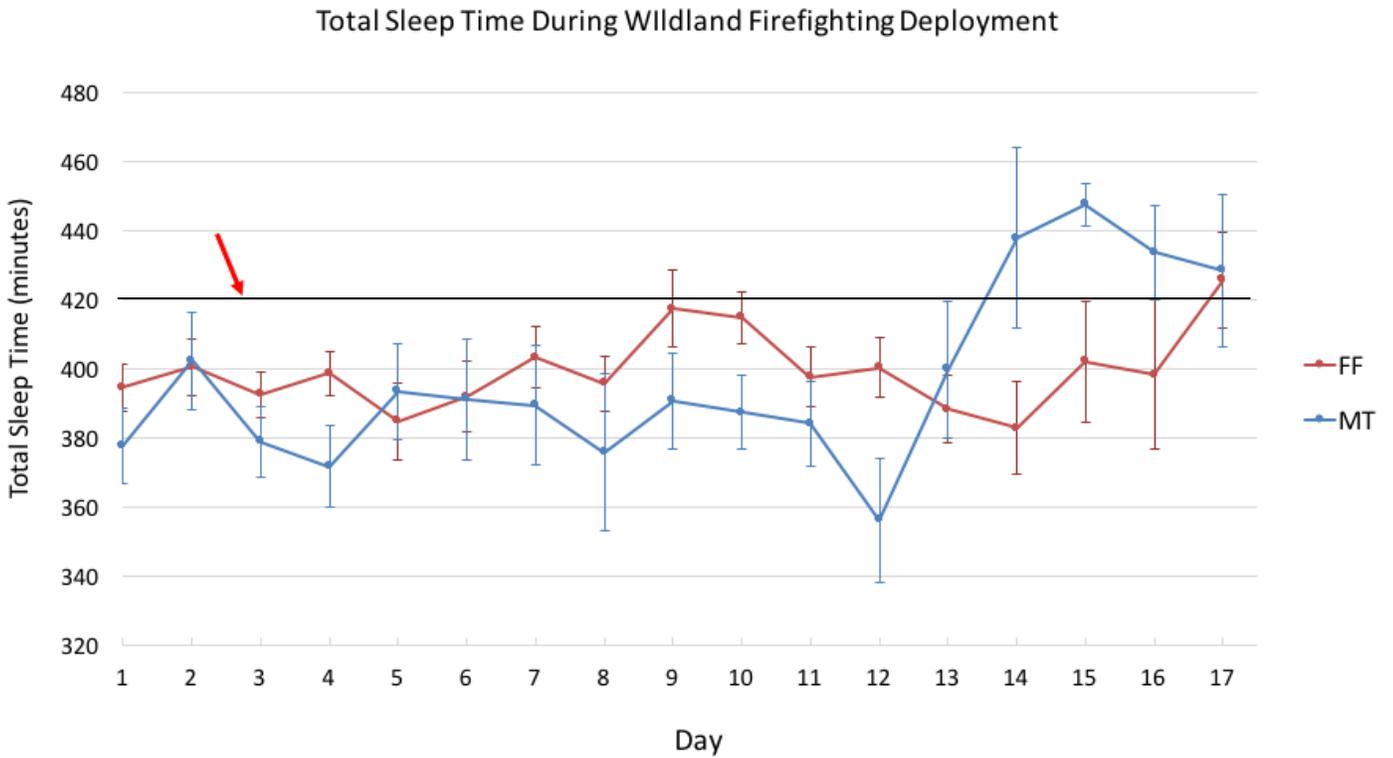


Figure 4: Total Sleep Time During Deployment: Red line indicates firefighters total sleep time and the blue line represents the total sleep time for management team. The red arrow indicates the recommended minimum amount of sleep that should be obtained each night.

Wake After Sleep Onset (WASO):

Wake After Sleep Onset (WASO) was not significantly different between firefighters ($M= 44.0 \pm 24.8$ minutes) and management ($M=45.7 \pm 22.2$ minutes), $p=.794$, during the 17-day deployment. There was not a significant interaction between time and group ($F(8, 297), = 964, p= .184, \eta_p^2 = .037, \varepsilon = .502$) or a significant main effect of time on WASO, $F(8, 297), = 1048.916, p= .138, \eta_p^2= .040, \varepsilon = .504$. Post hoc analysis revealed that WASO was not significantly different on day 1 ($M= 43.7 \pm 22.8$ minutes) compared to day 14 ($M= 40.0 \pm 24.9$ minutes) or day 17 ($M= 55.7 \pm 25.5$ minutes). There was an increase in 12.1 minutes in WASO on day 17 compared to day 1.

There was not a significant main effect of time on WASO in the firefighter group, $F(2, 217), = 1188, p= .105, \eta_p^2 = .055, \varepsilon = .467$. During post-hoc analysis, WASO did not significantly change from day 1 ($M= 41.4 \pm 22.7$ minutes) to day 14 ($M=40.8 \pm 27.9$ minutes) or to day 17 ($M= 52.2 \pm 25.9$ minutes), $p= 1.000$ and 1.000 respectively.

Analysis of separate groups did not demonstrate a significant main effect of time on WASO in the management group, $F(1,33), = 1905, p= .299, \eta_p^2 = .138, \varepsilon = .257$. Post-hoc analysis demonstrated that WASO did not significantly increase from day 1 ($M= 46.0 \pm 22.9$ minutes) to day 14 ($M=39.2 \pm 11.5$ minutes), $p= 1.000$. The average WASO for management during rest days was 58.6 ± 24 minutes, which was 15.7 minutes higher than the WASO average during fire days 42.9 ± 21.8 minutes.

Sleep Latency (SL):

Sleep latency was not significantly different between firefighters ($M= 4.5 \pm 5.6$ minutes) and management ($M= 4.4 \pm 4.1$ minutes), $p= 1.000$ during the deployment. There was no significant interaction between time and group, ($F(9, 333), = 45, p= .516, \eta_p^2 = .024, \epsilon = .562$) or a main effect of time on sleep latency, ($F(9, 333), = 46, p= .506, \eta_p^2 = .024, \epsilon = .562$). Post- hoc analysis did not demonstrate a significant difference between day 1 ($M= 5.38 \pm 4.8$ minutes) and day 14 ($M= 3.1 \pm 4.5$ minutes), $p= 1.000$.

During separate analysis of groups, there was not a significant main effect of time on sleep latency in firefighters, $F(1, 220), = 77.6, p= .261, \eta_p^2 = .043, \epsilon = .491$. Post hoc analysis revealed that there was not a significant difference in sleep latency between day 1 ($M= 5.6 \pm 5.5$ minutes) and days 14 ($M= 3.2 \pm 4.4$ minutes) and 17 (5.2 ± 8.7 minutes), $p= 1.000$ and 1.000 respectively.

There was not a significant main effect of time and sleep latency in the management group, $F(1, 39), = 73.7, p= .315, \eta_p^2 = .133, \epsilon = .307$. Post-hoc analysis revealed that there was not a significant difference in sleep latency between day 1 ($M= 5.2 \pm 1.7$ minutes) and days 14 ($M=3.0 \pm 2.5$ minutes) and 17 ($M= 6.3 \pm 5.8$ minutes), $p= 1.000$.

Sleep Efficiency (SE):

Our results did not demonstrate a significant difference in sleep efficiency (SE) (%) between firefighters ($M= 89.0 \pm 5.7\%$) and management ($M=88.6 \pm 4.8\%$), $p= .757$, during the 17-day deployment. There was no significant interaction between group and time, ($F(9,330), = 39, p= .286, \eta_p^2 = .032, \epsilon = .557$) or a significant overall main effect of time on sleep efficiency ($F(9, 330), =56, \eta_p^2 = .046, \epsilon =.557$). Post-hoc analysis for all participants demonstrated that there was no significant differences between SE on day 1 ($M= 88.7 \pm 5.2\%$) compared to day 14 ($M= 90.0 \pm 5.5\%$). The average SE score for participants during the rest period was ($M= 88.1 \pm 6.3\%$) compared ($M=89.1 \pm 5.4\%$) during fire days.

During separate analysis of groups, firefighters had a significant main effect of time on sleep efficiency, $F(8, 228), = 81.552, p= .023, \eta_p^2 = .073, \epsilon = .492$. Post-hoc analysis revealed significantly lower SE scores on day 5 ($M= 85.9 \pm 7.5\%$) compared to day 9 ($M= 90.5 \pm 4.3\%$), $p=.044$. Sleep efficiency did not differ from day 1 ($M= 89.3 \pm 5.2 \%$) to day 14 ($M= 89.5 \pm 6.1\%$) or to day 17 ($M= 87.3 \pm 6.2\%$), $p= 1.00$ and 1.00 respectively. The average SE score during the rest period was $M= 88.4 \pm 6.7 \%$ compared $89.2 \pm 5.5\%$ during fire days.

There was not a significant main effect of time on SE in the management group, $F(5,37), = 78.5, p= .322, \eta_p^2 = .132, \epsilon = .285$. Post-hoc analysis did not reveal any significant differences in SE between days 1 ($M= 88.1 \pm 5.2\%$) and days 14 ($M=90.4 \pm 3.1 \%$) and 17 ($M= 85.6 \pm 4.9\%$). The average SE score during the rest period for MT was $86.8 \pm 4.3\%$ which was notably lower than the SE score during fire line days, $90 \pm 4.9\%$.

Table 4 - Sleep Variables for Firefighters (FF) and Management Team (MT) During a 17-Day Firefighting Deployment

	Overall (N=39)		FF (n=30)		MT (n=9)	
	Mean	SD	Mean	SD	Mean	SD
Total Sleep Time (mins)	398.7	59.4	399.3	57.5	396.8	46.2
WASO (mins)	44.4	24.7	44.0	24.8	45.7	22.2
Sleep Latency (mins)	4.5	5.5	4.53	5.6	4.40	4.1
Sleep Efficiency (%)	88.9	5.6	89.0	5.7	88.6	4.8
Sleep Quality	3.3	0.9	3.30	0.9	3.20	0.8
VAS-Sleepiness	5.0	2.2	5.10	2.1	4.60	2.0

*Significant ($p < .05$) difference between Firefighter (FF) and Management (MT) group

4.3.2 Subjective Sleep Measures

Sleep Quality:

Sleep quality did not significantly differ between firefighters ($M= 3.3 \pm 0.9$) and management ($M=3.2 \pm 0.8$), $p= .361$, during the 17-day deployment. Our results did not demonstrate a significant interaction between time and group, ($F(9, 340), = 341, p=.955, \eta_p^2 = .010, \epsilon = .575$) or a main effect of time on sleep quality, $F(9,341), = 1.4, p= .274, \eta_p^2 = .032, \epsilon = .575$. Post-hoc analysis did not demonstrate a significant difference between day 1 ($M= 3.1 \pm 1.0$) and day 14 ($M= 3.2 \pm 0.9$). The average sleep quality was higher during deployment days ($M= 3.3 \pm 0.9$) compared to rest days ($M= 3.0 \pm 1.0$).

When analyzed separately, firefighters did not have a significant main effect of time on sleep quality, $F(8, 235), = 2.001, p=.109, \eta_p^2 = .054, \epsilon = .507$. Post-hoc analysis demonstrated that day 1 ($M= 3.1 \pm 1.0$) was not significantly different than days 14 ($M= 3.2 \pm 0.9$) or 17 ($M=3.1 \pm 1.2$). Sleep quality during rest days ($M= 3.1 \pm 1.0$) were lower than during fire line days ($M= 3.4 \pm 0.9$).

Our results demonstrated that there was not a significant main effect of time on sleep quality for the management group, $F(1, 43), = 1.1, p=.806, \eta_p^2 = .056, \epsilon = .340$. Post-hoc analysis revealed no significant differences between day 1 ($M= 3.0 \pm 1.0$) and days 14 ($M= 3.2 \pm 1.1$) or day 17 ($M= 3.0 \pm 0.9$). The average sleep quality during rest days ($M= 3.0 \pm 0.9$) was lower than during fire line days ($M= 3.2 \pm 0.8$).

VAS-Sleepiness:

There was no significant difference between levels of subjective sleepiness during deployment between firefighters ($M=5.1 \pm 2.1$ mm) and management ($M=4.6 \pm 2.0$ mm), $p= .202$. We did not have a significant interaction for time and group, ($F=8, 291$), $= 7$, $p= .471$, $\eta_p^2 = .025$, $\epsilon = .491$) but our results did demonstrate a significant main effect for time, ($F=8, 291$), $= 40$, $p= <.0005$, $\eta_p^2 = .126$, $\epsilon = .491$. Subjective levels of sleepiness were significantly higher on days 13 ($M=6 \pm 2.1$ mm) and 14 ($M=6. \pm 2.0$ mm) compared to day 1 ($M= 4.0 \pm 2.2$ mm), $p= .002$ and $.003$ respectively. Reports of subjective sleepiness were higher during rest days ($M= 5.4 \pm 2.4$ mm) compared to fire line days ($M= 4.9 \pm 2.2$ mm).

During separate analysis of groups there was a significant main effect of time on subjective sleepiness for the firefighter group, ($F=4, 238$), $= 28$, $p= <.0005$, $\eta_p^2 = .112$, $\epsilon = .513$. During post-hoc analysis, firefighters did not have a significant increase in reported sleepiness on day 1 ($M=4.3 \pm 2.2$ mm) compared to day 14 (6.0 ± 2.0 mm), $p= .454$. Subjective sleepiness was significantly higher on day 16 ($M=6.5 \pm 2.3$ mm) compared to day 1 ($M=4.3 \pm 2.2$ mm), $p= .068$. The average sleepiness during fire line days ($M= 5.0 \pm 2.1$ mm) was lower than during rest days ($M= 5.6 \pm 2.4$ mm).

There was a significant main effect of time on subjective sleepiness in the management group, ($F=4, 25$), $= 55$, $p= .023$, $\eta_p^2 = .316$, $\epsilon = .197$. There was a significant increase in subjective sleepiness on day 14 ($M= 6.3 \pm 1.8$ mm) compared to day 2 (2.4 ± 1.7 mm), $p=.026$. Post-hoc analysis did not reveal any significant difference in sleepiness on day 1 ($M= 2.8 \pm 2.5$ mm)

compared to days 14 (6.3 ± 1.8 mm) and 17 ($M= 4.8 \pm 2.5$ mm), $p= 1.000$ and 1.000 respectively. The average scores of subjective sleepiness during rest days ($M= 4.7 \pm 2.6$ mm) were similar to scores during fire days ($M= 4.6 \pm 1.9$ mm).

4.4 Discussion

The aim of this study was to investigate and quantify the impact that the current BCWS firefighting schedule has on the sleep behavior of BCWS firefighters and management personnel. The main finding was that total sleep time was suboptimal during both fire and non-fire days in all participants. Our other significant main finding was that participants reported being significantly sleepier during rest days compared to fire line days, indicating the potential for sleep deprivation and fatigue prior to their next deployment.

The results of our study did not demonstrate a significant difference between total sleep time in BCWS firefighters ($M= 397.3 \pm 49.2$ minutes) and management team personnel ($M=388.3 \pm 47.0$ minutes) during the 17-day fire deployment. It should be noted that the sleep obtained for both these groups is below the current recommended guidelines for adults, 7-9 hours a night (Hirskowitz et al., 2015; Watson et al., 2015). Our results demonstrated that firefighters and management obtained different amounts of total sleep time during the recovery days of deployment. Management personnel were able to obtain nearly 30 minutes more sleep a night than wildland firefighters during the 3-day rest period. In our sample of firefighters, TST was only 6.8 hours during recovery nights. This result was particularly disconcerting given that firefighters in our study had just worked 14 consecutive shifts in which they slept on average less

then 7 hours a night. These wildland firefighters also both reported higher subjective levels of sleepiness during the rest period compared to fire line days and sleep quality was only reported as “average” during sleep in their home environment during the recovery period. The findings of our study indicate that firefighters may not be achieving optimal sleep while on recovery and therefore could be at an increased risk of being fatigued prior to entering their next 14-day deployment. Although our research did not follow firefighters for multiple deployments it is worth highlighting that participants had notably poor cognitive scores on the PVT test on day 1 compared to later days in the deployment. In addition, total sleep time was only 6.5 hours and self-reported fatigue was high on day 1 given that they had just come from a 3-day rest period. These findings further support the suggestion that participants were poorly recovered before the next deployment. We suggest that further research should be conducted to follow firefighters over multiple deployments to better understand how the work schedule and rest period interact to impact sleep behaviors and to also measure cognitive performance during the rest period, which was a limitation of our study. We also suggest that future research should investigate the activities that firefighters do during recovery days and we recommend sleep hygiene and fatigue training to increase the amount of sleep that firefighters are achieving during their rest days.

The results from our study suggest that the majority of firefighters in this study were accumulating sleep debt for upwards of 17 consecutive days. Previous research has shown that chronic sleep restriction has detrimental effects on alertness, vigilance, psychomotor skills, judgment and health (Van Dongen et al., 2003; Durmer & Dinges, 2005; Czeisler & Gooley, 2007; Yeo et al., 2013). Notably, the ability to sustain attention, maintain cognitive performance and prevent attentional failures deteriorates when sleep is chronically restricted to 7 or fewer

hours per night for a week or longer (Institute of Medicine, 2006; Belenky et al., 2003; Van Dongen et al., 2003). Firefighters and management personnel in our study on average slept less than 7 hours a night for 14 consecutive nights. Other research suggests that subjective measures of stress, tiredness, sleepiness, irritability, hostility and distractibility increase with chronic sleep deprivation, as well as increases in total mood disturbance and impairment of judgment (Anderson & Horne, 2006; Dinges et al., 1997). Our results demonstrated a trend, where firefighters reported higher levels of fatigue and sleepiness with consecutive days worked, although this finding did not reach significance. The effects of sleep deprivation are not overcome with a single night's sleep, but can carry over several days. Chronic sleep deprivation leads to an increased probability of experiencing lapses of attention and falling asleep in inappropriate or dangerous situations (Van Dongen et al., 2003; Dinges, 1995). Despite intermittent opportunities for recovery sleep, individuals exposed to such schedules become increasingly vulnerable to the adverse effects of sleep loss on performance (Van Dongen et al., 2003). Cohen et al. (2010) showed that even when a 10-hour sleep opportunity in bed in a dark and quiet room was insufficient to reverse vulnerability to sleep loss associated with a week of chronic sleep restriction to 6 hours of time in bed. In fact, six hours of time in bed per night for a week or two brings the average adult to the same level of neurobehavioral impairment as 24 hours of wakefulness (Van Dongen et al., 2003).

The total sleep time results from our firefighting study are similar to other studies that have been conducted amongst wildland firefighters in the field (Vincent et al., 2016; McGillis et al., 2017). In these two studies, total sleep time was reported as 6.1 h (Vincent et al., 2016) and 6.2 h (McGillis et al., 2017), both are below the level considered optimal for sleep duration (7-9 h) in

adults (Hirshkowitz et al., 2015). In a study conducted amongst Canadian firefighters in Ontario, total sleep time was reported as 6.2 hours during base camp work deployments (McGillis et al., 2017). McGillis et al. (2017) also demonstrated that total sleep time during the initial wildfire suppression deployment was only 4.8 h and during non-fire days on base was 6.2 hours. The finding that non-fire work was associated with suboptimal sleep is important given the risk of pre-deployment sleep deprivation and inadequate rest (McGillis et al., 2017). An objective study conducted by Vincent et al. (2016) amongst Australian firefighters suggested that they slept on average 6.1 hours during deployment, 54 mins less than on days not fighting wildfires.

Total sleep time was not the only sleep parameter to demonstrate that sleep behaviour was disrupted during the 17-day work cycle. Wake after sleep onset (WASO) was significantly high during fire days in both BCWS firefighters ($M= 44.0 \pm 24.8$ minutes) and management team personnel ($M=45.7 \pm 22.2$ minutes). The recommended threshold for WASO is 31 minutes (Ohayon et al., 2004). Both firefighters and management fell above the recommended threshold of WASO scores during both the fire and rest days, indicating poorer sleep quality. Another measure of sleep quality, sleep efficiency (%) was not significantly different between fire and rest days or between firefighters and management. It is worth mentioning the sleep efficiency on average was above the recommend levels, >85%. In the study conducted amongst Canadian firefighters by McGillis et al. (2017) it was found that WASO during project fires was $M= 51.4 \pm 33.7$ minutes, also indicating poor sleep quality across the project fire; however, WASO was not measured during rest days. Vincent et al. (2016) demonstrated there was no differences between fire and non-fire days in subjective sleep quality, sleep efficiency and number of times awoken during the night during wildfire suppression. These poor results of sleep quality during the rest

days may be due to the fact that the effects of sleep deprivation are not overcome with a single night's sleep but can carry over several days (Van Dongen et al., 2003; Banks, 2007; Cohen et al., 2010). The longer the exposure to sleep restriction, the greater cognitive deficits. The less sleep obtained and the longer this continues the more quickly cognitive deficits become evident.

The findings of our study indicate that firefighters may not be achieving optimal sleep both on the fire line and during the allocated recovery period and firefighters could be at an increased risk of a suboptimal recovery. Our results demonstrate that firefighters could be entering a deployment inadequately rested and fatigued from their previous deployment. Fatigue and subsequent sleep restriction from working an additional 14-days could impact workplace performance, well-being and safety. Our findings suggest that management and organizations should consider fatigue management training to promote practices of good sleep hygiene to maximize recovery opportunities and ensure firefighters are adequately rested.

Chapter 5: Bio-mathematical Model of Fatigue

5.1 Introduction

Complete elimination of fatigue risk, at the top the hierarchy of control in Occupational Health and Safety (OHS), is not possible in the context of firefighting. Given the nature of forest firefighting, it is difficult to implement prescription-of-hours or to reduce the consecutive days worked when communities and lives are at stake. However, fire agencies and organizations must utilize countermeasures that focus on controls which limit, rather than prevent, exposure. A useful tool that fire agencies and organizations can use to assist in the decision-making and management of fatigue is validated bio-mathematical models of fatigue. These models, based on best available evidence on biological sleep processes, are capable of 1) predicting the level of fatigue associated with a pattern of work; and 2) promoting good design of work hours by identifying shift parameters which contribute to fatigue (Dawson et al., 2011; Williamson et al. 2013). To our knowledge, no study has used a bio-mathematical model of fatigue in a firefighting environment, however, several studies have looked at the impact of shift parameters on fatigue in firefighting (McGillis et al., 2017; Vincent et al., 2016). The purpose of this chapter is to use the CAS model to predict the risk of fatigue in the current BCWS firefighting schedule (14-on-3-off) and to provide information on current shift parameters to the BCWS organization for targeting interventions or strategies in managing fatigue.

Using a model will provide important insights into the current shift patterns of BC firefighters. Shift characteristics that contribute to occupational fatigue were examined in the 17-day

firefighting deployment and included; shift duration, shift start and end times, time between two successive shifts, extended wakefulness (>16 hr), and total weekly hours (Williamson & Friswell, 2013; Dawson et al., 2011; Satterfield & Van Dongen, 2013; Lerman et al., 2012).

5.2 Methods

Firefighter deployment data from the same 39 participants was made available to the lead researcher, AJ, by the BCWS after the completion of the study. This data included shift start times, shift end times, and deployment lengths. This data was then manually entered into the CAS software by AJ. Next, using both participant sleep logs and actigraphy data, time in bed was manually entered into the software to allow CAS to generate fatigue scores for each participant. The shift variables of interest were; 1) shift start times, 2) duration of shift, and 3) time between shifts. Using the deployment data provided by the BCWS, total shifts and total work hours for firefighter and management groups were calculated.

5.3 Results

A total of 551 shifts and 7186.8 hours were worked during the study period by all participants (FF (N=30) = 416 shifts and 5322.5 hours and MT (N=9) = 135 shifts and 1864.3 hours). The average shift duration for firefighters was 12.8 hr \pm 30 mins and 13.6 hr \pm 46 mins for the management team, as seen in figure 7. During deployment, 72% (N=97) of shifts for management firefighters were >14 hours in length, as seen in table 5. During deployment for firefighters, 30% (N=125) of shifts were >14 hours in length. The average shift start time during

deployment was 7:02 am \pm 6 minutes for firefighters and 7:20 am (\pm 1 min) for management, as seen in figure 9. Of 551 shifts, only 5% (N=28), started before 07:00am. The average shift end time for firefighters was 8:09 pm \pm 1 minute and 9:06 pm \pm 2 mins for the management team. The average time between shifts was 10.6 hours \pm 2 mins for firefighters and 9.9 hr \pm 47 mins for management, as seen in figure 8. Of 551 shifts during the study, only 2.4% (N=13) allowed for \leq 8 hours between shifts and 14.9% (N= 82) allowed for \leq 9 hours off between shift. A full description of shift characteristics during deployment are reported in Table 5.

The average CAS score for all BCWS firefighters during a 17-day deployment was 29.7 ± 6.2 , as seen in figure 6. No firefighter had a high fatigue risk score (>60) and the range of CAS scores was between 21.6 to 56.3. The top 3 risk factors for fatigue generated by the CAS model based on the BC wildland firefighter schedule were; 1) Total hours worked, 2) Desynchrony of circadian clock, and 3) Sleepiness risk on duty.

CAS Fatigue Score = 29.4

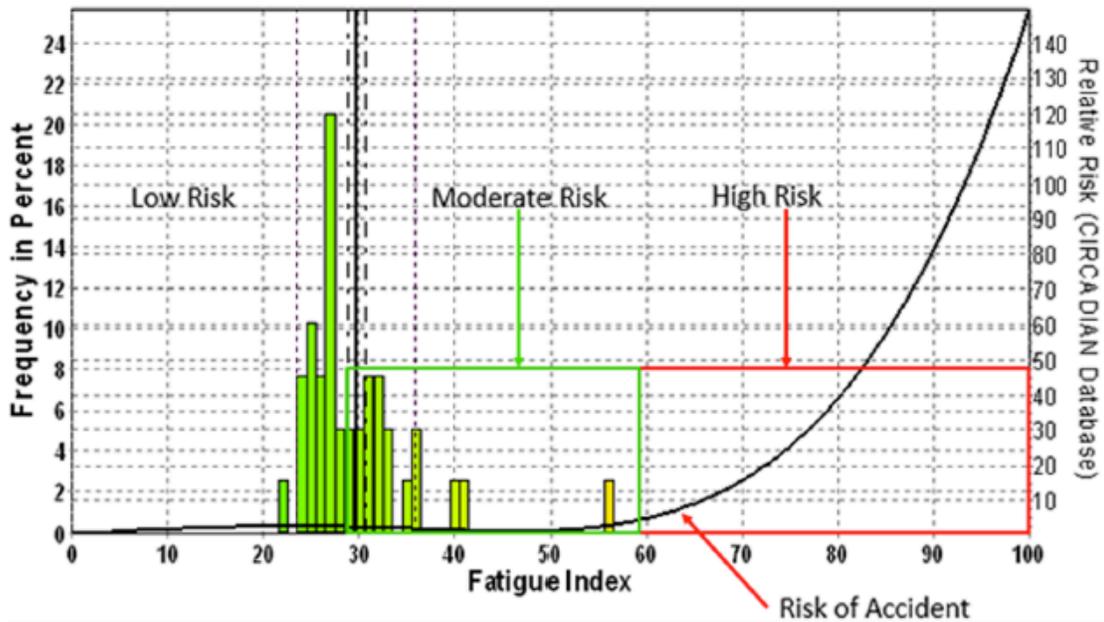


Figure 5: Breakdown of CAS Scores for Participants. Bars indicate the frequency of firefighter’s fatigue index scores. Red arrow indicates when relative risk of an injury increases exponentially in the High Risk Zone. No firefighter was in the High Risk Section. The average score for all participants (N= 39) is 29.4.

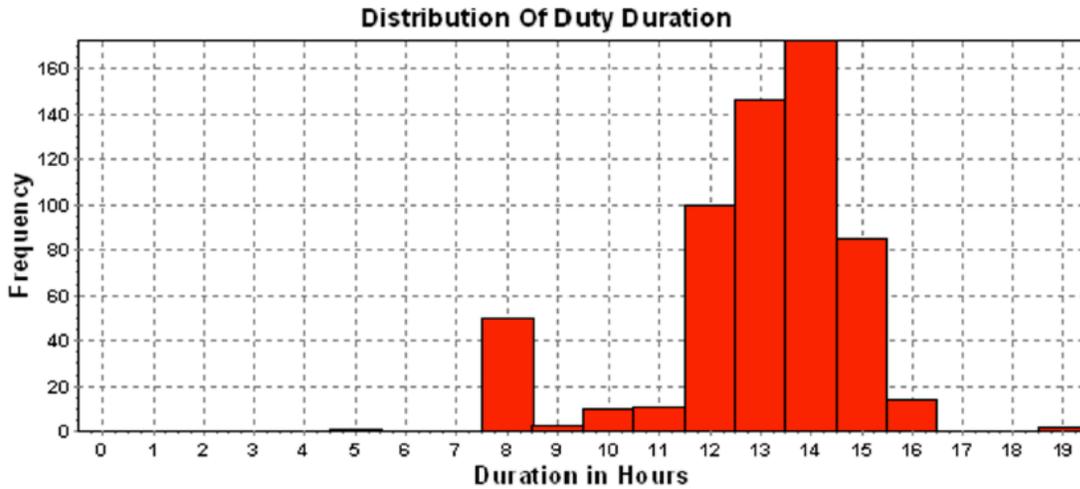


Figure 6: Distribution of Duty Duration During Deployment: Red bars indicated the frequency of shifts of the various lengths during the 17-day deployment for participants (n= 39).



Should avoid a schedule that only allows 8-hours between schedules

Figure 7: Distribution of Time Off Between Successive Duty Periods: Red bars indicate frequency of shifts of varying time off (hrs) between successive days during a firefighting deployment. Red arrow indicates number of shifts with only 8 hours rest.

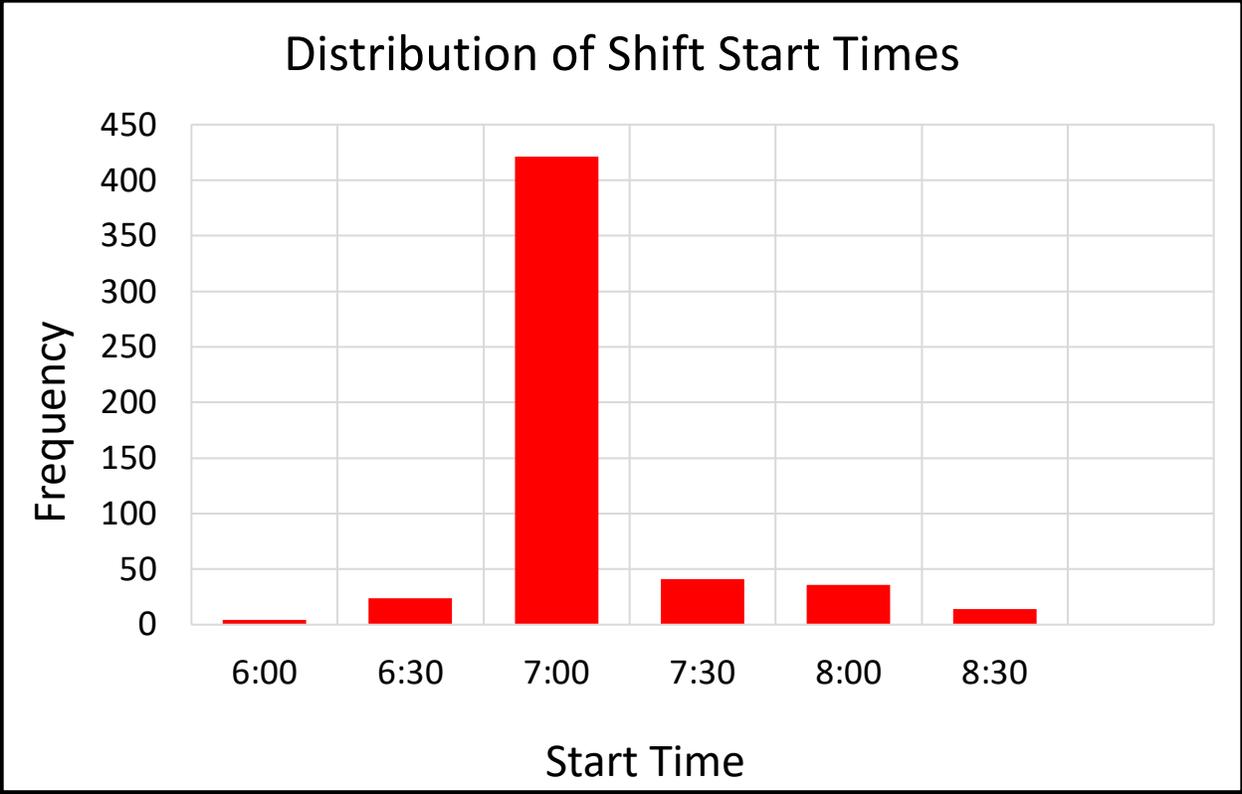


Figure 8: Distribution of Shift Start Times During Deployment: Red bars indicate frequency of shift start times (am) for firefighters during the 17-day deployment.

Table 5 - Schedule Characteristics for Firefighters (FF) and Management Team (MT)

	Overall (N=39)			FF (n=30)			MT (n=9)		
	Mean	SD	Range	Mean	SD	Range	Mean	SD	Range
Shift Duration (hr:min)	13.0	0:43	5.0 - 19.0	12.8	0.30	5.0 - 19.0	13.8	0.46	8.0 - 16.0
Shift Start time (am)	7:07	0:06	06:00 - 08:30	7:02	0.06	06:30 - 08:30	7:20	0.01	06:00 - 08:30
Shift End Time (pm)	20:24	0.02	16:00 - 23:00	20:09	0.01	16:30 - 22:30	21:06	0.02	16:00 - 23:00
Time between Shifts (hr:min)	10.4	0:46	8.0 - 16.0	10.6	0.02	8.0 - 16.0	9.9	0.47	8.0 - 15.0

5.4 Discussion

Operational shift parameters including shift length and shift start times can be major contributors to inadequate sleep and fatigue in firefighting and other shift work settings (Cater et al., 2007; Vincent et al., 2016; Williamson & Friswell, 2013). One of our main findings was that 72% of management and 30% of firefighters worked >14 hours a day. Shifts of this length leave little opportunity to sleep and as a consequence, increase the homeostatic pressure to sleep and the risk of a workplace injury (Scatterfield & Van Dongen, 2013; Folkard and Tucker, 2003; Lombardi et al., 2010). Dembe and his colleagues (2005) demonstrated that workers who worked >14 hours a day had over two times the risk of a workplace accident than those that worked 8 hours. Shift workers that work > 64 hours a week had an 88% greater risk of a workplace injury compared to workers who worked 40 hours a week (Vegso et al., 2007). In our study, all the participants worked > 85 hours a week during the deployment. McGillis et al. (2017) found the the average shift length during project fires was 12.3 hr \pm 60 minutes and that 26% (N=31) of shifts were >13 hours. Firefighters in our study worked on average 12.8 hr \pm 30 mins and 30% (N=125) of shifts were \geq 14 hours in length. McGillis et al. (2017) demonstrated a downward trend in sleep quantity with increasing shift length, 16 min less sleep when shifts > 13 hours compared to when shifts are <12 hours. Vincent et al. (2016) further highlighted that the average shift length amongst Australian firefighters was 11.4 hr \pm 3.0 hr and shifts that were > than 14 hours in duration were associated with 48 minutes less sleep than shifts < than 14 hours. These are important findings to the BCWS organization as 72% of management shifts in our study were \geq 14 hours. Furthering this risk, the average age of this group is 48.1 \pm 6.3 years and as you age,

sleep becomes more fragmented and of poorer quality, therefore sleeping 48 minutes less with shifts >14 hours is a significant finding. A limitation in our study is that we did not investigate different shift lengths and respective associations with subjective and objective levels of fatigue and sleep. Thresholds for increased likelihood of fatigue and related impairment are shown for shifts as little as 10 hours in length (Folkard & Tucker, 2003). Given the nature and dependency of the work firefighters do, long shifts will continue in this occupation. Therefore, identifying and highlighting deployment information such as shift duration is essential for fire agencies as they continue to manage and mitigate fatigue as an occupational challenge.

The results from our study found that no shifts started before 6 am and in fact only 5.0% (n=28) shifts began before 7 am. Shifts with early start times have been shown to reduce total sleep time in forest firefighters (McGillis et al., 2017; Vincent et al., 2016; Cater et al., 2007). In a study amongst Australian wildland firefighters, shifts starting before 6 am resulted in 60 minutes less sleep when compared to shifts starting after 6 am (Vincent et al., 2016). Total sleep time was also 75.9 minutes less in shifts that started between 5 and 6 am when compared to shifts starting between 6 and 7 am in Canadian firefighters (McGillis et al., 2017). Collectively, this suggests that whenever possible fire agencies should preferentially implement later shift start times to mitigate the risk of truncated sleep. Early start times and shortened sleep has also been shown in other shift work populations (Williamson & Friswell, 2013; Folkard et al., 2005; Akerstedt et al., 2009). For example, in train drivers when shifts started at 6 am, total sleep time averaged 5.5 hours compared to 7.7 hours when shift times were moved to 9 am (Ingre et al., 2008). A reduction in sleep quantity from earlier shift start times could be attributed to maladjusted bed times and circadian physiology (Boivin & Boudreau, 2014). For instance, workers who attempt

to move their bed time earlier when their circadian physiology has a low sleep propensity may have difficulties in falling asleep (Boivin & Boudreau, 2014). The BCWS should continue to avoid early shift start times as the evidence suggests that even a small advance of 1 hour of the start time of a shift (6 am vs. 7 am) will result in truncated sleep (Smith et al., 1998). Fire agencies and organizations should also be aware that although the same amount of sleep opportunity may be given to firefighters, if at different times of the day when sleep propensity is low, total sleep time and quality will be compromised (Jay et al., 2008).

A serious risk factor for fatigue in shift work occupations is schedules that do not offer enough opportunity to sleep and recover (Williamson & Friswell, 2013; Belenky et al., 2003; Dinges et al., 1997; Van Dongen et al., 2003; Axelsson et al., 2004). Prolonged wakefulness produces a sleep debt and homeostatic drive to sleep that can have serious effects on performance capacity and safety outcomes (Durmer & Dinges 2005; Williamson et al., 2011; Akerstedt et al., 2009). Our study demonstrated that there were only 13 (2.4%) firefighting shifts that provided only 8 hours between successive shifts and only 82 (14.9%) firefighting shifts that provided 9 hours between start times. Ideally work schedules would make the time between shifts ≥ 12 hours, to maximize sleep, however this is often not possible in firefighting environments. The current National Sleep Foundation recommends for adults to obtain 7-9 hours of sleep per day (Hirshkowitz et al., 2015) and therefore shifts that only provide only 8 and 9 hours between the next shift start times seriously compromise sleep opportunity. It has been shown that truncated sleep can have serious cognitive and occupational consequences (Dinges, 1995; Durmer and Dinges, 2005; Williamson et al., 2011) and it is important that firefighters get adequate restorative sleep while on deployment. Restorative and adequate sleep is particularly important

in such a physically and cognitively demanding occupations such as wildland firefighting. It is important for fire agencies to continue to control, identify, and minimize scheduling features that only allow 8 and 9 hours between successive shifts to ensure fatigue and worker safety.

Previous research using CAS in shiftwork operations has demonstrated that the rate of human error accidents starts to climb exponentially once fatigue risk scores exceed 60 (Moore-Ede et al., 2004). The average CAS score for firefighters was 29.4, a low risk fatigue score. In fact, no firefighters during the 17-day deployment had a high risk score. For reference, an office worker sleeping 8 hours every night including weekends, at exactly the same time of day and working from 9am to 5pm on Mondays to Fridays, with no weekend work and no overtime hours, has on average a CAS Fatigue Risk Score of 5 (Circadian, 2018). In contrast, a surgical resident working a duty cycle of 36- hours non-stop, with 12 hours off before starting the next 36-hour non-stop shift averages a CAS Fatigue Risk score of 95 (Circadian, 2018). Several firefighters had a 'moderate' fatigue risk. In order for fire agencies and organizations to gain insight on which shift characteristics may be contributing to fatigue we took a closer look at a duty schedule for a participant with a moderate fatigue risk during deployment. The fatigue risk factors generated by CAS for this participant were: 1) Total hours worked, and 2) Sleepiness risk on duty. This analysis revealed that the firefighter worked on average 15 hour days, he had sleepiness risk on duty due to his shortened sleep periods and potential for sleep inertia (<15 minutes of time awake before starting his shift). To our knowledge this is the first study to use a bio-mathematical model of fatigue in a firefighting setting. We utilized this model to highlighted important shift characteristics that should be reviewed and considered when planning firefighting deployments to minimize fatigue in the workplace.

Chapter 6: Recommendations and Future Directions

The current study sought to objectively and subjectively assess fatigue and sleep behaviour in Canadian wildland firefighters. This study provides valuable insight into understanding the role of fatigue and sleep patterns in B.C. wildland firefighters. The results of this project provide some recommendations to the BCWS and aim to support the development, continuous improvement, and implementation of a structured and comprehensive safety training program. The results also provide discussion and ideas for future research to ensure the ongoing safety of wildland firefighters.

6.1 Applying Fatigue Research to the Field

The BCWS revitalized a 5-year (2012-2017) strategic plan to ensure itself as one of the foremost leaders in wildfire management (Province of British Columbia, 2018c). They created a mandate that aims to deliver effective wildfire management and emergency response on behalf of the government of British Columbia to protect life and values at risk (Province of British Columbia, 2018c). The mission in meeting this mandate is to provide an effective, innovative, cost-efficient, and most importantly a safe workplace for staff and the public (Province of British Columbia, 2018c). In order to assist in meeting this goal one of the objectives of this research project was to guide discussion with stakeholders and management in ensuring a comprehensive fatigue risk management system (FRMS) would be in place in the BCWS.

6.2 Workplace Fatigue Risk Management Systems

Fatigue risk is an ever-present challenge to the safety, health, and quality of life for forest firefighters and must be effectively managed and controlled every day. In the last 10 years there has been an emergence and implementation of FRMS as a more effective approach to managing and mitigating employee fatigue risk in the workplace (Dawson & McCulloch, 2005). A FRMS can be defined as a scientifically based, data-driven and cooperative system, designed by all stakeholders to manage employee fatigue in a flexible manner appropriate to the level of risk exposure and the nature of the operation (Lerman et al., 2012). Important to the success of implementation of a comprehensive FRMS is understanding the key characteristics as suggested by Lerman et al. (2012):

- Science based- Supported by peer-review science
- Data driven- Decisions based on collection and objective analysis of data
- Cooperative- Designed together by all stakeholders
- Fully Implemented- System-wide use of tools, systems, policies, and procedures
- Integrated- Built into the corporate safety and health management systems
- Continuously Improved- Progressively reduces risk using feedback, evaluation, and modification
- Budgeted- Justified by an accurate return of invest business case
- Owned- Responsibility accepted by senior corporate leadership

Although the above key characteristics need to be considered in implementation of a FRMS, organizations such as the BCWS also need to ensure the on-going improvement of fatigue and safety through identifying hazards in the workplace. A FRMS system should continuously evolve and improve over time to progressively reduce fatigue. For example, to achieve this one of the goals of the project was to identify hazards associated with the current work schedule of B.C. wildland firefighters to allow for the BCWS to review and potentially modify the current system.

6.2.1 Core Components of an FRMS

The core components of an FRMS as suggested by Lerman et al. (2012) are:

1. Fatigue management policy
2. Fatigue risk management; including collecting information on fatigue as a hazard, analyzing its risk, and instigating controls to mitigate that risk
3. Fatigue reporting system for employees
4. Fatigue incident investigation
5. Fatigue management training and education for employees and management

The following recommendations to the BCWS are addressed to each of the above core components.

6.3 Recommendations

6.3.1 Fatigue Management Policy

Specific policy recommendations and changes are beyond the scope of this research but it is intended that the following recommendations will guide discussion amongst stakeholders and management.

- Ensure that employees get at least 10 hours off between shifts:

This is a significant recommendation because shortened breaks of 8 and 9 hours reduces the likelihood that a BCWS firefighter can obtain adequate sleep between successive shifts and increases the likelihood that they are sleep deprived for their next shift.

- Review internal driving policies and risks following a work cycle:

Many of the firefighters and management personal that were involved in this study had long commute times of >6 hours at the beginning and end of their 14- day shift. Working 14 consecutive days can lead to fatigue which significantly increases the risk of fatigued related traffic accidents (Williamson et al., 2011). Possible mitigation strategies would be to shorten work days when crews have long commutes, provide opportunity for drivers to nap if needed prior to leaving, avoid long night time drives the same day, provide fatigue and driver behavior

technology in the trucks, or set driving limits based on distance (mileage) and hours immediately following a shift.

- Avoid shifts that start or end between 1am-5am:

Although night burning is rare amongst BCWS firefighters, shifts that start or end between 1-5am should be avoided due to the circadian low and significantly increased accident risk (Lerman et al., 2012). Our results from this study demonstrated that the BCWS had no shifts that started before 6am.

- Ensure that there are systems in place to detect excess fatigue:

This may involve a careful review of staffing levels, scheduling, excessive overtime, and accident and near miss investigations. This also may include a screening program to detect sleep disorders in the incident command teams or populations at risk for such sleep disorders.

6.3.2 Fatigue Risk Management Plan

To proactively manage fatigue, it is recommended that the BCWS develop a fatigue risk management plan for their operations. This will provide all employees, supervisors, contractors, and stakeholders with an overall operating standard, ensuring that everyone understands their roles and responsibilities for managing fatigue in the workplace. Such a plan or document will

serve to systematically control and reduce the costs, risks, and liabilities of fatigue-related human error and may involve:

➤ Collecting information on fatigue as a hazard:

Tracking information on work hour exceptions that may contribute to workplace fatigues, for example distribution (%) of shift lengths that are >12, and > 14 hours, > 16 hours and attempt to understand the rationale for when shifts exceed 14 hours. It is recommended that there should be a review of annual turnover, absenteeism, and overtime statistics.

➤ Identify the high fatigue risk population within BCWS:

This will include those that work the night shift, have off site daily commutes and routinely have shifts > 12.5 hours in length. It is suggested to educate, evaluate and implement protocols to ensure that these populations are safe as they are at the highest risk.

➤ Conduct and review annual accident and injury rates attributed to fatigue:

By including a fatigue accident investigation protocol and annual review it would enable the BCWS to know the true cost and impact of fatigue during fire season.

➤ Begin to benchmark fatigue:

It is recommended that BCWS monitors fatigue on an ongoing basis by using root cause accident investigations where fatigue may have been a causal factor, capturing work hour exceptions and potentially implementing a fatigue model. By examining historic data (e.g. comparing 2015 to 2016) for trends it can determine the impact and success of BCWS' fatigue risk management programs/initiatives.

6.3.3 Fatigue Reporting System for Employees

Knowledge of how to recognize fatigue is a component of the training that employees need to receive. However, employees typically only bring these matters to the attention of their supervisors if the organization succeeds in creating a “safety culture” that recognizes fatigue. It is recommend that the BCWS:

- Have a reporting process that is both simple and straightforward:

It is crucial that problems are identified and dealt with in a timely manner and investigations do not focus on who made the mistake but how and why the defenses failed.

6.3.4 Fatigue Incident/Accident Investigation

A comprehensive FRMS needs to provide an incident investigation process to identify how and why the control mechanisms failed. Therefore, it is recommend that the BCWS:

- Conduct a Fatigue Root Cause Assessment of all BCWS Accidents and Incidents:

To further quantify the impact fatigue is having on BCWS operations, it is recommended that BCWS conducts a fatigue root cause analysis on all their accidents, incidents, and near misses. By including fatigue in their accident investigation protocol, and calculating the probability that the person was impaired by fatigue at the time of the incident, it will enable BCWS to identify accident trends and to know the true cost and impact fatigue has throughout its operations. Once fatigue is deemed a likely causal factor for an incident, it is also recommended to examine what factors led to the individual being fatigued (e.g. scheduling patterns, lack of sleep, time on task, workload, etc.)

Some other factors that investigators should consider are:

- Time of Day incident occurred
- Amount of mental stimulation involved in task during incident
- Work schedule issues- hours on the job at the time of the incident overtime in the last 7 days
- Sleep patterns
- Sleep disruptions
- Start time of work shift

- Sleep-wake duration in the 72 hours prior to the incident and consecutive hours awake at the time of incident
- Sleep and or medical disorders, including medications

6.3.5 Fatigue Management Training and Education

As previously noted, fatigue risk management is a shared responsibility. Although many interventions to minimize fatigue and enhance alertness of the workforce are in the hands of management, some of the most important elements are under the individual employee's control. The only remedy for sleep deprivation is sleep, and it is the employee's responsibility to use sleep opportunities to obtain rest, sleep, and meals. Employees have the primary responsibility to report to work well rested and fit for duty. However, it is incumbent upon management to provide the motivation, knowledge, and in some cases, the resources to allow them to do so. That said, fatigue risk management training can positively impact both knowledge and behaviour. It is suggested by Lerman et al. (2012) that employees should be educated on the following principles concerning fatigue and alertness in the workplace:

- 1- Hazards of working while fatigued and the benefits of being well rested
- 2- Impact of chronic fatigue on personal relationships, mental/physical well-being, as well as general life satisfaction
- 3- Recognizing that although fatigue cannot be eliminated, it can be managed and minimized
- 4- Adequate quantity and quality of sleep is key to managing fatigue

- 5- Basics of sleep physiology, circadian rhythms, and what is getting adequate sleep
- 6- Sleep hygiene—how to obtain adequate quantity and quality of sleep
- 7- Sleep disorders—why they matter, how to tell if one may have one, and what to do about it
- 8- Importance of diet, exercise, stress management, and management of other health conditions that affect fatigue, as well as information about how to address these issues
- 9- How to recognize fatigue in oneself or one's coworkers
- 10- Alertness strategies to be used while at work such as appropriate use of caffeine, rest or exercise breaks, and social interactions

Supervisors have special responsibilities to be alert for signs of excessive fatigue among their staff and therefore should require some additional training. They need to understand how to implement the company's approach to shift scheduling, including any guidance for determining when and how deviations can be implemented. They should be trained in how to recognize fatigue and what can be done to mitigate or manage it both in the short-term and when/if it seems to be chronic.

In order for the training, to be effective, it will need periodic reinforcement. This reinforcement may take the form of newsletters and bulletins, computer-based refresher training, and/or tail gate safety meetings. Research has shown when evaluating the effectiveness of training, improvement in knowledge is found when the training was conducted live by a trained professional (Lerman et al., 2012).

6.4 Future Directions

To our knowledge this is only the second study conducted amongst firefighters in Canada. In our study we attempted to characterize the effects of chronic sleep restriction on firefighters and the levels of fatigue during deployment. We suggest further attention and research be focused on the firefighter recovery period as sleep behaviour did not significantly improve during rest periods. Future research should focus on sleep education, sleep environments, sleep hygiene training, fatigue awareness training and what happens during recovery time. We also suggest that research be carried out over multiple deployments with the same firefighters to see the development of fatigue and sleep behaviours in BC firefighters. Lastly, we suggest research be conducted amongst BCWS fire crews that work night shifts during controlled burns and the impact of this schedule on their levels of fatigue and sleep behaviour.

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Appendix A - Wildfire Study Questionnaire

Participant ID: _____

Date: _____

Part A) Work History:

- 1.1 How many years have you been a forest firefighter? _____
- 1.2 How long have you been working for the Wildfire Management Branch [WMB]? _____
- 1.3 What is your current position (job title) within the WMB? _____
- 1.4 When was your first day of work in 2015? _____
- 1.5 How many deployments have you been on this year? _____
- 1.6 Roughly, how many days have you worked so far this year? _____
- 1.7 Please indicate in the table below the amount of time spend on the following activities during a typical 3-Day rest:

ACTIVITIES	Times per 3-Day rest	Average Duration (Min)
a. STRENUOUS EXERCISE (HEART BEATS RAPIDLY, SWEATING)(e.g., running, jogging, hockey, soccer, long distance bicycling, heavy weight training)		
b. MODERATE EXERCISE (NOT EXHAUSTING, LIGHT PERSPIRATION) (e.g., fast walking, baseball, tennis, easy bicycling, swimming)		
c. MILD EXERCISE (MINIMAL EFFORT, NO PERSPIRATION) (e.g., easy walking, yoga, bowling)		

d. TRAVEL (time spent commuting between work and home)		
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1.8 What is your other part time occupation when not working for WMB? _____

Part B) Medical History:

1.1 Have you ever been diagnosed by a physician with a Sleep Disorder?

No Yes

If so, describe: _____

1.2 Have you ever been diagnosed by a physician with Chronic Fatigue Syndrome?

No Yes

Part C) Training History:

Before the forest firefighting season started, over a typical 7-day week, how many times on average do you engage in following types of exercise for more than 15 minutes?

INTENSITY OF EXERCISE	Times Per Week	Average Duration (Min)
a. STRENUOUS EXERCISE (HEART BEATS RAPIDLY, SWEATING)(e.g., running, jogging, hockey, soccer, long distance bicycling, heavy weight training)		
b. MODERATE EXERCISE (NOT EXHAUSTING, LIGHT PERSPIRATION) (e.g., fast walking, baseball, tennis, easy bicycling, swimming)		
c. MILD EXERCISE (MINIMAL EFFORT, NO PERSPIRATION) (e.g., easy walking, yoga, bowling)		

1.1 What is the frequency (days/week) of resistance training (machine, weights, body weight, bands)? _____

1.2 What is the frequency (days/week) of aerobic (running/cycling) training? _____

1.3 What is the frequency (days/week) of interval (sprint) training? _____

1.4 In general, would you say that your current fitness level is?

Very Poor Poor Average Good Very Good

Part D) Individual Characteristics:

1.1 Sex: M or F What is your current age? _____

1.2 How would you classify your ethnicity? Please check the appropriate box

<input type="checkbox"/> Caucasian	<input type="checkbox"/> Korean
<input type="checkbox"/> First Nations/Inut/Metis	<input type="checkbox"/> African
<input type="checkbox"/> Latin (Hispanic)	<input type="checkbox"/> Japanese
<input type="checkbox"/> West Asian (e.g. Iranian, Afghan)	<input type="checkbox"/> Chinese
<input type="checkbox"/> Southeast Asian (e.g. Vietnamese, Cambodian, etc.)	<input type="checkbox"/> Arab
<input type="checkbox"/> South Asian (e.g. East Indian, Sri Lankan, etc.)	<input type="checkbox"/> Other, if other please define: _____

Appendix B - Letter of Intent

THE UNIVERSITY OF BRITISH COLUMBIA



School of Kinesiology
Faculty of
Education

Rm. 128, Unit II Osborne Centre
6108 Thunderbird
Blvd.

Participant Information and Consent Form

Title of Project: Novel Approaches To Understanding Risk Factors Cognitive Fatigue in Wildland Firefighters

Principal Investigator: D. Warburton, Ph.D.- School of Kinesiology, UBC
Co-Investigators: A. Jeklin (Masters Student)- Kinesiology, UBC

Institutions: University of British Columbia

Contact Person: Dr. Darren Warburton's Laboratory:

We would like to invite you to participate in an investigation evaluating fatigue and sleep deprivation in firefighters. Forest firefighters between the ages of 18-65 years old and working for the Wildfire Management Branch will be included in the study. We are interested in evaluating the cognitive function, vascular health, and sleep dynamics throughout a work cycle and during the rest period to better understand how various occupational factors may lead to workplace injuries. The results of this investigation will provide valuable insight into modifiable determinants of fatigue in order to mitigate future injuries in wildland firefighting and improve worker safety. We are seeking 35 firefighters to take part in this investigation.

You should not participate in this investigation if you: 1) are not employed by the Wildfire Management Branch, 2) are over the age of 65

Your Participation is Voluntary:

Your participation is entirely voluntary, so it is up to you to decide whether or not to take part in this study. Before you decide, it is important for you to understand what the research involves. This consent form will tell you about the study, why the research is being done, what will happen to you during the study and the possible benefits, risks, and discomforts. If you wish to participate, you will be asked to sign this form. If you decide to take part in this study, you are still free to withdraw at any time and without giving any reasons for your decision. Please take time to read the following information carefully and to discuss it with your family, friends, and doctor before you decide.

Procedures:

Please review the following consent form, which will outline all aspects of the investigation. If you have any questions or are interested in participating in this investigation please contact the laboratory by phone or email Andrew Jeklin. A researcher with the study will further discuss the investigation and the consent form will be reviewed at the first session and your written consent will be sought should you decide to participate. This study will require 17 days of testing over a 17-day period, requiring a total time commitment of approximately 10-12.5 hours.



The measurement sessions

The health assessments that will be conducted will consist of measurements of vascular health (blood pressure and heart rate variability), sleep activity (wrist accelerometers, subjective questionnaires, and daily sleep logs), and cognitive fatigue (psychomotor vigilance test and fatigue questionnaires). Blood pressure and cognitive fatigue measures will be obtained post shift throughout the work cycle while heart rate variability will be collected before work as participants wake up. Sleep will be objectively measured each night with a wrist accelerometer that participants wear to bed.

Prior to each day of testing, **you will be asked to refrain from smoking for 1 hour.** The testing sessions will be conducted at either the Kamloops fire center or near by fire camp.

In order to understand how these measures are influenced and change at rest, participants will be expected to continue to monitor heart rate and sleep at home during a typical 3-day rest cycle. More specifically, each participant will collect 7 minutes of resting heart rate data in the morning, wear the sleep accelerometer at night, and complete the short subjective questionnaires each afternoon while they are on their rest days. There will be a short de-brief at the end of the work cycle with the research team to ensure that participants understand the equipment and how they are able to return the equipment (pre-paid envelopes).

Questionnaires: You will be asked to complete several short questionnaires upon arrival at the testing location. 1) PARQ+, aims to assess readiness for physical activity, 2) Pittsburgh Sleep Quality Index (PSQI), is a subjective questionnaire that asks about sleep history and quality 3) Fatigue Assessment Scale, is a 10-item subjective questionnaire for chronic fatigue, 4) Wildfire Study Questionnaire, subjects will be asked to briefly respond to questions about work and exercise training history. These questionnaires all take <5 minutes and are only done once. After each shift, and during your rest period, you will be required to do fill out the [Karolinska Sleepiness Scale](#), a widely used 9-item scale to measure sleepiness; this will take <1 minute.

Body Composition/Anthropometric and Grip Strength Measurements: First we will ask you to remove your shoes to measure your height and weight. Then we will ask you to lift up the bottom of your shirt slightly to expose your waist to measure your waist circumference. To measure your grip strength, you will be asked to squeeze a grip strength dynamometer as hard as you can, twice with each hand. These are all non-invasive and painless. These measures should take about 5 minutes to complete and will only be tested during the beginning and end of the study

Heart Rate Variability: Heart rate variability (HRV) will be measured using Polar Heart Rate monitors. To ensure accurate resting measurements, you will lay on your back, in bed for 7 minutes while the monitor is recording heart rate. You will be asked to relax and lay as still as possible. HRV is a commonly used measurement for observing changes in parasympathetic and sympathetic activity, divisions of the autonomic nervous system that regulate heart rate and is often used to determine the degree to which individuals recover from a strenuous activity. It is required that participants have a smartphone in which the data from the heart rate monitors can transfer to a free app, Elite HRV, using Bluetooth that is then transferred to the researchers via email. HRV will be collected during every testing day. Participants will also be expected to collect 3 consecutive days of resting data during their rest period.



Sleep Accelerometry: Throughout the trial, you will be asked to attach a wrist accelerometer before bed each night. Wrist accelerometry is a reliable and highly sensitive objective tool to measure the amount of sleep each night. The accelerometer continually records the movements it undergoes. The data can be later read to a computer and analyzed. It is a non-invasive procedure that will not interfere with a participant's sleep. Again, participants will be expected to wear the accelerometers for 3 consecutive days during their rest.

Daily Sleep Diary: You will be asked to fill out a daily sleep diary before bed each night and work each day. This is a subjective tool that will be used to compare results from the objective measurements of the wrist accelerometers. Each diary consists of 8 questions and will take between 2-3 minutes to complete. This measure will also be expected to be used during the full rest period.

Visual Analogue Scale-Fatigue & Sleepiness: A Visual Analogue Scale is a rapid tool used to subjectively measure fatigue and sleepiness. Participants are required to mark on a line their perceived level of fatigue and sleepiness. VAS scales range from 0-100. This test will be administered at each training session and during the rest period. The procedure will take less than 1 minute.

Cognitive Fatigue: Cognitive fatigue will be assessed using the Psychomotor Vigilance Test (PVT) on a portable device (Asus Tablet). A university-trained clinical exercise physiologist will administer and explain the test to each participant. The PVT test is highly sensitive, reliable, and the gold standard in occupational field testing in evaluating impairments of attention, concentration, and reaction time. The PVT also precisely measures the changes in vigilance performance caused by sleep loss. There is absolutely no pain or discomfort with this procedure and this procedure will take 5 minutes for each assessment. The PVT will be administered each day, after work. In addition to the psychomotor vigilance test, we will take measures of general cognitive function. To do so, we will perform a short series (15 trials) of choice (identify and respond to stimulus on computer) and reaction time trials at the beginning (day 1), middle (day 7), and end (day 14). Each test will take approximately 5 minutes.

Disclosure of Race/Ethnicity

Studies involving humans now routinely collect information on race and ethnic origin as well as other characteristics of individuals because these characteristics may influence how people respond to different medications and experience different chronic conditions. Providing information on your race or ethnic group is voluntary.

Risks:

There are no known permanent adverse side effects that have resulted from any of the measures used in the following study. All exercise testing and body composition measures will be performed under the supervision of a Certified Exercise Physiologist. These individuals have received the most advanced exercise training in Canada and are certified in first aid, CPR and the use of an automated external defibrillator (AED). The research team is equipped with an AED.

Since there is a variable response from individuals during exercise, unanticipated complications may occur that would require treatment. Every effort will be made to conduct the test in such a way as to minimize discomfort and risk. There is the risk of discomfort, bruising, pain, tingling or numbness during the cuff occlusion of the blood pressure assessment. As a participant, you may not benefit from the study directly. Signing this consent form in no way limits your legal rights against the sponsor, investigators, or anyone else.



Benefits:

You will receive complete individual and group summaries of body composition, cardiovascular health, and results on current sleep patterns, quality and duration from this investigation. If an abnormality in any measurement is observed (at any time period) that indicates an elevated risk a member of our research team will contact you directly regarding the findings.

Reimbursement

You will receive no financial reimbursement for your participation in the study.

Rights and Welfare of the Individual:

You have the right to refuse to participate in this study. You may withdraw from this study at any time without giving reasons. If you choose to enter the study and then decide to withdraw at a later time, you have the right to request the withdrawal of your information collected during the study. This request will be respected to the extent possible. Please note however that there may be exceptions where the data will not be able to be withdrawn for example where the data is no longer identifiable (meaning it cannot be linked in any way back to your identity) or where the data has been merged with other data. If you would like to request the withdrawal of your data please let the research team know. Your identity will remain confidential as all individual records and results will be analyzed and referred to by number code only and kept in a locked cabinet in the Cardiovascular Physiology and Rehabilitation Laboratory at the University of British Columbia. This lab will remain locked and only those directly involved in the study (namely the principal investigator) will have access to your records and results. You will not be referred to by name in any study reports or research papers.

Your confidentiality will be respected. However, research records and medical records identifying you may be inspected in the presence of the investigator and the UBC Clinical Research Ethics Board for the purpose of monitoring the research. No information or records that disclose your identity will be released or published without your specific consent, nor will any information or records that disclose your identity be removed or released without your consent unless required by law. No records which identify you by name or initials will be allowed to leave the investigators offices.

You will be assigned a unique study number as a participant in this study. This number will not include any personal information that could identify you (e.g., it will not include your Personal Health Number, SIN, or your initials, etc.). Only this number will be used on any research-related information collected about you during the course of this study, so that your identity will be kept confidential. Information that contains your identity will remain only with the Principal Investigator and/or designate. The list that matches your name to the unique study number that is used on your research-related information will not be removed or released without your consent unless required by law.

Your rights to privacy are legally protected by federal and provincial laws that require safeguards to insure that your privacy is respected. You also have the legal right of access to the information about you that has been provided to the sponsor and, if need be, an opportunity to correct any errors in this information. Further details about these laws are available on request to your study investigator



Who do I contact if I have any questions or concerns about my rights as a participant?

Please be assured that you may ask questions at any time. We will be glad to discuss your results with you when they have become available and we welcome your comments and suggestions. Should you have any concerns about this study or wish further information, please contact Dr. Darren Warburton or Andrew Jekin at the University of British Columbia. If you have any concerns or complaints about your rights as a research participant and/or your experiences while participating in this study, contact the Research Participant Complaint Line in the University of British Columbia Office of Research Ethics by e-mail at RSIL@ors.ubc.ca or by phone.

What happens if something goes wrong?

By signing this form, you do not give up any of your legal rights and you do not release the research team, participating institutions, or anyone else from their legal and professional duties. If you become ill or physically injured as a result of participation in this study, medical treatment will be provided at no additional cost to you. The costs of your medical treatment will be paid by your provincial medical plan.



INFORMED CONSENT FORM:

Project: Novel Approaches To Understanding Risk Factors of Cognitive Fatigue in Wildland Firefighters

Participant Consent:

I, _____
(Please Print Your Name)

have read and understood the subject information and consent form. I have had sufficient time to consider the information provided and to ask for advice if necessary. I have had the opportunity to ask questions and have received satisfactory answers to all inquiries regarding this study. I understand that all of the information collected will be kept confidential and that the results will only be used for scientific objectives. I understand that my participation in this study is voluntary and that I am completely free to refuse to participate or withdraw from this study at any time without changing in any way the quality of care I receive. I understand that I am not waiving any legal rights as a result of signing this consent form.

I consent to participate in this study and agree to return the provided equipment immediately following the end of the study.

Signature of Participant

Printed name

Date

Person Obtaining Consent

Printed name

Study Role

Date

Appendix C - Daily Sleep Log

DAILY SLEEP LOG															
Participant ID:							Date:								
Instructions:															
1 Enter information twice daily: at bedtime and wake-up time															
2 Enter clocktimes in military format (for example 11pm is 23:00) Or please be sure to enter AM or PM															
3 Many people go to bed after midnight. Bedtime for Thursday May 17 might actually be on Friday morning on May 18 (e.g. 1:00 AM), but you should still enter that as the bedtime for Thursday May 17. We will understand what it means.															
4 A 'work' day is defined as a day when you have to get up to go to work, school or other obligations.															
A 'free' day is a day where you are free to set your own preferred wake up time.															
Enter this information at bedtime							Enter this information when you get up in the 'morning'								
FILL IN DATE		YOU HAD A NAP TODAY		CAFFEINATED DRINKS			NEXT DAY		How long did it take to fall asleep last night?		If you woke in the night what time?		How long did you stay awake?		Is today a (f)ree or (w)ork day?
Date	day	Nap onset time	Nap end time	Cigarettes smoked? number	Did you take any sleep aids? Y/N	Coffee #cups	Tea or softdrink #cups	Bedtime (lights out) clocktime	wakeup time clocktime	minutes	clocktime	minutes	minutes	letter	
Example:	Thursday	13:00	14:00	0	N	2	1	23:30	7:30:00 AM	10	2:00	20	W		
26/08/15	Wednesday														
27/08/15	Thursday														
28/08/15	Friday														
29/08/15	Saturday														
30/08/15	Sunday														
31/08/15	Monday														
1/9/15	Tuesday														
2/9/15	Wednesday														
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10/9/15	Thursday														
11/9/15	Friday														
12/9/15	Saturday														
13/9/2015	Sunday														