Fighting fires and fatigue: sleep, physical activity, and physical task performance

by

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Bachelor of Sport and Exercise Science (Honours)

Submitted in fulfilment of the requirements for

the degree of Doctor of Philosophy

Centre for Physical Activity and Nutrition Research

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Deakin University

May 2015

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Acknowledgements

This thesis is dedicated to two inspiring men who are sadly no longer with us. My grandfather, Dr. Alfred Vincent, a great mind of his generation who pushed the boundaries of human thought, and challenged the status quo. My honours supervisor, Dr. Johann Edge, who through his enthusiasm for science instilled in me a passion for teaching and research.

First and foremost, I would like to thank my family, Dad, Mum, Kate, and Tessa. Dad and Mum, thank you for working so hard to provide me with the opportunities to pursue my goals. Dad, through the story of Abraham Lincoln's Gettysburg address you taught me that 'less is more' when it comes to writing. Mum, you have always told me that if you want to achieve something it requires hard work and commitment, it certainly does. Kate and Tessa, it is a difficult task being the eldest to two incredibly talented young women, thank you for your support.

I would like to express my gratitude to my supervision team, Dr. Brad Aisbett, Professor Sally Ferguson, and Dr. Nicola Ridgers for your guidance, support, expertise, and advice. I could not have asked for a better supervision experience and you have all become lifelong friends – thank you.

Brad, thank you for your constant support during the low moments but more importantly for making sure I celebrated the highs. I will always be so grateful to you for having faith in me, and I hope we can celebrate many more Hawks wins in the years to come.

Sal, when I felt like I couldn't think more about a topic, you pushed me harder – it has really brought out the best in me and my work, thank you. You have inspired me to follow a career in sleep research. I've appreciated your honesty and advice in every situation.

Nicky, your addition to my supervision team in the last six months has been invaluable. Thank you for your patience in getting me up to speed with the physical activity literature.

Thank you to the Occupational Exercise Science research group and to all the students, academics, and support staff in the School of Exercise and Nutrition Sciences. In particular, I would like to thank PhD students Alexander Wolkow, Sarah Hall, and Cara Lord. Alex, thank you for always checking in on me, and for setting the standard of hard work. Sarah, thank you for your unconditional support, and helping me with problems big and small. Cara, thank you for asking the tough questions and troubleshooting all my practical problems.

Thank you to the Bushfire Co-operative Research Centre and Deakin University for providing financial and logistical support for this research and to all the firefighters who volunteered their time to participate.

I would like to thank all of my friends and extended family, both in Australia and New Zealand – you have shared in this journey with me. In particular, I would like to thank my Australian family the Francis', and friends, Chiara Romano, Ané Swart, and Liz Pressley for your constant support and encouragement.

And finally, to the two people I couldn't have done this without, PhD students Jacqueline Tran and Brianna Larsen.

Jac – you are the human version of google. You push the boundaries and demonstrate the true value of collaboration. I've enjoyed our intellectual debates and you have taught me so many skills that have enriched my PhD experience.

Brianna – we started this journey together and you have been there every step of the way. You have challenged me to be a better scientist and believed in me in those times where I doubted my ability. I am eternally grateful for your support.

This great adventure has exceeded all expectations.

List of Publications

Published

G.E Vincent, S.A Ferguson, J. Tran, B. Larsen, A. Wolkow, B. Aisbett. 2015. Sleep Restriction during Simulated Wildfire Suppression: Effect on Physical Task Performance. *PLoS One,* 10, e0115329.

G.E Vincent, B. Aisbett, S.J Hall, S.A Ferguson. Fighting fire and fatigue: sleep quantity and quality during multi-day wildfire suppression, accepted for publication in *Ergonomics*, August 2015.

G.E Vincent, N.D Ridgers, S.A Ferguson, B. Aisbett. Associations between firefighters' physical activity across multiple shifts of wildfire suppression, accepted for publication in *Ergonomics*, August 2015.

Conference Presentations

G.E Vincent, B. Aisbett, S.J Hall, S.A Ferguson. Fighting fires and fatigue: sleep during wildfire suppression (Oral presentation). Working Time Society Travel Grant to attend the 22nd International Symposium of Shift Work and Working Time, 2015. *Awarded 2nd best oral presentation for early career researchers.

G.E Vincent, B. Aisbett, S.A Ferguson. Sleep quantity and quality during planned burn operations (Oral Presentation and Poster). Sleep Downunder 2014, Perth, Australia, October 9–11, 2014.* Awarded Best Conference Poster.

G.E Vincent, S.A Ferguson, B. Aisbett. Long shifts: are the breaks important? (Poster) Presented at Australasian Fire and Emergency Service Authorities Council Conference, Wellington, September 2–5, 2014.

G.E Vincent, B. Aisbett, S.J Hall, S.A Ferguson. Fighting fires while fighting fatigue: firefighter sleep quantity and quality during bushfire suppression (Oral Presentation and Poster). Presented at the World Congress on Safety and Health at Work 2014, Frankfurt, Germany, August 24– 27, 2014.

G.E Vincent, S.A Ferguson, J. Tran, B. Aisbett. Fighting bushfires and fatigue (Oral Presentation). Presented at Associated Professional Sleep Societies 2014, Minneapolis, United States, May 31–June 4, 2014.

G.E Vincent, S.A Ferguson, J. Tran, B. Aisbett. Fighting fires and fatigue: sleep deprivation during simulated bushfire suppression (Poster). Presented at the Australian Association for Exercise and Sports Sciences Conference, Adelaide, Australia, April 16–19, 2014.

G.E Vincent, B. Aisbett, S.A Ferguson. Fighting Fires While Fighting Fatigue: How do firefighters sleep during bushfire suppression? (Poster). Presented at Australasian Fire and Emergency Service Authorities Council Conference, Melbourne, Australia, September 2–5, 2013.

G.E Vincent, B. Aisbett, S.A Ferguson. Extended wakefulness and work physiology of wildland firefighters (Poster). Presented at Australasian Fire and Emergency Service Authorities Council Conference, Perth, Australia, August 28–31, 2012.

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List of Symbols and Abbreviations

α	alpha
β	parameter estimate, in mixed models
%	percentage
$\%HR_{max}$	percentage of maximal heart rate
+	plus
±	plus or minus
<	less than
=	equals
>	greater than
≤	less than or equal to
≥	greater than or equal to
°	degrees
~	approximately
AEE	activity energy expenditure
ACSM	American College of Sports Medicine
AFAC	Australian Fire Authority Council

ANOVA	analysis of variance
AUD	Australian Dollars
beats·min^{-1}	beats per minute
BMI	body mass index
C	Celsius
CFA	Country Fire Authority
CFS	South Australian Country Fire Service
CI	confidence interval
cm	centimetre(s)
CON	control group
DLW	doubly labelled water
e.g.	for example
et al.	and others
GLLAMMs	Generalised Linear Latent and Mixed Models
gllamm	generalised linear latent and mixed model software
HR	heart rate
HR_{max}	maximum heart rate
h	hour(s)
ICC	intra-class correlation coefficient

i.e.,	that is
$kcal \cdot min^{-1}$	kilocalories per minute
$kcal \cdot day^{-1}$	kilocalories per day
kg	kilogram(s)
kJ	kilojoule(s)
L	litre(s)
$L \cdot min^{-1}$	litres per minute
LPA	light-intensity physical activity
m	metre(s)
$m \cdot s^{-1}$	meters per second
MET	metabolic equivalent
min	minute(s)
$MJ \cdot day^{-1}$	megajoules per day
mL	millilitre(s)
$mL \cdot kg^{-1} \cdot min^{-1}$	millilitres per kilogram per minute
MPA	moderate-intensity physical activity
n	sample size/number of observations
P	significance value
PSG	polysomnography

RPE	rating of perceived exertion
s	second(s)
SD	standard deviation
SPSS	Statistical Package for the Social Sciences
SE	standard error
SED	sedentary time
SR	sleep restricted group
t	time
USD	United States Dollar
VO_2 max	volume of maximum oxygen uptake
VO_2	volume of oxygen consumption
VPA	vigorous-intensity physical activity

Glossary of Key Terms

Activity energy expenditure	the energy expenditure associated with physical activity (Heil 2002).
Doubly labelled water methodology	the gold standard for measuring total energy expenditure in free-living individuals (Schoeller 1999; Westerterp 1999).
Physical activity	'all bodily actions produced by the contraction of skeletal muscle that increase energy expenditure above basal level' (Butte et al. 2012, p. S5).
Sleep	a reversible behavioural state, characterised by a perceptual disengagement from and unresponsiveness to the environment (Carskadon & Dement 2011).

Total energy expenditure	the sleeping metabolic rate, the energy cost of arousal, the thermic effect of food, and the energy cost of physical activity (Ravussin et al. 1986).
Wildfires	are any uncontrolled, non-structural burning in grass, scrub, bush, or forests (Everett et al. 2012) (known as bushfires in Australia).

Chapter 1: Introduction

1.1 Background

Wildfires are any uncontrolled, non-structural burning in grass, scrub, bush, or forests (Everett et al. 2012). Wildfires can have a debilitating impact on communities in North America, South America, Southern Europe, and Australia, with the loss of property, livestock, and human life (Hunter 2003; Schmuck et al. 2004; Hyde et al. 2008). The financial burden of wildfire is immense. For example, the average annual cost of wildfire in Australia is $77 million (AUD) (McLennan & Birch 2005). Globally, the frequency, duration, and severity of wildfires is predicted to escalate (Liu et al. 2010), due, at least in part, to climate change resulting in hotter and drier summers (Westerling et al. 2006; Pitman et al. 2007; Hasson et al. 2009). The increase in wildfire activity (Liu et al. 2010) will result in more frequent and/or longer deployments which may exacerbate the cognitive and physical demands placed on wildland firefighting personnel.

During deployments, wildland firefighters are subjected to a myriad of stressors and adverse, volatile working environments (Aisbett et al. 2012). Depending on fire severity and availability of personnel, firefighters are typically rostered to work a 12-h day or night shift, but can work shifts of up to 16 h for 3–5 consecutive days, during deployments (Cater et al. 2007; Phillips et al. 2007; Aisbett et al. 2012). These typical elements of shift work such as long working hours, consecutive shifts, and night work have all been associated with reduced sleep and an increased risk of fatigue-related accidents (Edkins & Pollock 1997; Åkerstedt 2000; Folkard & Tucker 2003). While the effects of multiple days of sleep restriction on cognitive function are well established (Belenky et al. 2003;

Van Dongen et al. 2003), much less is known about the effects of sleep restriction on physical activity and physical task performance, which is fundamental to wildfire suppression.

1.2 Research Problem

Sleep is a basic requirement for human health and is an important component of worker recovery due to its physiological and psychological restorative effects (Rechtschaffen 1998; Knutson et al. 2007; Cirelli & Tononi 2008). Previous research indicates that wildland firefighters self-report a large range in sleep hours during multi-day wildfire suppression deployments (Gaskill & Ruby 2004; Cater et al. 2007). While activity monitors have been previously utilised in other field-based studies to objectively measure sleep behaviour of shift workers (Lamond et al. 2005; Darwent et al. 2008; Ferguson et al. 2010), no such research has been conducted in wildland firefighters. Furthermore, identifying specific shift characteristics, and the degree to which they contribute to reduced sleep opportunities (and/or durations), may provide fire agencies with targets for possible interventions. For example, early start times (Ingre et al. 2008) and the duration between successive work periods (Kurumatani et al. 1994) have previously been shown to reduce total sleep time in shift working populations. Therefore, given the current literature is limited and utilises exclusively self-report measures, a more comprehensive objective assessment of firefighters' sleep during wildfire suppression (and the factors that may moderate sleep duration) is warranted.

Wildland firefighting is a physically demanding occupation (Aisbett et al. 2012). Determining whether firefighters' sleep duration between shifts moderates physical activity levels may be valuable information for wildfire operations, and in safeguarding firefighters' health and safety. For example, examining whether firefighters who obtain more sleep are more physically active than those who obtain less sleep may have important implications for workforce productivity estimates. To date, several studies have examined firefighters' physical activity levels during wildfire suppression deployments (Heil 2002; Cuddy et al. 2007; Raines et al. 2012; Raines et al. 2013; Cuddy et al. 2015; Raines et al. 2015). Collectively, this research provides insight into how physical activity requirements may change within or between shifts, but not whether the amount of physical activity in one shift is associated with physical activity during the following shift. This information is critical for fire agencies in terms of workforce planning, as well as health and safety management, throughout a multi-day wildfire suppression deployment. If firefighters are able to maintain physical activity levels between consecutive shifts then the need to deploy additional personnel to subsequent shifts may be reduced. In turn, this may limit the number of firefighters exposed to potentially hazardous environmental stressors (e.g., radiant heat, smoke, etc.), and reduce the overall short- and long-term financial costs associated with wildfire suppression operations.

Given the inherent variability of the wildfire environment, determining the precise impact of restricted sleep on physical task performance is difficult without implementing a controlled laboratory protocol. Previous laboratory studies have identified adverse effects of multiple days of sleep restriction on cognitive performance (Belenky et al. 2003; Van Dongen et al. 2003). However, there is a lack of robust empirical evidence detailing the effects of restricted sleep on submaximal physical task performance (inherent to many physically demanding occupations (Rodgers et al. 1995)), and total physical activity levels. Previous research indicates that long-duration self-paced tasks may be impaired by total sleep deprivation (Myles & Romet 1987; Rodgers et al. 1995), but maximal task performance can be maintained (Symons et al. 1988; Rodgers et al. 1995). However, this research has largely focused on periods of total sleep deprivation as opposed to sleep restriction, which is more commonplace in wildland firefighting (Aisbett et al. 2012). If physical performance on firefighting tasks is compromised due to restricted sleep, this may adversely impact firefighters' health and safety and the collective emergency response.

1.3 Thesis Objectives

The primary objective of this thesis was to examine the interplay between firefighters' sleep, physical activity, and physical task performance during real and simulated multi-day wildfire suppression. The specific aims of this thesis are as follows:

1. To objectively determine firefighters' sleep quantity and quality during multi-day emergency wildfire suppression, and assess how sleep location, shift length, shift start time, and incident severity impact these variables;

2. To examine associations between firefighters' physical activity levels between consecutive shifts during a multi-day emergency wildfire and whether sleep duration moderates these associations; and

3. To assess the effect of sleep restriction on firefighters' physical task performance, physiology, and perceptual responses during simulated multi-day wildfire suppression.

1.4 Relevance of the Research

Increased wildfire frequency and severity, requiring longer shifts and more frequent deployments, represent a significant threat to the operational readiness of wildland firefighters. Preserving firefighters' operational readiness relies on a robust and occupation-specific evidence base from which to develop policy and best practice. Elevated and unsustainable levels of firefighter fatigue and/or degradation of firefighters' physical activity and physical task performance could increase their individual risk of injury, increase demand on other crew members, and compromise the overall wildfire suppression operation. This research will provide agencies with cutting edge information to make evidence-based decisions on workforce planning and will provide a platform when developing risk controls. In turn, this may reduce both the financial costs associated with firefighting operations, and firefighters' exposure to an environment that contains inherent health and safety dangers.

By utilising a combination of field-based and laboratory research, this thesis makes a novel contribution to understanding the interplay between sleep, physical activity, and physical task performance. Using wildland firefighting as a model, this research will also have broader implications for other physically demanding occupations (e.g., emergency service, civilian and military work). For example, those occupations that have shift structures or physical work domains (e.g., intermittent self-paced submaximal work) that are comparable to wildland firefighting.

1.5 Note for Readers

The three studies completed as part of this degree have been published or accepted in scientific journals (see journal title and status on the opening page of each study chapter). With the exception of minor edits, the content provided in each of the study chapters is consistent with the content submitted to the respective journals. However, for ease of reading, all study chapters have been formatted in a style consistent with the remainder of the thesis. Given that all manuscripts were prepared in parallel and submitted within a six-month time frame, each study has been written as a stand-alone piece of research. Thus, the studies do not always explicitly reference each other throughout the body of the thesis. However, critical reflection on all studies as one program of research has been provided in the general discussion chapter of the thesis.

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Chapter 2: Literature Review

2.1 Introduction

This review of the literature will explore the interplay between sleep, physical activity, and physical task performance in occupational settings. It begins with a brief overview of the worldwide impact of wildfires and the predicted future increases in wildfire severity, frequency, and duration. The physical and physiological demands of wildland firefighting will then be explained, with a specific focus on firefighters' physical activity levels during wildfire suppression. Sleep, the measurement of sleep, and the impact of shift-work settings on sleep will then be discussed. Finally, the relationships between shift work, sleep restriction, physical activity, and physical task performance will be explored.

2.2 Wildfires

Wildfires (known as bushfires in Australia) are any uncontrolled, non-structural burning in grass, scrub, bush, or forests (Everett et al. 2012). Rural and regional areas of North and South America, Southern Europe, and Australia are particularly susceptible to wildfire (Liu et al. 2010). In the United States, resources for suppression and recovery efforts, and wildfire damages, exceed $1.6 billion dollars (USD) annually (Whitlock 2004). Of major concern to fire agencies and communities are the predicted global increases in wildfire frequency, duration, and severity, due mostly to climate change (Liu et al. 2010). Elevated wildfire activity will, in turn, place greater demands on fire agencies and their wildland firefighters, whose work is critical for safeguarding communities from the loss of property, livestock, and human life (Hunter 2003; Schmuck et al. 2004; Hyde et al. 2008).

2.2.1 Wildfire in Australia

Australia is recognised as the most fire-prone country in the world (Hennessy et al. 2005; Lucas et al. 2007; Pitman et al. 2007). The hot and dry summers, low average annual rainfall, and fire-sensitive ecosystem all combine to heighten wildfire risk, leading to some of the world's most destructive and catastrophic wildfires (Buxton et al. 2011; Australian Government 2012). Since 1851, it is estimated that Australian wildfires claimed over 700 human lives, destroyed thousands of homes, ravaged vast areas of land, and cost over $2.5 billion dollars (AUD) in suppression and recovery efforts (Bureau of Transport and Economics 2001; Blong 2005; Haynes et al. 2010). Annually, Australia's rural fire agencies respond to approximately 50,000 wildfire-related incidents at a combined cost of $77 million (AUD) (Bureau of Transport and Economics 2001). It is the responsibility of volunteer and career (i.e., salaried) firefighters to protect Australian communities from the threat of wildfire (McLennan & Birch 2005). This workforce consists of approximately 220,000 personnel (83% male, 17% female), of which the vast majority (99.9%) are volunteers (McLennan & Birch 2005).

2.2.2 Future wildfire predictions

Worldwide, the frequency and severity of large uncontrolled wildfires are predicted to increase (Pechony & Shindell 2010). Western regions of the United States are experiencing more frequent wildfires, with longer wildfire events and longer wildfire seasons than ever before (Westerling et al. 2006). This is thought to be due, at least in part, to global climate change, resulting in hotter and drier summers (Westerling et al. 2006; Pitman et al. 2007; Hasson et al. 2009). Across Australia, for instance, the average overall temperature is predicted to increase 0.2–2.2ºC by 2030 and 0.4–6.7ºC by 2070 (Suppiah et al. 2007). Seasonal flooding is also predicted to rise across Australia, which will heighten wildfire risk as flammable vegetation proliferates rapidly post-flood (Dunlop & Brown 2008). In addition, the suburban expansion of property into fire-prone areas may place additional stress upon wildland firefighters, as more homes and lives are at risk (Haight et al. 2004; Stewart et al. 2007).

Wildfires place considerable demands on wildland firefighters, who are subjected to a myriad of operational and environmental stressors for extended periods (e.g., prolonged shifts, physically demanding work, high ambient temperatures, smoke inhalation) (Aisbett et al. 2012). If, as predicted, wildfires continue to become more frequent and severe, the number and length of wildland firefighting deployments are likely to increase in response, thereby escalating the work demands and health and safety risks for firefighting personnel (Aisbett et al. 2012).

2.3 Wildland Firefighting

In Australia, wildland firefighting can be categorised into two major types: dry firefighting and tanker-based suppression (Aisbett et al. 2007). Tanker-based firefighting is Australia's principal firefighting defence during major wildfire emergencies (Phillips et al. 2007). Land management agencies are primarily responsible for containing wildfires on public lands, while the majority of fires on private lands are suppressed by rural fire authorities (Hunter 2003; Country Fire Authority 2004; Country Fire Authority 2006). In North America and Southern Europe, wildland firefighters employ similar dry firefighting techniques to those used by Australia's land management agencies to protect both private and public lands (Cuddy et al. 2007). As such, the work demands and resultant activity levels of wildland firefighting can vary depending on the methods of suppression, containment, and prevention that are employed by each fire agency. In order to describe the physical and physiological demands of wildland firefighting, research investigating both dry and tanker-based wildfire suppression will be drawn upon.

During wildfires, which can last hours, days, or even weeks, continuous around-the-clock operations are performed by fire crews to protect life and property, (Hunter 2003; Aisbett et al. 2012; Rodríguez-Marroyo et al. 2012). Shift lengths and the number of consecutive shifts are dependent on the jurisdiction of each national fire agency. In Australia, firefighting personnel are typically rostered to work a 12-h day or night shift, but can work shifts of up to 16 h for 3–5 consecutive days (Cater et al. 2007; Phillips et al. 2007). In North America, firefighter's work 10–16 h shifts and can be deployed for up to 14 days at a time (Heil 2002; Ruby et al. 2002; Ruby et al. 2003). In both populations, the long shifts reduce the rest between work periods, resulting in truncated sleep opportunities (Gaskill & Ruby 2004; Cater et al. 2007; Aisbett et al. 2012). Furthermore, sleep opportunities can be limited by lack of replacement crews, fires that are burning out of control, and suboptimal sleeping conditions (Cater et al. 2007).

The combination of inadequate sleep, long periods of wakefulness, physical work, and extreme environmental conditions, make wildland firefighters highly vulnerable to fatigue and fatigue-related risks. Currently, there is no commonly agreed definition of fatigue, and the theoretical explanations of fatigue are limited by the context in which they are used (Abbiss & Laursen 2007). For example, the word 'fatigue' has been used to define tiredness, a reduction in the physical capacity to produce force, or failure of a specific physiological system to retain homeostasis (Abbiss & Laursen 2007). For the purposes of this thesis, fatigue is defined in accordance with Australasian Fire and Emergency Authorities Council policy documentation as: 'a state of weariness that results from sleep loss, exposure to harsh environments, and/or prolonged mental or physical work' (Occupational Health and Safety Group 2003, p.1). Given the unique and complex challenges faced by wildland firefighters, fire agencies require more information to guide personnel management in order to optimise worker performance, and mitigate fatigue-related risks to preserve firefighters' health and safety. To do so requires better understanding of the factors that influence firefighters' physical activity and physical task performance within and between shifts, as well as the impact of shortened sleep opportunities on firefighters' work.

2.3.1 Characteristics of wildland firefighting work tasks

For this section, the physical activity taxonomy of frequency, intensity, duration, and type as prescribed by ACSM (2010) will be used to scaffold descriptions of wildland firefighting.

Type

'Dry' wildfire suppression techniques are primarily employed by Australia's land management agencies and North American wildland firefighters (Aisbett & Nichols 2007), whereas a combination of 'wet' and 'dry' techniques is utilised by Australia's tanker-based firefighters (Phillips et al. 2012).'Dry' techniques utilise hand-tools to manually clear combustible fuels through raking, sawing, and cutting (Budd et al. 1997; Budd et al. 1997; Budd et al. 1997), and can also involve hiking up steep terrain (Sharkey 1999; Bosua 2006; Country Fire Authority 2006). 'Wet' techniques describe the hose-based tasks to douse fires with water and other liquid suppressants delivered by hoses connected to firefighting trucks, also known as tankers (Nichols et al. 2003).

Australian rural fire service documentation previously reported hose dragging, rake work (i.e., hand-tool), carrying a knapsack, and lifting equipment as the most physically demanding tasks performed during wildfire suppression deployments (Dwyer & Brooker 2005). These types of tasks were comparable to a more recent, formal, job task analysis of Australian tanker-based firefighters which identified seven tasks as physically demanding and common to wildfire suppression deployments (Phillips et al. 2012). These tasks were further categorised into three hose-based, and four hand-tool related activities (Phillips et al. 2012). Carry, drag, and dig/rake actions were identified as the primary movements and the operational importance of these tasks ranged from moderate to critical (Phillips et al. 2012).

Frequency and duration

Research from Budd and colleagues (1997) directly evaluated (live observation) raking task performance of Australian land management firefighters during controlled fires lit for experimental purposes. Firefighters raked for an average of 38 s (range: 1–127 s) followed by a 10 s rest. However, task frequency was not clearly reported, as the histogram presented shows how often all tasks of different lengths were completed rather than the frequency of individual tasks. In a separate study, the same authors reported physiological measurements to accompany task frequency and duration (Budd et al. 1997), yet these measures were not matched to individual firefighting tasks. Furthermore, the frequency and duration of tasks involving hose-related duties, hand-tool work during post-fire clean up, or spot fire containment, all of which are characteristic to tanker-based firefighting (Phillips et al. 2012), were not examined. In a job task analysis of Australian tanker-based firefighters, seven tasks were identified by subject matter experts as being physically demanding (Phillips et al. 2012). The frequency with which these tasks were completed ranged from 1–700 times during a four-month wildfire season, with a task duration ranging from 3–30 min per repetition (Phillips et al. 2012). However, the subject matter experts' recall of task frequency and duration were highly variable (Phillips et al. 2012) which is inherent to job task analysis work (Larsen & Aisbett 2012). In order to verify the job task analysis findings, the same authors utilised video footage to evaluate the frequency and duration of tasks across four real wildfire suppression shifts (Phillips et al. 2015). Per shift, the task frequency ranged from 1–103 times and task durations lasted from 4–461 s (0.1–7.7 min) (Phillips et al. 2015). The three most frequent tasks (lateral repositioning, purposeful walks, and supporting a colleague with a charged hose) were performed 66–103 times across a 6-h shift. The three longest tasks (team building a fire break using hand-tools, dousing burnt debris during post-fire clean-up work, and extracting water from a water point) ranged from 119–461 s. The authors hypothesised that the difference in findings between the job task analysis and video observation could arise from legitimate discrepancies in task frequency and durations between jurisdictions. A further explanation is that the subjective job task analysis involved firefighters reflecting on a lifetime exposure to wildfire suppression work, whereas the video observation provided data from only four wildfire suppression shifts (Phillips et al. 2015).

Intensity

Wildland firefighting work is mostly self-paced and is therefore dependent on the interest, motivation, and mood of the participant (Myles & Romet 1987). There is limited research investigating the physical task performance of wildland firefighters during specific firefighting tasks. Brotherhood and colleagues (1997) investigated self-paced ‘slow’, ‘normal’, and ‘fast’ fireline construction rates of Australian land management firefighters. From ‘slow’ to 'fast' construction rates, average raking productivity increased from 1.5 to 3.3 m^2 of fire line constructed per minute, heart rate ranged from 137–180 beats·min^{-1}, and oxygen consumption ranged from 47–88% of maximal oxygen uptake (Brotherhood et al. 1997). However, Australian land management firefighters may have a greater level of cardiorespiratory physical fitness compared to their tanker-based volunteer counterparts (Phillips et al. 2011). Indeed, the cardiorespiratory physical fitness of North American firefighters, whose work demands are similar to Australian land management firefighters, has previously been shown to influence work performance and productivity (McFadyen et al. 1996). Fitter firefighters completed 27% more handline per hour, and could carry and deploy hoses, 9% and 14% faster respectively, than less fit firefighters (McFadyen et al. 1996). In addition, throughout a work shift, fitter firefighters worked at a greater rate of oxygen consumption for a lower maximal heart rate (McFadyen et al. 1996). These data indicate that firefighters with higher aerobic fitness levels have greater work productivity during wildfire suppression tasks. However, these studies only assessed heart rate and oxygen consumption during mostly land management tasks (McFadyen et al. 1996; Brotherhood et al. 1997), which may not fully represent the physical fitness and work characteristics of tanker-based firefighters.

Research by Phillips and colleagues (2015) evaluated firefighters' cardiovascular responses (heart rate and oxygen consumption) during seven simulated tanker-based wildfire suppression tasks. While each task had a unique duration and intensity, the mean oxygen consumption for hose-based tasks ranged from 21–27 ml·kg·min^{-1} and hand-tool tasks from 28–34 ml·kg·min^{-1} (Phillips et al. 2015). Heart rates ranging from 77–87% and 85–95% of %HR$_{max}$ were also observed for hose-based and hand-tool related tasks, respectively (Phillips et al. 2015). These cardiovascular responses corresponded to ‘moderate’ and ‘hard’ work intensities as classified by the American College of Sports Medicine (ACSM 2010). Phillips and colleagues (2015) also directly measured the work task intensity of tanker-based firefighters during actual wildfire suppression, and reported that average heart rate ranged from 55.7 ± 8.7 to 86.2 ± 10.8 %HR$_{max}$. Three tasks were identified as the most intense tasks: a) team building firebreaks using hand-tools, b) carrying a hose and, c) rolling a hose.

2.3.2 Energy expenditure and physical activity of wildland firefighters within a shift

While the characteristics of firefighting tasks have been determined, there is relatively less research describing firefighters’ work across a shift. Shift level analyses of total energy expenditure and physical activity levels provide an understanding of firefighters’ work patterns within and between shifts. Total energy expenditure refers to the sleeping metabolic rate, the energy cost of arousal, the thermic effect of food, and the energy cost of physical activity (Ravussin et al. 1986). Physical activity is defined as, ‘all bodily actions produced by the contraction of skeletal muscle that increase energy expenditure above basal level’ (Butte et al. 2012, p. S5).

Methods of measuring physical activity include activity monitors (e.g., accelerometers) and self-report measures. Whilst self-report measures are useful for determining activity behaviours, as they typically require participants to log their activity, they are cumbersome especially in a physically demanding occupation and are not accurate when estimating the absolute amount of physical activity (Sallis & Saelens 2000). Therefore, activity monitors are preferred over self-report measures as free-living physical activity can be assessed without relying on participant recall (Crouter et al. 2011). In addition, validated estimates of energy expenditure, sedentary time (< 1.5 metabolic equivalent (MET)), and time spent in light, (≥ 1.5–2.99 METs), moderate (≥ 3.0–5.99 METs), and vigorous (≥ 6 METs) intensity physical activity can all be obtained from physical activity monitors (Bassett 2000; Bassett et al. 2000). This information can provide information about the patterns of physical activity across and within work shifts.

In the last decade, research attention has focused on investigating the impact of nutrition (Cuddy et al. 2007; Montain et al. 2008; Cuddy et al. 2011) and hydration strategies (Cuddy et al. 2008; Raines et al. 2012; Raines et al. 2013) on firefighters' self-selected work activity during wildfire suppression. Collectively, these studies report firefighters' average physical activity levels during a wildfire suppression shift under different nutritional and hydration constraints. These studies utilised activity monitors (typically known as accelerometers) which are relatively unobtrusive and provide a cost-effective method for determining frequency, duration, and intensity of physical activity over long periods of time (Chen & Bassett 2005; Kavanagh & Menz 2008). Activity monitors continuously record dynamic bodily movements (i.e., acceleration and deceleration in different axes). Once collected, the raw data are converted into physiologically meaningful units through validated prediction equations (Heil 2002). Within a work shift, North American salaried firefighters' spent 61–74% of time engaging in sedentary time (defined as 0–99 counts per minute), with 21–38% of time spent in light-intensity (100–1499 counts per minute), and 2–7% moderate/vigorous-intensity (≥ 1500 counts per minute) physical activity (Cuddy et al. 2007; Cuddy et al. 2011). These findings are comparable to Australian volunteer firefighters who spent 50–62% of a shift sedentary, 32–43% in light-intensity, and 2–3% in moderate/vigorous-intensity physical activity (Raines et al. 2012; Raines et al. 2013).

The proportion of time firefighters spent sedentary during an average shift in both populations is surprising given the high total daily energy expenditures previously reported (Ruby et al. 2002). However, many wildland firefighting tasks, such as standing and waiting for spot fires or monitoring weather patterns, are included in sedentary time as no or little ambulatory movement is produced during these activities (Owen et al. 2010). Further, the battery life and memory of the device requires epochs of 1-min to capture the whole period required for monitoring. Therefore, those tasks (e.g., lateral repositioning, hose bowling) that are less than 1-min in duration may not be accurately represented depending on the physical activity levels during the remainder of the epoch (Trost et al. 2005). Another potential explanation is that the previous research has positioned each firefighter's activity monitor on the xiphoid process (Raines et al. 2012; Raines et al. 2013) or jacket chest pocket (Cuddy et al. 2007; Montain et al. 2008; Cuddy et al. 2011). The central location of these devices may be less sensitive to certain tasks performed using isolated limb movements during wildfire suppression, such as raking areas of smouldering debris. Furthermore, it has been suggested that activity monitors placed on other central regions, such as the hip, cannot accurately detect energy expenditure associated with upper body movements (Swartz et al. 2000). Advancements in monitoring devices have resulted in smaller and more compact models, enabling physical activity levels to be evaluated using validated measures at the wrist (Heil 2006). Wrist located measurement may be more accurate in capturing the upper body work tasks that characterise wildland firefighting.

Heart rate monitoring can be used to determine an individual's cardiovascular response to wildfire suppression work. Recently, Rodriguez-Marroyo and colleagues (2012) measured heart rate responses of Spanish wildland firefighters during actual wildfires. As wildfire duration increased, a non-significant decrease in mean %HR_{max} was observed, <1 h (70.8% HR_{max}), between 1 and 3 h (67.0% HR_{max}), between 3 and 5 h (63.3% HR_{max}), and >5 h (61.6% HR_{max}). These findings are not surprising given the initial containment phase of wildfire suppression involves high-intensity physical work (Brotherhood et al. 1997; Rodríguez-Marroyo et al. 2012). Furthermore, heart rate responses can vary significantly depending on the wildfire suppression tactics employed (Rodríguez-Marroyo et al. 2011). The authors considered 'direct' and 'indirect' attacks when firefighters worked near (< 5 m) or far (> 100 m) from the flames, respectively. The authors did not provide an explanation for how tactics of work between 5–100 m were defined. 'Mixed' attacks referred to situations where firefighters performed both 'direct' and 'indirect' attacks in the same wildfire. Those performing 'direct' (67.2% HR_{max}) and 'mixed' (66.3% HR_{max}) attacks exhibited higher heart rates compared to 'indirect' attacks (58.1% HR_{max}) (Rodríguez-Marroyo et al. 2011). Two studies by Raines and colleagues (2012, 2013) reported that firefighters spent approximately 55%, 51%, and 4% of the work shift in light (35–54% HR_{max}), moderate (55–69% HR_{max}), and hard (70–89% HR_{max}) heart rate zones, respectively. Devices that combine heart rate and activity monitor data can result in an accurate measure of energy expenditure (e.g., Sensewear and Actiheart devices). However, such devices necessitate battery charging every seven days, which may be difficult in wildfire environments that often have limited electrical supply. More importantly, heart rate can be influenced by a multitude of variables, such as high ambient temperature and humidity, hydration, emotional state, age, gender, and training status (Leger & Thivierge 1988; Melanson et al. 1996), all factors present in the aforementioned wildfire suppression studies. Therefore, based on these limitations, using heart rate as a sole measure to determine firefighters' work intensity during wildfire suppression may be problematic.

2.3.3 Energy expenditure and physical activity of wildland firefighters across multiple wildfire suppression shifts

In addition to the research investigating energy expenditure during a shift, research has been conducted that examines energy expenditure across multiple shifts (Heil 2002), often using the doubly labelled water (DLW) methodology (Ruby et al. 2002). The doubly labelled water methodology is the gold standard for measuring total energy expenditure in free-living individuals (Schoeller

1999; Westerterp 1999). Briefly, the DLW technique tracks the washout kinetics of body water that has been labelled with detectable isotopes (Heil 2002). Energy expenditure is then determined by assessing the rate at which these isotopes are cleared from the body by assessing urine samples collected over 4–16 consecutive days (Heil 2002; Ruby et al. 2002). Ruby and colleagues (2002) were the first to use the DLW technique to determine North American firefighters' total energy expenditure during five days of wildfire suppression. Firefighters' total daily energy expenditure ranged from 12.6–26.2 $MJ{\cdot}d^{-1}$ (3000–6260 $kcal{\cdot}d^{-1}$). This variability suggests that a range of factors may influence firefighters' total daily energy expenditure, such as shift length and the types of tasks performed. However, these values are comparable to previous research examining energy expenditure in other occupations (e.g., military operations) or athletically demanding activities (Westerterp et al. 1986; Forbes-Ewan et al. 1989; Hoyt et al. 1991; Pulfrey & Jones 1996). This study also reported that the energy expenditure associated with physical activity (i.e., activity energy expenditure) ranged from 4.2–12.6 $MJ{\cdot}d^{-1}$ (1000–3000 $kcal{\cdot}d^{-1}$) (Ruby et al. 2002).

Despite its accuracy and sensitivity, the DLW technique is an invasive and expensive method for determining energy expenditure ($1000–$1500 (USD) per participant), and therefore can limit research participant numbers. Moreover, wildfires are unpredictable, therefore it is challenging to set up firefighters for DLW analyses in a timely fashion, especially when firefighters are required to urgently attend a wildfire event. Furthermore, to accurately calculate the isotope elimination rate, the minimum collection period is four days (Ruby et al. 2002). This prohibits the use of the DLW technique for assessing energy expenditure during short duration wildfires or short bouts of specific firefighting tasks. In addition, while DLW technique captures total energy expenditure (including basal), physical activity measurement cannot be ascertained.

Unlike the DLW technique, activity monitors permit detailed day-by-day, hour-by-hour, or minute-by-minute recordings of energy expenditure. Heil (2002) was the first to use activity monitors for estimating total energy expenditure and activity energy expenditure during actual wildfire suppression. Across the day, total and activity energy expenditure averaged 4768 kcal·d^{-1} and 2585 kcal·d^{-1}, respectively. When these values were directly compared to the energy expenditures evaluated previously using the DLW technique, no differences were observed (Ruby et al. 2002). As physical activity monitors are validated for measuring physical activity intensities (Heil 2006) and have minimal participant burden in emergency settings, they can be used to assess firefighters' physical activity levels across a multi-day wildfire suppression deployment.

Studies utilising activity monitors to examine multiple wildfire suppression shifts have examined shift-to-shift differences in firefighters' physical activity levels (Cuddy et al. 2015; Raines et al. 2015). Raines and colleagues (2015) concluded that the physical activity levels of Australian land management firefighters did not differ between two consecutive shifts during a planned burn operation. This finding is not surprising, as firefighters anecdotally report that work between successive shifts is more consistent during planned burn operations compared to actual wildfire suppression (Personal Communication, 2014). Recently, Cuddy and colleagues (2015) observed a stepwise decrement in North American firefighters' physical activity levels (measured as total activity counts) across three days of actual wildfire suppression. However, each wildfire suppression shift is variable in severity, terrain, smoke, and heat exposure (Brotherhood et al. 1997; Budd et al. 1997; Budd 2001; Wegesser et al. 2009). These factors contribute to differences in the intensities of work required and thus may impact firefighters' total and activity energy expenditure (Heil 2002; Ruby et al. 2002). Thus, the stresses incurred in each wildfire shift, the characteristics of the work tasks involved, and the work-to-rest ratios performed throughout the day appear to differentially impact firefighters' physical activity requirements both during and between shifts.

While the existing research provides insight into how firefighters' physical activity may change between shifts, it does not examine whether the amount of physical activity firefighters engage in during one shift subsequently affects their physical activity in the following shift. This information is integral for workforce planning, and health and safety management between shifts during multi-day wildfire suppression deployments. For example, if firefighters are able to maintain physical activity levels between consecutive shifts, additional personnel may not be required for subsequent shifts. In turn, this may limit the number of firefighters exposed to environmental stressors and reduce the overall financial costs associated with wildfire operations. Despite these important applications no research has examined the associations between physical activity levels across consecutive wildfire suppression shifts.

Summary

Overall, the available body of research characterises wildland firefighting as a physically demanding occupation, involving self-paced intermittent manual handling work. The limited literature describing the physical and physiological demands of tanker-based wildland firefighting is likely due to the practical challenges of collecting valid physiological data in naturalistic environments (often remote and hazardous), without compromising the firefighter’s ability to perform their work. The impact of the various operational and environmental stressors on firefighters’ physical activity and physical task performance may have implications for work productivity estimates, as well as firefighters’ health and safety during wildfire events. For example, if wildfires can be controlled more quickly due to a higher total work output, damages and overall cost can be reduced. While several studies have assessed the impact of nutrition and hydration strategies on firefighters’ physical activity during wildfire, there is little understanding of the impact of other potential stressors (Budd et al. 1997), such as ambient temperature, smoke, and restricted sleep. Anecdotally, Australian fire agencies are concerned about the health and safety risks arising from sleep restriction during wildfire suppression deployments. Further, along with nutrition and exercise, sleep forms ‘the three pillars’ of healthy living (Rajaratnam 2015). As such, the importance of sleep and the consequences of restricted sleep will be discussed in the following section.

2.4 Sleep

Sleep is defined as a reversible behavioural state, characterised by a perceptual disengagement from and unresponsiveness to the environment (Carskadon & Dement 2011). Sleep is a basic requirement for human health and has numerous physiological and psychological restorative effects (Rechtschaffen 1998; Knutson et al. 2007; Cirelli & Tononi 2008). However, despite these perceived benefits, the research into why humans sleep remains equivocal (Sejnowski & Destexhe 2000; Tononi & Cirelli 2006). Normal human sleep is divided into two distinct states: rapid eye movement (REM) and non-rapid eye movement (NREM) (Carskadon & Dement 2011). NREM is further sub-divided into three stages: N1, N2 and N3 (Iber et al. 2007). Sleep begins in NREM and progresses through the NREM stages before the first episode of REM occurs 80–100 min later (Carskadon & Dement 2011). A normal night's sleep involves 90-min cycles of NREM sleep and REM sleep, until awakening (Carskadon & Dement 2011). Early in sleep, NREM dominates but as sleep duration progresses, the length and frequency of REM periods increase (Carskadon & Dement 2011).

To understand the regulation of the sleep wake cycle, several theoretical models have been proposed, including the 'two process' and 'three process' models (Borbely 1982; Daan et al.1984; Borbely & Achermann 1999). Two process models cite that the homeostatic process (also called 'process S'), and circadian process (also called 'process C') govern the sleep wake cycle (Borbely 1982; Daan et al. 1984). Three process models include an additional factor, the ultradian process (Borbely & Achermann 1999) (Figure 2.1). The homeostatic process is dependent on prior sleep, and describes the basic premise that the drive for sleep increases with wakefulness, and decreases with sleep (Van Dongen & Dinges 2003). The circadian process is a periodic (nearly 24-h), self-sustaining oscillating rhythm, largely independent of prior sleep/wake history, and regulated both endogenously and exogenously (Weitzman et al. 1970; Dijk et al. 1987; Dijk et al. 1989).

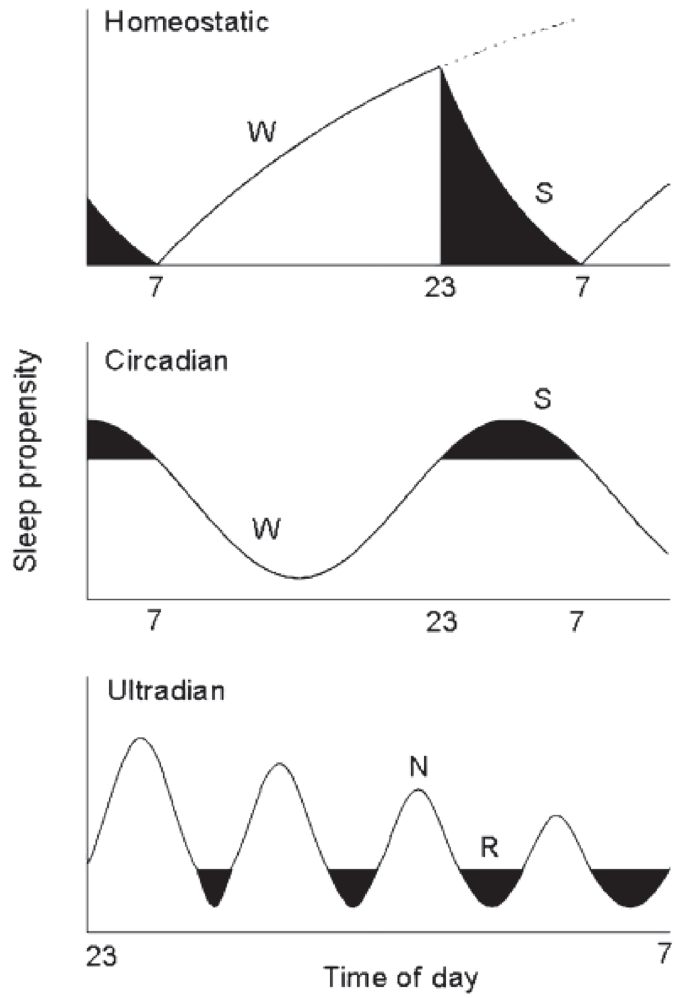

Figure 2.1: The three process model of sleep regulation (Borbely 2004, p.S67). W = wake; S = sleep; N = non-rapid eye movement; R = rapid eye movement. The progressive decline of non-rapid eye movement sleep intensity is represented both in the top and bottom diagram (decline of ultradian amplitude). The increase in the duration of successive rapid eye movement sleep episodes is indicated.

Endogenously, circadian rhythms are regulated by the suprachiasmatic nucleus, located in the hypothalamus (Beersma & Gordijn 2007) while exogenously, circadian rhythms are entrained by zeitgebers (derived from the German zeit 'time' and geber 'to give') (Moore 1982; Sedgwick 1998). The primary zeitgeber is light and as such, circadian rhythms become entrained to the 24-h solar day (Sedgwick 1998). The ultradian rhythm represents the 80 to 90 min oscillation of the two major sleep states, NREM and REM (Borbely 2004).

To evaluate the physiological effects of sleep loss, various methods can be employed to misalign the homeostatic and circadian processes, including total sleep deprivation or sleep restriction. Total sleep deprivation is the elimination of sleep for a period of time (at least one night) to significantly prolong wakefulness (Reynolds & Banks 2010). In contrast, sleep restriction (or partial sleep deprivation) is when an individual's normal sleep wake cycle is partially disturbed or the amount of sleep needed on a regular basis to maintain optimal performance is reduced (Boonstra et al. 2007; Reynolds & Banks 2010). For example, during a wildfire suppression deployment if sleeping conditions are not conducive to obtaining adequate sleep (e.g., due to a high ambient temperature, uncomfortable sleeping environment) then firefighters' sleep may be restricted. The majority of previous research has focused on total sleep deprivation, and revealed consistent and well defined physiological and behavioural effects (Horne 1978; Pilcher & Huffcutt 1996). While total sleep deprivation produces a high level of sleep pressure, sleep restriction is more commonly encountered in real-world settings (Banks & Dinges 2007), including during wildfire suppression (Gaskill & Ruby 2004; Cater et al. 2007).

The current literature indicates that restricting sleep to 6 h per night for four or more consecutive nights has been shown to impair normal healthy individuals' cognitive performance (Belenky et al. 2003; Van Dongen et al. 2003), glucose metabolism (Spiegel et al. 1999), appetite regulation (Spiegel et al. 2004), and immune function (Krueger et al. 2011).

2.4.1 Measuring sleep

The three primary methods for measuring sleep in laboratory or field studies include: polysomnography, activity monitoring (also known as actigraphy), and subjective (self-report) measures. Polysomnography is the gold standard method for measuring sleep (Kushida et al. 2005). Measures of brain activity (electroencephalogram) provide information necessary to identify periods of sleep and wake, as well as the individual sleep stages. The variables derived from polysomnography include: total sleep time, sleep-onset latency, wake after sleep onset, sleep efficiency, sleep fragmentation index, number of awakenings, time in each sleep stage, and sleep stage percentage. While polysomnography is appropriate for evaluating sleep in laboratory studies, traditional techniques are difficult to employ in the field, as the measurement setup is relatively intrusive, arduous, and usually require an on-site sleep technician (Ancoli-Israel et al. 2003). More recent electroencephalogram technologies, such as 'SmartCap', utilise dry electrodes and do not necessitate an on-site sleep technician (Butler et al. 2015). This allows for a less intrusive and more accessible measure of sleep in field settings. However, the cost of the equipment limits the ability to assess sleep in large populations (Ancoli-Israel et al. 2003).

Activity monitoring (actigraphy) provides an objective, non-invasive, and practical free-living alternative to polysomnography (Signal et al. 2005; Morgenthaler et al. 2007). Activity monitors indirectly assess sleep by sensing motor activity at the wrist and use validated algorithms to distinguish sleep from wakefulness (Ancoli-Israel et al. 2003; De Souza et al. 2003; Signal et al. 2005). These devices are useful for collecting data continuously for long periods of time and permit concurrent estimates of energy expenditure and physical activity, and sleep (Weiss et al. 2010). The variables derived from activity monitors include: total sleep time, sleep-onset latency, wake after sleep onset, and sleep efficiency. However, unlike polysomnography, activity monitors cannot be used to evaluate the specific sleep stages. In normal healthy adults, activity monitors have been shown to be reliable (Littner et al. 2003) and valid when measured against polysomnography in both laboratory (De Souza et al. 2003) and field settings (Signal et al. 2005). Whilst activity monitors can have a tendency to overestimate total sleep time, as periods of quiescent wakefulness can be misidentified as sleep (Pollak et al. 2001), these biases are deemed minimal especially when low thresholds (i.e., cut points) of activity are used to determine wake periods (Ancoli-Israel et al. 2003).

Subjective sleep assessments can also be obtained using sleep diaries or logs (Lockley et al. 1999). Sleep diaries allow for a large amount of data to be collected at low cost, and provide information on an individual's perceptions regarding their sleep (Signal et al. 2005). For example, sleep quality can be subjectively measured by asking participants to provide numerical ratings of perceived sleep quality and/or restfulness upon waking, and to report the number of night awakenings. Compared to activity monitors, sleep diaries yield similar data for sleep timing, sleep duration, sleep onset, and sleep offset, but not for sleep latency, number and duration of night awakenings, or number of naps (Lockley et al. 1999). In addition, activity monitoring is superior to subjective sleep assessments when directly compared to polysomnography (Monk et al. 1999). Nevertheless, self-reported sleep is not without value; the accuracy of sleep assessments using activity monitors can be improved when analysed in conjunction with subjective measures (Kushida et al. 2001; Acebo et al. 2005). For example, using both measures minimises the possibility of incorrectly scoring periods of sedentary wakefulness (e.g., watching television) as sleep, or restless sleep as wake. Thus, in situations where polysomnography is not feasible, concurrent use of activity monitors and self-report measures should be implemented.

Activity monitors and self-report measures allow for sleep measurement with minimal disruption to normal behaviours, thus are typically preferred in occupational settings. In wildfire environments, polysomnography is considered impractical for measuring the sleep obtained by firefighters, as sleeping locations are often remote, restricting access for researchers. Furthermore, the sophisticated arrangement of electrodes required for polysomnography may restrict firefighters' ability to respond to urgent calls to perform wildfire suppression work. Previous research has utilised subjective measures to assess firefighters' sleep during wildfire suppression deployments (Gaskill & Ruby 2004; Cater et al. 2007). However, given the aforementioned limitations of self-reported sleep assessments, further research is warranted using objective yet practical measures to more accurately determine the characteristics of sleep obtained during wildfire suppression deployments. In lieu of objective sleep data that is specific to wildland firefighting, useful insights may be obtained from other occupations where workers face similar challenges impacting upon their sleep (e.g., shift work). To date, researchers have primarily used actigraphy in conjunction with sleep diaries to assess the sleep behaviours of shift workers in mining and train driving populations (Lamond et al. 2005; Darwent et al. 2008; Jay et al. 2008; Ferguson et al. 2010), which will be reviewed here.

2.4.2 Sleep and shift-work

Modern industrial nations rely on a workforce that is available throughout the day and night. As a result, many people work and sleep outside their natural sleep/wake cycle. Shift work is a system of organising daily working hours, in which different people or teams work in succession to cover more than the usual 8-h day (up to and including the whole 24 h) (Costa 2003). Characteristic elements of shift work such as long working hours, consecutive shifts, and night work, have all been associated with increased fatigue and reduced sleep (Edkins & Pollock 1997; Åkerstedt 2000; Folkard & Tucker 2003). Circadian disruption and sleep loss are well-established outcomes of shift work schedules (Åkerstedt 2003; Driscoll et al. 2007). Importantly, chronic levels of decreased sleep and increased sleepiness can lead to cognitive performance deficits, which in turn increase fatigue-related risks (Folkard & Tucker 2003). As a result, the likelihood of work and non-work related accidents increases (Kuhn 2001; Åkerstedt & Nilsson 2003).

Sleep is impacted by a range of factors such as biological timing, environmental conditions, and individual specific characteristics (e.g., age) (Åkerstedt 2003; Muzet 2007; Folkard 2008). Thus, it is often difficult to identify which aspects of the sleeping context contribute to inadequate sleep. During deployments, firefighters can sleep in temporary accommodation near the fireground (Cater et al. 2007; Aisbett et al. 2012). These environments may be hot, smoky, and/or noisy (Cater et al. 2007; Cuddy et al. 2007); all factors that are known to adversely impact sleep quantity and quality (Groll-Knapp 1982; Libert et al. 1988; Lenné et al. 2004). Furthermore, there is some evidence to suggest that simply being away from familiar surroundings can affect sleep (Ferguson et al. 2005). However, a recent review suggested that the factors defining the sleep opportunity (specifically, the timing and duration of sleep periods) may exert a greater influence on sleep outcomes than sleep location (Jay et al. 2015).

Working environments that require round-the-clock operations, such as wildland firefighting, have traditionally used shift work rosters that provide one long period of work and one primary sleep opportunity per 24-h period. A 12-h on/12-h off work schedule is commonly employed in this setting, which achieves 24-h coverage, with two rotating crews. However, long shifts and early start times accompany such work schedules and may further impact a firefighter's ability to obtain adequate sleep. When the duration between successive work periods is decreased, total sleep time is also reduced (Kurumatani et al. 1994). Kurumatani and colleagues (1994) suggest that 16 h between work shifts are required to allow more than 7 h of total sleep time. When 12-h breaks were provided to locomotive engineers their average sleep was 3.1–7.9 h depending on when the break began (Roach et al. 2003). Objective data have revealed that in miners, power plant workers, and business and industrial personnel, individuals working consecutive 12-h shifts slept for 5.0–6.5 h (Axelsson et al. 1998; Tucker et al. 1998; Ferguson et al. 2010; Paech et al. 2010). Moreover, shifts with early start times have also been shown to substantially reduce sleep length (Ingre et al. 2008; Ferguson et al. 2010; Roach et al. 2012). For example, in train drivers, when shifts started at 0600 h total sleep time averaged 5.5 h compared to 7.7 h when the shift started at 0900 h (Ingre et al. 2008). Further, between 0430 h and 0900 h a near linear increase of 0.7 h more sleep was observed for every 1-h delay in shift start (Ingre et al. 2008).

Firefighters may be at risk of accumulated sleep deficiencies during wildfire suppression deployments, due to the duration of shifts, the timing of shifts, and the number of shifts performed consecutively over multiple days. However, research focusing specifically on the nature of sleep obtained during wildfire suppression deployments is required to verify whether this is the case. Operationally, the existing evidence indicates that shift structures should be evaluated and, where possible, modified to optimise workers' sleep opportunities. Moreover, identifying the specific shift characteristics and their relative contributions to reduced sleep opportunities and/or durations may provide fire agencies with targets for possible interventions. Furthermore, in situations where these factors cannot be modified, it is important to understand firefighters' exposure to fatigue-related risk so that appropriate controls can be designed to manage this risk, whilst simultaneously supporting the operational wildfire suppression objectives.

2.4.3 Sleep behaviour of firefighters during wildfire suppression deployments

Current reports that outline the sleep obtained by firefighters during wildfire suppression deployments are sparse and largely anecdotal (Gaskill & Ruby 2004; Cater et al. 2007). Cater and colleagues (2007) conducted structured interviews and post-deployment debriefs with a specialised group of firefighting experts, to determine the factors contributing to the fatigue experienced by Australian land management firefighters during wildfire suppression deployments. From these discussions, average shift lengths were ascertained; namely 13.8 h and 14.7 h for day- and night-shift rosters, respectively. In addition, firefighters described being awake in excess of 24 h during the initial wildfire suppression deployment (Cater et al. 2007). While the reasons for this were not reported, it is common in Australia for firefighters to be called to work an initial wildfire suppression shift after already working a full or partial day at their usual employment (Aisbett & Nichols 2007). When interviewed post-deployment, firefighters reported an average sleep duration of 3–6 h (Cater et al. 2007). Alarmingly, some firefighters recounted driving 2–3 h from the fireline to the staging area after having already worked a shift of at least 16 h. The authors concluded that the factors contributing to elevated fatigue included: length of shift, organisation of appropriate sleeping accommodation, the quality and length of rest for those working night shift, and driving while fatigued (Cater et al. 2007). In another study, Gaskill and Ruby (2004) investigated total sleep time during wildfire suppression deployments by administering sleep recall questionnaires (completed daily, the following morning) to Northern American wildland fire crews. In this cohort, sleep duration averaged 7 h per night, however reported sleep hours varied considerably: 13% reported <6 h, 27% reported 6–7 h, 28% reported 7–8 h, and 32% reported >8 h (Gaskill & Ruby 2004).

Together, these reports (Gaskill & Ruby 2004; Cater et al. 2007) suggest that many firefighters obtain less sleep than the current recommendations of 7–9 h for optimal cognitive function (Bonnet & Arand 1995; Ferrara & De Gennaro 2001). However, these studies share a major limitation in that sleep quantity was determined retrospectively using recall questionnaires, with variable hours since the firefighters last attended a wildfire event. Normal healthy sleepers tend to overestimate sleep duration when self-reporting their sleep behaviours (Fichten et al. 2005), as individuals can be often unaware of the precise time of sleep onset. Furthermore, these reports did not attempt to quantify the relationships between sleep duration and the operational and environment factors that may exacerbate sleep loss (e.g., sleeping location, shift start time, shift length, type of incident). The potential for sleep restriction in this population is considerable, yet the sleep of wildland firefighters has received little research attention to date. This gap in the literature may be attributable to the difficulty of monitoring firefighters' sleep behaviours in remote and environmentally extreme wildfire conditions, without interfering with firefighters' work and/or sleep. However, activity monitors provide a suitable means to overcome such challenges (Ancoli-Israel et al. 2003). Therefore, the use of activity monitors in combination with self-report measures would facilitate more accurate and objective assessment of the sleep obtained by firefighters. Such research should be completed by investigation into the key operational and environmental factors that may contribute to inadequate sleep during wildfire suppression.

2.5 The Physical Effects of Shift Work and Sleep

Wildland firefighting is a physically demanding occupation (Aisbett et al. 2012) and also requires a range of cognitive abilities in order to complete specific work tasks (Hayes et al. 2013). For example, firefighters must remain vigilant and make critical decisions in response to hazardous and unpredictable work environments (Elliott et al. 2009). Laboratory research has demonstrated that in healthy, non-shift working populations, significant cognitive performance decrements (e.g., slower reaction times, reduced levels of vigilance) occur when consecutive night-time sleep opportunities are restricted to less than 6 h (Belenky et al. 2003; Van Dongen et al. 2003). In addition, decrements in firefighters' attention (Christoforou et al. 2013) and an inability to perceive declines in cognitive performance (Armstrong et al. 2013) have been observed following a 4-h sleep opportunity. While the effects of multiple days of sleep restriction on firefighters' cognitive performance have been evaluated (Armstrong et al. 2013; Christoforou et al. 2013), little is known about the effects on their physical activity or physical task performance.

The available literature suggests that, during wildfire suppression deployments, sleep restriction is more prevalent than total sleep deprivation (Gaskill & Ruby 2004; Cater et al. 2007). Further, as previously described (*section 2.3*), wildland firefighting is characterised as mostly self-paced and intermittent work (i.e., submaximal) rather than requiring maximal physical performance. Few studies have investigated the impact of sleep restriction on submaximal performance. Due to the scarcity of firefighting-specific research, the effects of sleep loss on physical activity and/or physical performance in other physically demanding occupations, laboratory, and exercise contexts that resemble particular components of wildland firefighting will be discussed. Studies that will be reviewed in this section include, a) productivity and physical activity b) sleep restriction and submaximal physical performance c) total sleep deprivation and submaximal physical performance; d) sleep restriction and maximal physical performance. Studies that have investigated total sleep deprivation and maximal physical performance are not included in this review as they are, arguably, not relevant to wildland firefighting.

2.5.1 Productivity and physical activity

In occupational settings, physical task performance is often assessed by measuring worker productivity (e.g., the speed to complete a set amount of work, accuracy of completed work). Although only four studies (Browne 1949; Bjerner et al. 1955; Wojtczak-Jaroszowa & Pawlowska-Skyga 1967; Vidacek et al. 1986) have examined changes in productivity with different shift types (e.g., day, night and afternoon), the findings consistently suggest that productivity is compromised during night shifts and early in the morning.

Folkard and Tucker (2003) reviewed differences in 'real-job' measures of speed and accuracy across a 24-h day covered by various shift rosters for three occupational tasks. The measures were: 1) the delay in answering calls by switchboard operators (Browne 1949), 2) errors in reading meters (Bjerner et al. 1955); and 3) the time taken by spinners to tie broken threads in the textile industry (Wojtczak-Jaroszowa & Pawlowska-Skyga 1967). In all three studies, worker productivity was compromised during the night shift and the middle of the day, with the lowest productivity observed at 0300 h and 1200 h. Speed and accuracy measures were the greatest between 0700 h and 1900 h, with all other times impaired, especially during the early hours of the morning. Furthermore, Vidacek and colleagues (1986) examined the number of capacitors produced by workers during five successive 8-h, morning (0600-1400 h), afternoon (1400-2200 h), and night (2200-0600 h) shifts. Overall, productivity was greatest during the afternoon shift (1400-2200 h), and was 5% lower at night (Vidacek et al. 1986). Folkard and Tucker (2003) note that these studies are difficult to conduct, as there are variations in workforce personnel, and work practices on different shift types. In a wildland firefighting context, determining a firefighter's productivity across a shift is difficult as the conditions of the working environment (e.g., terrain, ambient air temperature, smoke exposure) and allocated tasks vary, both within and between deployments.

As yet, there have been no empirical investigations into firefighters' productivity across different shifts. Productivity measures lend themselves to work contexts where a known quantity or quality of work is to be completed on a regular basis. Thus, the paucity of firefighting productivity research is likely attributable to the highly variable work and environmental conditions encountered by firefighters, which can vary considerably within and between shifts. Despite this, firefighters' productivity can be indirectly assessed by monitoring physical activity levels during shifts and deployments (Heil 2002). To the author's knowledge, only one report has assessed the relationship between accumulated sleep loss and physical activity during wildfire suppression (Gaskill & Ruby 2002). North American wildland firefighters' total accumulated daily activity counts were moderately correlated (intra-class correlation coefficient (ICC) = 0.30) with firefighters' sleep duration the night before (Gaskill & Ruby 2002). Therefore, daily activity counts decreased with decreasing sleep hours, which may suggest physical effects of sleep-related fatigue. However, sleep was subjectively determined, which as previously mentioned (see section *2.4.1*) can be inaccurate as individuals are often unaware of their precise time of sleep onset (Baker et al. 1999). In addition, while total daily activity counts (an indicator of overall physical activity) were objectively measured using activity monitors, this study did not examine how physical activity was accumulated (i.e., time spent in different intensities), or evaluate physical activity associations between consecutive shifts. For these reasons it remains important to assess firefighter's physical activity and its relationship with sleep to provide agencies with important information for workforce planning, and health and safety management between wildfire suppression shifts. For example, if firefighters are able to maintain physical activity levels between consecutive shifts, this may reduce the need to add more personnel to subsequent shifts and in turn limit the number of firefighters exposed to environmental stressors. Therefore, by examining firefighters' physical activity levels during an actual wildfire, while concurrently measuring sleep duration, associations between these two variables can be evaluated.

2.5.2 Sleep restriction and submaximal physical performance

There is scant evidence describing the effect of sleep restriction during sustained submaximal exercise characteristic of wildland firefighting. In one of the few studies conducted, Reilly and Piercy (1994) observed decrements in maximal and submaximal weightlifting tasks, with a greater effect on submaximal tasks following 3 h of restricted sleep. Furthermore, the greatest impairments were noted following the second night of 3 h of sleep restriction, suggesting a cumulative effect of sleep-related fatigue (Reilly & Piercy 1994). Sleep restriction is prominent in other occupational settings that require submaximal physically demanding work, such as (e.g., emergency service work, military operations and wildland firefighting). However, there is little research on whether sleep restriction impacts physical activity or physical performance on work tasks. Thus, further research is warranted to determine whether sleep restriction adversely impacts physical work both in firefighting and other physically demanding occupations.

2.5.3 Total sleep deprivation and submaximal physical performance

No published research has examined firefighters' submaximal physical performance following total sleep deprivation. However, two studies have assessed the impact of total sleep deprivation on self-paced work (Rodgers et al. 1995) or exercise performance (Skein et al. 2011) when performing work intensities similar to that of wildland firefighting. Rodgers and colleagues (1995) examined the effects of 48 h of total sleep deprivation on self-paced physical work performance of healthy volunteers compared to a control group that were sleep deprived but performed no physical work. In those who performed work, declines in performance (17–43%) in five of the six physical work tasks, and self-selected walking pace (17–18%), were observed. Furthermore, the extent of the decrement in physical task performance due to total sleep deprivation may be dependent on the type of task evaluated, as those tasks requiring the involvement of the upper and lower body (characteristic of many wildland firefighting tasks) (Phillips et al. 2012) resulted in the greatest decrement in physical task performance.

Since the physiological test items (contractile properties, anaerobic power, resting blood glucose, and lactate levels) remained largely unaffected, this may have resulted in the maintenance of the maximal work efforts performed (Rodgers et al. 1995). However, higher ratings of perceived exertion were reported in those performing physical work. Therefore, the authors postulated that the potential mechanism underpinning the decline in self-paced work performance during periods of total sleep deprivation may involve alterations to a participants' level of interest, motivation, mood and/or the repetitive nature of the physical tasks involved. Thus, it is likely that the physical work, in conjunction with sleep deprivation, increased participants' perceived exertion. Rodgers and colleagues (1995) acknowledge that the inclusion of a third group that were not sleep-deprived, but performed the physical work tasks, would have enabled a more certain isolation of the factors contributing to a decline in physical work task performance.

A more recent study by Skein and colleagues (2011) investigated the effect of 30 h of total sleep deprivation on intermittent-sprint performance. Whilst the sleep deprivation period was substantially less than Rodgers and colleagues (1995), decrements in physical performance were observed. Slower mean sprint times, voluntary force, activation during maximal isometric knee extension, and increased perceptual effort were observed. Further, distances covered by sleep deprived participants during self-paced submaximal exercise bouts were lower in the final 10 min compared to control participants. While the available literature is extremely limited and equivocal, it seems that self-paced submaximal physical performance may be more susceptible to periods of total sleep deprivation than those tasks requiring maximal effort.

2.5.4 Sleep restriction and maximal physical performance

To date, no research has examined sleep restriction and effects on firefighters' maximal physical performance. As such, the impact of sleep restriction in exercise contexts, which have similar components to wildland firefighting tasks (e.g., intensity, movement patterns), may be drawn upon. A recent review concluded that both the effects of sleep restriction on athletic performance and the physiological responses to exercise remain equivocal (Fullagar et al. 2014). However, the authors contend that even though conflicting results exist, sleep restriction does not appear to affect singular bouts of aerobic performance or maximal measures of strength (Fullagar et al. 2014). Conversely, skill execution, and muscular and anaerobic power seem to decline following sleep restriction. While the empirical evidence is equivocal, the prevailing theories surrounding reduced exercise tolerance following sleep restriction are mostly attributed to perceptual changes (i.e., an increase in perceived exertion and mood), since the physiological responses remain largely unaffected (Fullagar et al. 2014). However, it is important to note that the duration of physical activity performed in exercise contexts is significantly shorter than a wildland firefighting shift (~12 h). In addition, whilst maximal performance capacities are of primary interest in exercise performance research, this has limited relevance to wildland firefighting which mostly requires submaximal efforts (Aisbett et al. 2012).

In lieu of firefighting-specific research, research investigating the effects of sleep restriction on military task performance may be of value. The extended work day of military personnel is similar to wildland firefighting: sustained activities of variable, low-moderate intensities, interrupted by short bursts of high-intensity activity (Lieberman et al. 2005; Tharion et al. 2005). Accordingly, several researchers have explored the effects of sleep restriction on physical performance by assessing maximal performance capacities before and after a period of submaximal work, which was designed to simulate work shifts completed over consecutive days (Murphy et al. 1984; Patton et al. 1989; Nindl et al. 2002). Following the simulated combat scenario involving a 4-h sleep opportunity, a decrease in mean upper body (elbow flexor) performance but no change in lower body (knee extensor) performance was observed (Murphy et al. 1984). The authors attributed this discrepancy to a high volume of upper body load bearing throughout the scenario, and a possible lower state of conditioning of the soldiers' upper body musculature. However, another study observed no decrements in physical fitness capacity or supervisor evaluated physical fatigue following sleep restriction (average 5.3 h) (Patton et al. 1989). Further research into soldiers' responses to caloric and sleep restriction observed decrements in three of the four physically demanding performance tests undertaken (Nindl et al. 2002). The largest decrement in physical performance (25%) was observed during a wall building task. The authors suggest this was due to the type of task, which was repetitive, monotonous, and included an absence of extrinsic motivation (which was present in other tasks). Tasks with these characteristics are inherent to wildland firefighting, such as creating a fire line. With a myriad of performance measures reported the authors suggest that tasks involving maximal efforts, (e.g., those tasks that are most critical to survivability, such as grenade throwing and marksmanship) can still be maintained. While such protocols have high content validity, it is difficult to determine the contribution of the singular effects of physical exertion, sleep restriction, energy restriction, and psychological stress on physical performance. Thus, controlled laboratory studies are needed to isolate the specific impact (if any) of sleep restriction on submaximal physical task performance.

2.5.5 Implications for wildland firefighting

Variations in the methods employed in the current literature make it difficult to isolate the effect of sleep restriction on firefighters' physical activity levels throughout a work shift and on physical task performance on specific firefighting tasks. However, it appears that participant motivation, the intensity of the physical work, the type of the physical tasks involved, the duration of sleep restriction period, and the length of the protocol are all important considerations. On balance, it appears that sleep restriction could decrease submaximal physical performance (characteristic of wildland firefighting), whilst having a relatively limited impact on maximal muscle function. Thus, wildland firefighters may be able to overcome the adverse effects of sleep restriction in single all-out efforts, but may be unable or unwilling to maintain intermittent self-paced performance. By assessing firefighters' physical task performance in a laboratory environment, with concomitant measures of physiology, both work productivity and an individual's ability to safely perform submaximal efforts can be determined. If self-paced work performance decreases as a result of restricted sleep, possible modifications to shift schedules may need to be implemented to mitigate the risks associated with reduced safety and productivity of wildfire personnel. Improvements in firefighter productivity within a shift may result in more work being completed and a wildfire being contained and extinguished in less time. This may reduce the costs associated with wildfire suppression and decrease the amount of time firefighters are exposed to hazardous environmental stressors.

The components of the work tasks also appear to influence whether physical task performance is adversely affected during periods of sleep restriction. For example, tasks involving the upper body and/or a high level of participant motivation seem to be more susceptible to decrements in physical performance following sleep restriction. However, the physical tasks employed in the aforementioned literature do not specifically reflect the movement patterns (e.g., dig, rake) and the work to rest ratios (e.g., intermittent, variable intensity), which are characteristic of wildland firefighting. Research is needed to investigate the effects of sleep restriction on those tasks that reflect the actions, fitness components, and movements performed during wildfire suppression. It is important to identify whether certain tasks, or specific characteristics of tasks, are more susceptible than others to sleep restriction across a wildfire suppression deployment. In the event that any are identified, crew leaders may be able to assign tasks to those individuals who have obtained the most sleep throughout their deployment, rotate those tasks that are most susceptible to sleep restriction, or implement more frequent rest breaks. Further, understanding the magnitude of the sleep-related decline in physical task performance may be valuable for work force planning and risk control.

Understanding whether different sleep durations influence physical activity levels between shifts is important for both wildfire operations and firefighters' health and safety. For example, if firefighters who obtain more sleep are more physically active and/or productive than those who obtain less sleep, this may have important implications for workforce productivity estimates. Thus, field-based research can assess whether sleep duration moderates firefighters' physical activity levels during actual wildfire suppression. However, while field research provides a global measure of firefighters' work productivity across a whole shift, physical activity monitoring is limited in its ability to assess performance on specific firefighting tasks. Furthermore, it is possible that sleep restriction may adversely affect some tasks more than others. Therefore, to quantify the effect of sleep restriction on firefighters' physical task performance, rigorously controlled laboratory protocols implementing a simulation that includes wildland firefighting specific work are required. More broadly, understanding what dimensions of physical activity and physical task performance are affected by sleep restriction may be relevant for other physically demanding occupations (e.g., emergency service, civilian and military workers).

2.6 Conclusion

The literature concerning the interactions between shift-work, sleep, physical activity, and physical task performance is sparse and remains equivocal. Firstly, establishing firefighters' sleep behaviour utilising objective measurement during wildfire suppression is required. Then, both field and laboratory based studies are needed to ascertain whether sleep impacts on physical activity and physical task performance. In safety-critical physically demanding occupations, such as wildland firefighting, compromised physical work can have adverse consequences on health and safety, as well as the entire emergency operation. Therefore, research is required to understand the extent and influence of the effect of sleep on firefighters' physical activity levels and physical task performance during multi-day wildfire suppression. This thesis will address this research gap.

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Chapter 3: Study One

Fighting fire and fatigue: sleep quantity and quality during multi-day wildfire suppression

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The content of this chapter is presented as per the accepted manuscript for publication in *Ergonomics*.

Abstract

Objective: The primary aim of the present study was to determine firefighters' sleep quantity and quality throughout multi-day wildfire suppression, and secondly to assess the impact of sleep location, shift length, shift start time, and incident severity on these variables.

Methods: Forty volunteer firefighters were recruited across Australia's fire agencies. Sleep was measured objectively using wrist actigraphy for a period of four weeks. All variables were examined in two conditions: 1) fire days, and 2) non-fire days. Time in bed, total sleep time, latency, and sleep efficiency were evaluated objectively. Subjective reports of pre- and post-sleep fatigue, sleep location, sleep quality, and number of times woken were also recorded.

Results: Analyses revealed that the quantity of sleep obtained on fire days was restricted compared to sleep on non-fire days. Pre- and post-sleep fatigue ratings were greater on fire days compared to non-fire days. Sleep quality, latency, efficiency, and number of times woken did not differ significantly between fire and non-fire days. On fire days, total sleep time was less when sleep location was in a tent or vehicle compared to at home or in a motel. Total sleep time was less when shifts were greater than 14 h, compared to all other shift lengths. There were no differences in total sleep time across different incident severity levels. Pre-shift total sleep time was less when shifts started between 0500–0600 h, compared to all other shift start times.

Conclusions: This is the first empirical investigation providing objective evidence that firefighters' sleep is restricted during wildfire suppression. The results of the study highlight that sleep location, shift length, and shift start time should be considered when designing appropriate controls to manage fatigue-related risk and preserve firefighter health and safety during wildfire events.

Introduction

Worldwide, the incidence and severity of large, uncontrolled wildfires is increasing (Hennessy et al. 2005; Lucas et al. 2007; Pitman et al. 2007; Pechony & Shindell 2010). These wildfires place considerable demands on wildland firefighters, who are subjected to a myriad of stressors and adverse working conditions (Aisbett et al. 2012). One of the major enduring stressors is restricted sleep, due to extended work periods, with little rest between consecutive shifts (Gaskill & Ruby 2004; Cater et al. 2007). During a wildfire, 24-h suppression work is performed by fire crews to protect life and property, which can last hours, days, or even weeks depending on fire severity and available personnel (Hunter 2003; Aisbett et al. 2012; Rodríguez-Marroyo et al. 2012). Australia's firefighting personnel are typically rostered to work a 12-h day or night shift, but can work shifts of up to 16 h for 3–5 consecutive days (Cater et al. 2007; Phillips et al. 2007). Consequently, the rest periods between shifts are reduced, resulting in truncated sleep opportunities (Aisbett et al. 2012).

The existing evidence surrounding firefighter fatigue during multi-day wildfires is largely subjective, and robust objective data on wildland firefighters' sleep behaviour is lacking. Australian firefighters have previously reported obtaining 3–6 h of sleep per night during wildfire suppression deployments (Cater et al. 2007). Similarly, North American firefighters reported sleep hours that varied considerably < 6 h (13%), 6–7 h (27%), 7–8 h (28%), and > 8 h (32%) (Gaskill & Ruby 2004). However, relying solely on these studies to determine firefighters' sleep quantities may be problematic given that normal healthy individuals tend to overestimate their sleep duration (Fichten et al. 2005), as they can be unaware of the precise time of sleep onset (Baker et al. 1999). Notwithstanding the limitations surrounding subjective reporting of sleep, there is also a large range in the reported sleep hours firefighters obtained (e.g., between 3 and >8 hours), thus limiting the capacity for agencies to adequately assess and control fatigue-related risk. Agencies need to understand the factors that influence sleep duration in order predict actual sleep and better manage risk (Dawson & McCulloch 2005; Lerman et al. 2012). Given the current literature is limited and utilises exclusively self-report measures, a more comprehensive objective assessment of firefighters' sleep during wildfire suppression (and the factors that may moderate sleep duration) is warranted.

In many work settings, inadequate sleep has been shown to impair cognitive performance and increase fatigue-related risk (Smith et al. 1994; Folkard & Tucker 2003). Previous research has also demonstrated that total sleep time is reduced when the duration between successive work periods is decreased (Kurumatani et al. 1994). As such, objective measurement of sleep in individuals working consecutive 12-h shifts (albeit not fighting wildfires) has resulted in sleep durations of between 5.0 and 6.5 h (Axelsson et al. 1998;

Tucker et al. 1998; Ferguson et al. 2010; Paech et al. 2010). Moreover, controlled laboratory studies have demonstrated that restricted or fragmented sleep adversely impacts reaction time, vigilance, concentration, and decision making (Gillberg et al. 1994; Dinges et al. 1997; Belenky et al. 2003; Lamond et al. 2003; Van Dongen et al. 2003), all of which are elements required for firefighting (Elliott et al. 2009). Given that shifts with an early start time have also been shown to substantially reduce sleep length (Ingre et al. 2008), the duration and timing of shifts, as well as the number of shifts performed consecutively during wildfire suppression could all contribute to cumulative sleep deficiency.

Operationally, shift structures should be evaluated and, where possible, modified to optimise workers' sleep opportunities. Identifying the specific shift characteristics, and the degree to which they contribute to reduced sleep opportunities and/or durations, provides targets for possible interventions. In situations where these factors cannot be modified it is important to understand firefighters' exposure to fatigue-related risk, in order to design appropriate controls to manage this risk, whilst simultaneously supporting operational suppression efforts (Dawson et al. 2011). To our knowledge, there is no objective research describing the quantity and quality of sleep during multi-day wildfire suppression. Therefore, the major aim of this study was to provide a detailed characterisation of the sleep quantity and quality of firefighters, using objective and subjective measures, during wildfire suppression deployments. The secondary aim was to describe the key operational factors that may contribute to inadequate or increased sleep.

Materials and Methods

Recruitment and participants

This study was advertised through communications officers and crew leaders from member agencies of the Australasian Fire and Emergency Services Authorities Council. Interested participants contacted researchers directly, were given information sheets, and provided written informed consent. Ethical approval was obtained from the Deakin University Human Research Ethics Committee (2012-300) prior to any data collection.

Despite the prevalence of wildfires in Australia (Country Fire Authority 2014), the timing and location varies from season to season. Approximately 250 accredited volunteer firefighters were initially contacted to participate in the study, and 90 were subsequently recruited for a four-week period during the 2012/2013 or 2013/2014 Southern Australian fire season (November-February). From that group, 61 performed wildfire suppression duties. Of those, only 43 completed day shifts as well as all aspects of data collection including completing the sleep/work diaries, both during wildfire suppression and at home, and wearing the activity monitor (actigraph) for the entire data collection period. Three participants' data were excluded from the analysis due to water damaged monitors, resulting in a final sample of 40 participants (31 males, 9 females). Of the 214 individual shifts recorded, nine were night shifts, and were subsequently excluded due to inadequate power for a comprehensive analysis. The contribution of the number of shifts recorded per participant was as follows: 28% provided 2–3 shifts of data, 30% 4–5 shifts, 25% 6–7 shifts and 17% 8–9 shifts.

Table 3.1: Self-reported demographics taken from self-reported answers on the General Health Questionnaire.

	Mean ± Standard Deviation	Range
Age (years)	39.6 ± 11.6	19–65
Body mass index (kg/m^2)[a]	27.7 ± 4.9	20–37
Firefighting experience (years)	10.8 ± 10.3	0–48
Total career multi-day deployments (number)	20 ± 32	0–150
Typical wildfire suppression deployment sleep (hours)	5.9 ± 1.2	4–9
Normal sleep (hours)	7.4 ± 1.2	3–9
Sleep quality[b]	2.5 ± 1.0	1–5

Note: (n=40); [a] Calculated from self-reported height and weight measurements in the General Health Questionnaire (ACSM 2010); [b] Sleep quality was assessed using a 5-point Likert Scale, where 1 = 'very good', 2 = 'good', 3 = 'average', 4 = 'poor', and 5 = 'very poor', as previously used by Paech et al. (2010).

Self-reported demographic data, obtained from a General Health Questionnaire (ACSM 2010), are presented in Table 3.1. Firefighters' age was evenly distributed across the sample with 25% of firefighters in each age group (19–29, 30–39, 40–49, and 50+ years old). No relevant diagnosed medical and/or sleep disorders were reported. Ninety percent reported that they regularly consumed beverages containing caffeine, 80% were either married or living with a partner, and 8% were smokers.

Sleep assessment

Activity monitoring (actigraphy) provides an objective, non-invasive, indirect assessment of sleep (Ancoli-Israel et al., 2003), and has been validated against polysomnography in both laboratory (De Souza et al. 2003) and field settings (Signal et al. 2005). Participants were required to wear an activity monitor (Actical MiniMitter/Respironics, Bend, OR) on their non-dominant wrist for the duration of the study. The Actical (28 × 27 × 10 mm, 17 g) device uses a piezo-electric omnidirectional accelerometer, which is sensitive to movements in all planes in the range of 0.5–3.0 Hz (John & Freedson 2012). Firefighters were instructed to remove the activity monitor during periods when submersion with water was likely (e.g., whilst showering). Actical data were downloaded and processed using a validated manufacturer propriety algorithm in the software (Actical v3.10) that generates a weighted score for each 1-min epoch based on the amount of activity recorded during that epoch and the surround 2 min (Kosmadopoulos et al. 2014). Epochs with scores below the specified sleep/wake threshold are classified as sleep. In the current study, the default medium threshold of 40 counts per epoch was employed to distinguish between sleep and wake states (Darwent et al. 2008). All actigraphy variables used in this study are defined in Table 3.2. All variables were examined in two conditions: 1) fire days, and 2) non-fire days. The inclusion criteria for the number of days of data on fire and non-fire days was 2 and 7 days, respectively. All participants contributed data to both conditions. Sleep diaries were completed by participants before and after each sleep period. This also included reporting nap timing and duration. The sleep period and naps were then combined to determine total sleep time in the 24-h period. Prior to each sleep period, participants were asked to record the time they attempted to sleep (i.e., 'lights out'), their sleep location, and pre-sleep fatigue level. Following each sleep period, participants were asked to record their wake time, sleep latency, sleep duration, number and duration of awakenings, post-sleep fatigue, and sleep quality.

Sleep location was categorised as 'home', 'motel', 'cabin', 'tent' or 'vehicle'. Sleep quality was assessed using a 5-point Likert Scale, where 1 = 'very good', 2 = 'good', 3 = 'average', 4 = 'poor', and 5 = 'very poor', as previously used by Paech et al. (2010). Pre- and post-sleep fatigue were evaluated by participants circling their current level of fatigue on a 7-point scale (Samn & Perelli 1982). This scale has previously been used to measure fatigue in other operational settings, for example mining (Ferguson et al. 2011) and rail (Jay et al. 2008).

To investigate the effect of early start times, pre-shift total sleep time was defined as the sleep obtained in the 24-h period prior to shift start (see Figure 3.1). For all other variables (non-fire days, fire days, sleep location, shift length,

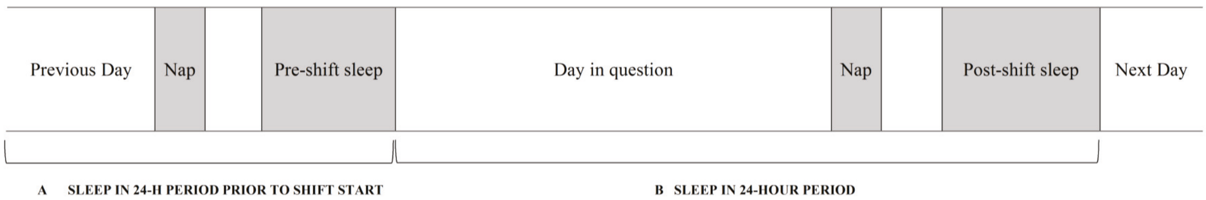

Figure 3.1: Definitions of total sleep time for each variable.

Note: ‘A’ denotes sleep in 24-h period prior to shift start; ‘B’ denotes sleep in 24-h period; grey = sleep; white = wake.

Table 3.2: Definitions of each sleep variable measured with actigraphy.

Time in bed (hhmm)	The time between bed times ('lights out') and get up ('lights on')
Total sleep time (hhmm)	The time between sleep start and sleep end
Sleep efficiency (%)	The proportion of time spent asleep while in bed (total sleep time/time in bed)
Sleep latency (min)	The latency before sleep onset following bed time ('lights out')

incident severity), total sleep time was defined as all sleep obtained in the 24-h period from wake time on the day in question (Figure 3.1). Two researchers cross-referenced participants' sleep diaries with the activity monitor data to determine time in bed, total sleep time, number of times woken, sleep quality, and timing of bedtime and sleep periods. This ensured the accuracy of the self-reported measures, as well as minimising the possibility of incorrectly scoring periods of sedentary wakefulness (e.g., watching television) as sleep, or restless sleep as wake.

Work diary

On fire days, firefighters also completed a customised work diary, which required them to provide information about the timing of their actual hours of work during their rostered shift, and their work responsibilities. Shift-start times were categorised into one of four hourly intervals: 0500-0600 h, 0600-0700 h, 0700-0800 h, 0800-0900 h. Given firefighters average shift length is 12 h (Aisbett et al. 2012), shift lengths were classified into one of four categories: < 10 h, 10-12 h, 12-14 h, or > 14 h. Travel time, and whether the individual was a driver or passenger, were also recorded. Incident severity was recorded as one of three levels: Level 1: resolved through the use of local or initial response resources only, Level 2: complex in size, resources or risk, or Level 3: degrees of complexity that may require establishments of other divisions for effective management of the situation (Australasian Fire Authorities Council 2005).

Statistical analysis

Statistical analyses were carried out using the IBM Statistical Package for the Social Sciences (SPSS; V.22.0.0, Armonk, NY). Exploratory data analysis, using Shapiro-Wilk tests was conducted to determine whether the data met parametric assumptions of normality. All variables were normally distributed. Actigraphy variables were analysed using a one-way mixed analyses of variance (AVOVA), with Day Type (non-fire, fire) as the fixed factor. Four additional one-way mixed ANOVAs were conducted to determine whether total sleep time was different depending on: 1) Sleeping location, 2) Incident severity level, 3) Shift length, and 4) Shift start time. Participant was specified as the random factor to account for inter-individual differences. Total sleep time for each sleep location was analysed for each sleep period, excluding sleep periods that were < 60 min in duration. Where significant effects were found, pairwise post-hoc comparisons (with Bonferroni corrections for multiple comparisons) were used to determine where significant differences occurred. Time is represented as hh:mm, unless otherwise stated. Statistical significance was set at $P < 0.05$ and all data are presented as means ± standard deviations (SD).

Results

Firefighting work

Firefighters completed a total of 205 shifts. 55% of fire events were 2–4 consecutive days in duration, with the remaining 45% between 5–7 days. The average shift length was 11:36 ± 3:04 h, with 71.9% of shifts over 10 h in duration. The majority of shifts started between 0800-0900 h (40%), with the remaining starting between 0700-0800 h (36%), 0600-0700 h (19%), and 0500-0600 h (5%). The average travel time to the fire location was 1:23 ± 1:00 h (included in shift length), and participants were the driver 55.7% of the time. Across the shifts, 48.7% of incidents were graded in severity as Level 1, 30.7% as Level 2, and 20.6% as Level 3.

Sleep quantity

Time in bed and total sleep time were 1.07 ± 0.19 h and 0.90 ± 0.25 h less during fire days compared to non-fire days, respectively (Table 3.3; $P < 0.001$). There was also a large inter-individual variation in total sleep time on fire days (8% < 4 h, 35% 4-6 h, 51% 6-8 h, and 6% > 8 h). Across all shifts, 10% of days included nap periods, with an average duration of 0.97 ± 0.96 h. When sleep location on fire days was analysed, total sleep time was less when in a tent or vehicle compared to at home or in a motel (Figure 3.2a; $P < 0.01$). The majority of sleep episodes on fire days occurred in a motel (51%), with the remaining in home (28%), cabin (10%), tent (7%) or vehicle (4%) locations.

Total sleep time was 0.81 ± 0.32 h less when shifts were greater than 14 h, compared to all other shift lengths (Figure 3.2b; $P < 0.05$). Pre-shift total sleep time was 1.0 ± 0.33 h less when shifts started between 0500–0600 h, compared to all other shift start times (Figure 3.2c; $P < 0.05$). There were no differences in total sleep time across different incident severity levels ($P \geq 0.600$).

Table 3.3: Sleep variables on non-fire and fire days.

	Non-Fire	Fire	P value
Actigraphy			
Time in bed (h)	7.9 ± 0.7	6.9 ± 0.8	< 0.001*
Total sleep time (h)	7.0 ± 0.9	6.1 ± 1.7	<0.001*
Efficiency (%)	88.1 ± 6.8	88.8 ± 5.4	0.190
Latency (min)	5.9 ± 5.3	5.4 ± 6.0	0.690
Subjective reports			
Times woken (number)	1.7 ± 0.9	1.7 ± 1.0	0.085
Sleep quality	2.4 ± 0.6	2.6 ± 0.7	0.100

Note: data presented as mean ± standard deviation (n=40), * denotes significance, $P < 0.05$.

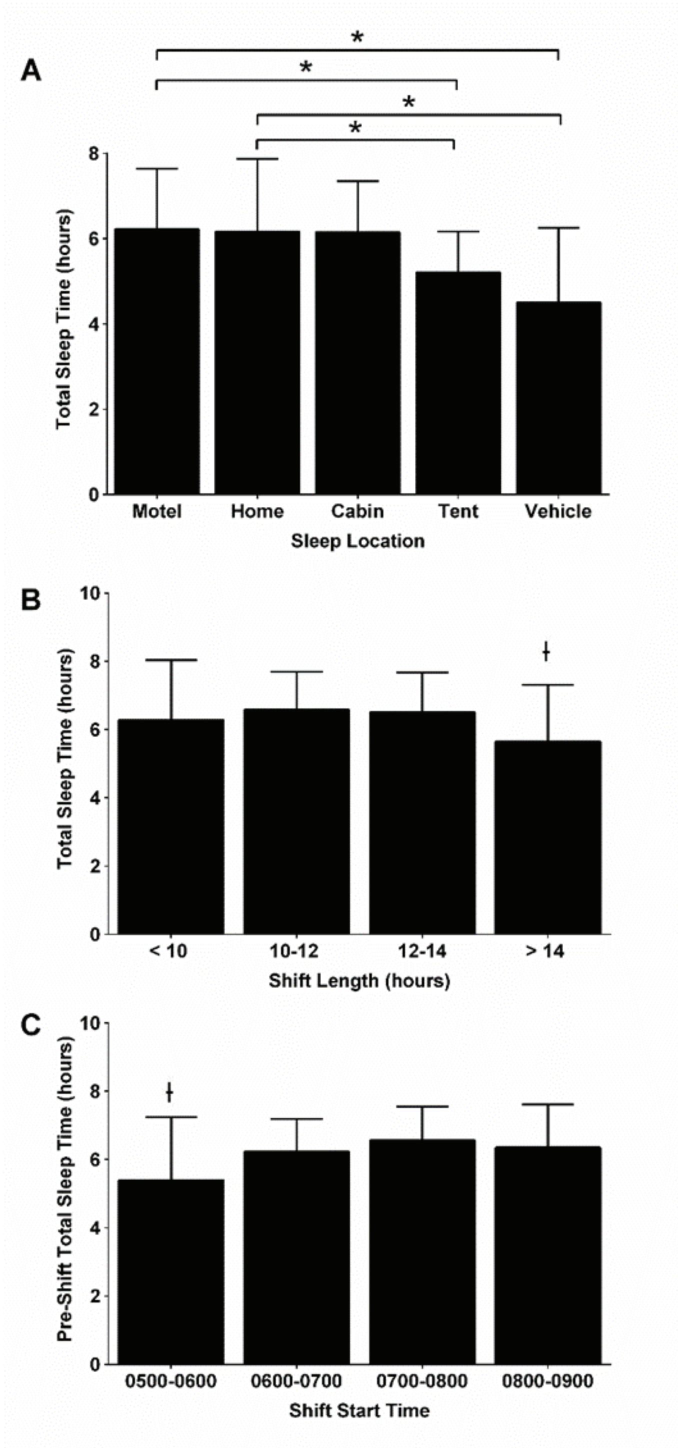

Figure 3.2: Total sleep time when comparing operational characteristics of work shifts on fire days. A) Total sleep time and location. B) Total sleep time and shift lengths. C) Pre-shift total sleep time and shift-start times. Mean ± standard deviation. * denotes significance, ƚ significantly different from all other categories, $P < 0.05$.

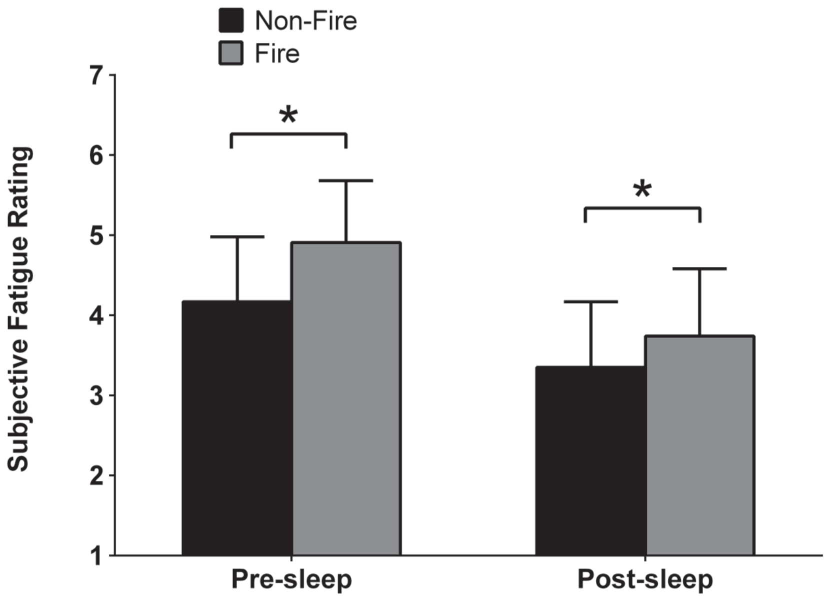

Figure 3.3: Subjective fatigue ratings on the 7-point Samn-Perelli scale (Samn & Perelli 1982) prior to a sleep period (pre-sleep) and following (post-sleep) a sleep period.

Note: data presented as mean ± standard deviation. * denotes significance, $P < 0.05$.

Sleep quality

There was no difference between non-fire and fire days for sleep efficiency, sleep latency, subjective reports of times woken or subjective sleep quality (Table 3.3).

Subjective fatigue

Subjective fatigue ratings were higher pre-sleep compared to post-sleep (Figure 3.3) on both fire days (1.17 ± 0.17) and non-fire (1.24 ± 0.18) days ($P < 0.001$). On fire days, pre-sleep (0.74 ± 0.18; $P < 0.001$) and post-sleep (0.39 ± 0.19; $P < 0.001$) fatigue were higher compared to non-fire days (Figure 3.3).

Discussion

The current study is the first to utilise objective measures to determine firefighters' sleep behaviour during wildfire suppression. Sleep quantity on fire days was significantly less than non-fire days. Moreover, self-reported levels of pre- and post-sleep fatigue were greater on fire days compared to non-fire days. On fire days, sleep in tents or vehicles, long shifts, and early start times, were accompanied by less sleep. However, there were no differences in self-reported sleep quality and times woken, or measures of sleep latency and efficiency, between non-fire and fire days. The current findings suggest that while sleep quantity is reduced during wildfire suppression, modifying specific characteristics of work shifts, and the sleeping environment, could improve sleep quantity.

On average, firefighters obtained 6.1 h of total sleep time on fire-days, 54 min less than non-fire days. Total sleep time was similar to previous anecdotal or subjective reports in wildland firefighters (Gaskill & Ruby 2004; Cater et al. 2007), and is considered to be an inadequate amount for most individuals (Ferrara & De Gennaro 2001). Perhaps more concerning are the potential consequences of consecutive nights of sleep restriction on firefighters' health, safety, and work performance. Firefighting requires a range of cognitive abilities to complete specific work tasks (Hayes et al. 2013). For example, firefighters must remain vigilant and make safety-critical decisions in response to hazardous and unpredictable work environments (Elliott et al. 2009). In the current study, 43% of fire day sleep periods were below 6 h in duration, often occurring over successive days. Laboratory research has demonstrated that in healthy, non-shift working populations, significant cognitive performance decrements (e.g., slower reaction times, reduced levels of vigilance) occur when consecutive night-time sleep opportunities are restricted to less than 6 h (Belenky et al. 2003; Van Dongen et al. 2003). Therefore, this finding is particularly concerning, as when total sleep time and cognitive performance decline, the ability for an individual to perform a task safely decreases, and fatigue-related risk increases (Folkard & Tucker 2003; Dawson & McCulloch 2005).

Factors that may influence wildland firefighters' total sleep time include sleep location, shift duration, and shift-start time. These factors may explain the variability in the amount of sleep firefighting personnel obtain across different wildfire suppression deployments, and may also provide modifiable targets to improve total sleep time. In the current study, total sleep time obtained in a tent or vehicle was significantly lower compared to sleep at home or in a motel. Anecdotally, sleeping in vehicles is not common practice for fire agencies, therefore it is likely that these sleeps may have been opportunistic. For example, a firefighter may have chosen to sleep in the back of a fire truck on the way to another wildfire, or during a less intense period of the wildfire event. Sleep is impacted by biological timing, environmental conditions, and individual specific characteristics (e.g., age) (Åkerstedt 2003; Muzet 2007; Folkard 2008). Therefore, it is difficult to separate the specific contribution of the different sleeping locations. Nevertheless, the environmental conditions associated with these sleeping locations such as noise, heat, and light exposure may adversely affect sleep onset and total sleep time (Cater et al. 2007). In the current study, firefighters most commonly reported anecdotally (in the comments section of their sleep diary) that 'heat', 'noise' (i.e., snoring), and 'the number of other people in the sleeping location' were the major contributing factors in obtaining less sleep during wildfire suppression deployments. Fire agencies may benefit from taking action to reduce these adverse effects by improving the sleeping environment. For example, noise has been shown to disrupt sleep (Muzet 2007). Therefore, setting up the sleeping area away from arriving crew members, or supplying firefighters with ear plugs, may make the sleeping environment more conducive to obtaining an adequate amount of sleep.

Despite the importance of sleep location, a recent review suggested that the factors defining the sleep opportunity, specifically the timing and duration of sleep periods, may be more crucial in dictating sleep outcomes (Jay et al. 2015).

In the current study, shifts that were beyond 14 h in length resulted in an average of 5.7 h sleep, or 48 min less sleep than shifts less than 14 h in duration. Extended shifts are common during wildfire suppression, often resulting from a lack of replacement personnel, or fires that are burning out of control that require urgent attention. Previous research has demonstrated that 16 h of non-work time is required for workers to obtain a total sleep time of 7–8 h (Sallinen et al. 2003). In addition, studies involving workers sleeping at home between 12-h shifts have demonstrated an average sleep time of approximately 6 h per night (Åkerstedt 1995). Collectively, these findings are in concert with the current study, suggesting that as shift length increases the resulting sleep opportunity decreases.

Previous research demonstrates that early start times substantially reduce sleep length (Ingre et al. 2008). This was reflected in the current findings, which showed that shifts starting before 0600 h resulted in 60 min less sleep, when compared to shifts starting after 0600 h. This suggests that wherever possible, fire agencies should preferentially implement later start times (and include travel time to the fire location) to safeguard personnel from receiving a truncated sleep opportunity. However, any changes to shift structures should be considered in terms of the entire wildfire suppression operation. For example, a shift that starts early may allow firefighters to work in cooler conditions or for rotating night shift crew to get to sleep before sunrise. Work shifts should be structured to provide frequent and sufficient recovery, especially in dangerous working environments where fatigue-related errors have severe consequences. In situations where this may not be possible, such as an extended shift length due to lack of available personnel, additional fatigue countermeasures may need to be implemented. These may include more frequent rest breaks (Tucker 2003), caffeine provision (Lorist & Tops 2003) or increased communication/supervision (Dawson et al. 2011; Lerman et al. 2012).

Although sleep quantity was reduced, firefighters did not take longer to fall asleep on fire days. Further, sleep efficiency, subjective sleep quality, and the number of times woken were no different between fire and non-fire days, suggesting that sleep quality was also similar between conditions. Firefighters did, however, report greater levels of pre- and post-sleep fatigue on fire days compared to non-fire days. Previous research had indicated that subjective and objective indicators of sleepiness, fatigue, and performance may not always correspond (Van Dongen et al. 2003; Tremaine et al. 2010; Curcio et al. 2001). This brings into question how accurately such tools can gauge individuals fatigue states. Thus, while the results of the current study indicate that firefighters were aware they were more fatigued on fire days, the extent of fatigue, and the possible consequences of that fatigue, may still be over or underestimated. Implementing a valid subjective tool to assess fatigue during wildfire operations, such as the one used in the current study, may result in early detection of fatigue-related risk. Consequently, in situations where firefighters report being fatigued, crew leaders could then employ strategies, such as enforcing breaks, to mitigate the likelihood of this risk translating into a fatigue-related incident. However, self-report tools cannot be the only means of managing fatigue-related risk.

A possible limitation of the current study is that participants were asked to rate their fatigue post-waking at an unspecified time. Sleep inertia, the cognitive impairment experienced as 'grogginess' post-waking (Tassi & Muzet 2000), can last for up to 2 h after waking (Jewett et al. 1999). As such, sleep inertia could have confounded the results, causing an overestimation of post-sleep fatigue ratings. It is also difficult to determine what cues firefighters used to assess their fatigue, and if this was influenced by other factors, such as prior sleep, time of day, workload, or previous ratings (Ferguson et al. 2012). For example, pre-sleep fatigue could have been influenced on fire days due to administration of the scale at a different time of day, as would be the case if a shift started early. Future research could incorporate electronic time-stamp reporting of self-reported fatigue values so that time of time can be accounted for in analyses procedures. In addition, it is unknown whether the physical fatigue experienced after a day of performing physically demanding wildfire suppression tasks contributed to the pre- or post-sleep fatigue ratings. It should also be noted that activity monitors have a tendency to overestimate total sleep time, as periods of quiescent wakefulness can be misidentified as sleep (Pollack et al. 2001). However, these biases are deemed minimal, especially when low thresholds (i.e., cut points) of activity are used to determine wake periods (Ancoli-Israel. 2003), as was employed in the current study. Future studies are required to validate activity monitor sleep/wake estimates within specific populations and in field settings for specific activity monitor devices (Blackwell et al. 2011).

While the major focus of this study was to characterise firefighters' sleep quantity and quality during a wildfire event, future studies should explore other contributing factors to firefighter fatigue. For example, determining the frequency and the amount of caffeine consumed would have provide more insight into firefighters' fatigue management strategies. Further, it is difficult to elucidate whether the physical tasks completed during a work shift counteract the declines in cognitive performance caused by prior sleep restriction, or cumulatively contribute to firefighters' fatigue. It would also be of interest to understand how firefighters utilised their time off between shifts, and how this, in turn, impacted their sleep opportunity. While the current study has focused on night time sleep when work was performed during the day, wildfire suppression also occurs at night, requiring firefighters to sleep during the day (Cater et al. 2007). Sleep on night-shifts is often shorter and more disturbed than on a day-shift (Escribà et al. 1992; Smith-Coggins et al. 1994; Åkerstedt 1995; Åkerstedt 1998). Therefore, understanding wildland firefighters' sleep behaviour during night shifts, and the impact on their physical and cognitive performance, is another important area for future research. Future research should also explore how various individual factors, such as age, sex, body mass index, fitness and firefighting experience may influence firefighters' sleep during wildfire suppression.

During wildfire suppression, wildland firefighters are exposed to a multitude of adverse risk factors, which can have significant ramifications for workplace performance and safety. Sleep behaviour could represent a potentially modifiable risk factor within this occupation. This study found that sleep quantity was compromised following wildfire suppression shifts. Features of sleeping location, shift length, and shift start times have been identified as potential targets to improve sleep quantity, and as such, should be the focus of future fatigue risk management policy for fire agencies. Further understanding the relationship between sleep, work, and non-work behaviour will enable fire agencies and other similar industries to better manage firefighters' fatigue related risk.

Acknowledgements

We would like to acknowledge the Bushfire Co-operative Research Centre for providing logistical support for this project. We would like to thank all the firefighters that generously volunteered their time to participate in this research.

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Chapter 4: Study Two

Associations between firefighters' physical activity across multiple shifts of wildfire suppression

Authors

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The content of this chapter is presented as per the accepted manuscript for publication in *Ergonomics*.

Abstract

Objectives: To examine associations between firefighters' physical activity levels across successive shifts during a multi-day emergency wildfire and determine whether sleep duration moderated these associations.

Methods: Forty volunteer firefighters (31 males, 9 females) wore an activity monitor on their non-dominant wrist to concurrently measure physical activity and sleep duration. Activity monitors were set to sample in 1-min epochs, with a sensitivity of <40 counts per epoch to determine total sleep time. Sedentary time and time spent in light- (LPA), moderate- (MPA), and vigorous-intensity physical activity (VPA) during each shift were determined using monitor-specific cut points. Multilevel analyses were conducted using generalised linear latent and mixed models.

Results: During any given shift, every additional 60 min spent in LPA was associated with 7.2 min more LPA and 27.6 min MPA the following shift. There were no other significant positive or negative associations. No significant moderating effect of total sleep time was observed.

Conclusions: Wildland firefighters are able to maintain and/or increase their physical activity intensity across successive shifts. Further research is needed to understand firefighters' pacing and energy conservation strategies during emergency wildfire suppression deployments to assist fire agencies with work productivity estimates.

Introduction

Wildfires can have a debilitating impact on communities worldwide through the loss of property, livestock, and human life (Hunter 2003; Schmuck et al. 2004; Hyde et al. 2008). In Australia, a workforce of 220,000 volunteer firefighters play a vital role in protecting the community from the threat of wildfire (McLennan & Birch 2005). During deployments, wildland firefighters are subjected to a myriad of stressors, such as long working hours (up to 16 h) and restricted sleep, often over consecutive days and under dangerous working conditions (Cater et al. 2007; Phillips et al. 2007; Aisbett et al. 2012). Globally, the frequency, duration, and severity of wildfires is predicted to escalate (Liu et al. 2010), which is likely to increase the cognitive and physical demands placed on wildland firefighting personnel. Therefore, understanding the impact of pertinent operational and environmental stressors on work behaviour is paramount in preserving firefighter health and safety.

Previous studies have examined the physiological (Cuddy et al. 2007; Rodríguez-Marroyo et al. 2012; Raines et al. 2013), environmental (Budd 2001; Cuddy et al. 2007), and musculoskeletal (Neesham-Smith et al. 2014) demands of wildland firefighting. However, few studies have examined physical activity levels during wildfire suppression deployments, particularly using objective monitoring techniques. Wildland firefighting is described as predominately intermittent, sedentary to light-intensity physical work, punctuated with short periods of moderate- to vigorous-intensity physical activity (Heil 2002; Cuddy et al. 2007; Cuddy et al. 2011; Raines et al. 2012; Raines et al. 2013; Cuddy et al. 2015; Raines et al. 2015). However, the majority of studies have evaluated firefighters' physical activity levels during a single wildfire suppression shift, not across successive shifts. Of the studies examining multiple shifts, research has either used these data to describe average activity levels during wildfire suppressions shifts (Heil 2002; Cuddy et al. 2007) or reported differences in physical activity levels across successive shifts undertaken by salaried firefighters during planned burn operations (Raines et al. 2015) or wildfires (Cuddy et al. 2015). This provides insights into how the physical activity levels may change across successive shifts, but does not examine how the amount of physical activity firefighters engage in during one shift subsequently affects their physical activity in the following shift. This information is integral for workforce planning, and health and safety management across shifts on multi-day wildfire suppression deployments. For example, if firefighters are able to maintain physical activity levels across successive consecutive shifts, this may reduce the need to add more personnel to subsequent shifts. In turn, this may limit the number of firefighters exposed to environmental stressors and reduce the overall financial costs associated with wildfire operations.

Previously, hydration (Ruby et al. 2003), nutrition (Montain et al. 2008; Cuddy et al. 2011), and stress responses (Main et al. 2012) have been explored in relation to the influence they may have on firefighters' activity patterns over multiple shifts. One under-investigated stressor is sleep duration between shifts (Aisbett et al. 2012; Vincent et al. 2015). Australia's firefighting personnel are typically rostered to work a 12-h day or night shift, but can work shifts of up to 16 h for 3–5 consecutive days (Cater et al. 2007; Phillips et al. 2007), resulting in truncated sleep opportunities (Aisbett et al. 2012). The existing evidence surrounding firefighters' sleep during multi-day wildfires is largely anecdotal, and the lack of robust objective measures of firefighters' sleep is surprising given the considerable potential for sleep restriction. Subjectively, Australian and United States firefighters have reported obtaining 3–6 h of sleep per night (Gaskill & Ruby 2004; Cater et al. 2007). To the authors' knowledge, only one industry report has assessed the relationship between accumulated sleep loss and physical activity levels during wildfire suppression (Gaskill & Ruby 2002). This report found that North American wildland firefighters' total accumulated daily activity counts were moderately correlated (ICC: 0.30) with firefighters' sleep duration the night before (Gaskill & Ruby 2002). However, sleep in this report was subjectively determined, which can be inaccurate as individuals are often unaware of their time of sleep onset (Baker et al. 1999). In addition, while total daily activity counts were objectively measured using accelerometry, this study did not examine how physical activity was accumulated (i.e., time spent in different intensities), or evaluate physical activity patterns across successive shifts. Determining whether different sleep durations moderate associations of physical activity levels across successive shifts is important for both operations and wildland firefighters' health and safety. For example, if firefighters who obtain more sleep are more active than those who obtain less sleep, this may have important implications for workforce productivity estimates.

Developing an understanding of firefighters' physical activity patterns across multi-day deployments, and the factors that moderate them, is important to facilitate operational effectiveness during a wildfire event. The aim of the current study was to examine associations between firefighters' physical activity levels across successive shifts during a multi-day emergency wildfire. The secondary aim was to determine whether sleep duration moderated these associations. It was hypothesised that the more time firefighters spend at higher intensities of physical activity, the lower their subsequent physical activity levels will be during the following shift. Furthermore, it was hypothesised that sleep duration would moderate these associations.

Materials and Methods

Recruitment and participants

This study was advertised through fire agency crew leaders and Australasian Fire and Emergency Services Authorities Council communications officers. Interested participants contacted researchers directly, were given information sheets, and provided written informed consent. Ethical approval was obtained from the Deakin University Human Research Ethics Committee (2012-300).

Despite the prevalence of wildfires in Australia (Country Fire Authority 2014), the timing and location varies from season to season. Approximately 250 accredited volunteer firefighters were initially contacted to participate in the study, and 90 were subsequently recruited for a four-week period during the 2012/2013 or 2013/2014 Southern Australian fire season (November-February). From that group, 61 performed wildfire suppression duties. Of those, 43 completed all aspects of data collection, which included completing their sleep/work diaries and wearing the activity monitor for the entire data collection period. Three participants' data were excluded from the analysis due to water damaged monitors, resulting in a final sample of 40 participants. Self-reported demographic data, obtained from a General Health Questionnaire (ACSM 2010), were collected prior to the study commencing (Table 4.1). Participants self-reported their firefighting experience and height and weight measurements (used to calculate their body mass index). No relevant diagnosed medical and/or sleep disorders were reported.

Work diary

Firefighters completed a daily work diary, which required them to provide information about the timing of work during their rostered shift, as well as a brief description of their work duties (e.g., creating a fire break, extinguishing smouldering debris).

Physical activity

Participants were asked to wear an activity monitor (Actical MiniMitter/ Respironics, Bend, OR) on their non-dominant wrist for the duration of the study. The activity monitor was used to concurrently and objectively measure physical activity and sleep duration. The Actical (28 × 27 × 10 mm, 17 g) device uses a piezo-electric omnidirectional accelerometer, which is sensitive to movements in all planes in the range of 0.5–3.0 Hz (John & Freedson 2012). Firefighters were instructed to remove activity monitor during periods when submersion with water was likely (e.g., whilst showering) and was set to sample in 1-min epochs.

Activity monitor data were downloaded using Actical software (Actical MiniMitter, software v. 3.10, Respironics, Bend, OR). This software uses validated location-specific algorithms that determines time spent in light- (LPA, ≥ 1.5–2.99 METs), moderate- (MPA, ≥ 3.0–5.99 METs), and vigorous- (VPA, ≥ 6 METs) intensity physical activity (Heil 2006). When the average activity counts for three consecutive minutes was less than 50 counts·min^{-1}, it was classified as Sedentary Time (SED) (Respironics, personal communication). The activity energy expenditure (AEE) values for each epoch were summed and multiplied by the participant's weight. Total activity counts (C) per epoch were the sum of all counts generated in each minute of monitoring. Data were then reduced using a customised Microsoft Excel macro to determine physical activity intensities during work shifts. The macro classified each epoch with a physical activity intensity (SED, LPA, MPA, VPA) based on the aforementioned cut points (Heil 2006). Durations were summed for each shift. Non-wear time during awake periods was defined as intervals with at least 60 min of consecutive zeroes. In order for a shift to be included for analysis, firefighters had to wear the monitor for 50% of the shift duration in accordance with previous studies of activity patterns (Ridgers et al. 2012). All shifts that were deemed to be valid were included in the analyses. It should be noted that the battery life and memory required for the monitoring period, and sleep measurement necessitated an activity monitor epoch length of 1-min. It is possible therefore that the relative proportions of SED and the physical activity intensities (LPA, MPA, VPA) may be affected by the recorded epoch length. For example, VPA in the current study may have been underestimated as it is possible that firefighters were performing bursts of high intensity activity for short durations (e.g., < 1 minute; Phillips et al., 2015).

Sleep assessment

Activity monitoring provides an objective, non-invasive, indirect assessment of sleep (Ancoli-Israel et al. 2003) and has been validated against the gold standard, polysomnography, in both laboratory (De Souza et al. 2003) and field settings (Signal et al. 2005). Actical data were downloaded and processed using a validated manufacturer propriety algorithm in the software (Actical v3.10) that generates a weighted score for each 1-min epoch based on the amount of activity recorded during that epoch and the surround 2 min (Kosmadopoulos et al. 2014). Epochs with scores below the specified sleep/wake threshold are classified as sleep. In the current study, the default medium threshold of 40 counts per epoch was employed to distinguish between sleep and wake states (Darwent et al. 2008). Sleep onset was determined by a consecutive period of 10 min of immobility. The propriety algorithm retrospectively determined sleep offset from participant's self-reported wake up time. The difference between sleep onset and offset results in the sleep duration. Total sleep time was defined as all sleep obtained in the 24-h period from wake time on the day in question. Two researchers cross-referenced participants' sleep diaries with the activity monitors to determine total sleep time. This ensured the accuracy of the self-reported measures, and minimised the possibility of incorrectly scoring periods of sedentary wakefulness (e.g., watching television) as sleep, or restless sleep as wake.

Statistical analyses

All statistical analyses were conducted using Stata 12.0 (StataCorp, Texas, USA). Descriptive statistics (mean ± standard deviation (SD)) were calculated for all measured variables. Multilevel analyses were conducted using Generalised Linear Latent and Mixed Models (GLLAMM) (*gllamm;* version 2.3.20) (Rabe-Hesketh & Skrondal 2008). This modelling procedure has previously been employed in sleep (Van Dongen et al. 2003; Ingre et al. 2004; Vincent et al. 2015) and physical activity literature (Ridgers et al. 2014). GLLAMMs account for the serial correlation of data points over time, and are more suitable when analysing nested data that are not independent of each other (Molenberghs & Verbeke 2001).

The analyses utilised GLLAMMs to examine the relationship between temporally adjacent values (pairs of shifts) of physical activity (e.g., LPA on shift s with LPA on shift $s - 1$). In all models, the random structure considered random intercepts at the participant level. A two-level model was used in all these analyses; shift (level 1) and participant (level 2). All models were adjusted for age, sex, body mass index, firefighting experience, and actigraphy wear time, which were identified as a priori as potential covariates. Wear time was included as a covariate as each individual had a unique shift length. The potential moderating effect of sleep on observed associations was estimated by including appropriate interaction terms. The final parameter estimates are reported as β coefficient ± 95% CI, *P* value. Statistical significance was set at an α level of 0.05 and all data are presented as means ± SD.

Results

All 40 participants (31 males, 9 females) met the physical activity data inclusion criteria and were included in the analyses. Descriptive data are presented in Table 4.1. There were no significant differences in demographic characteristics between the wildland firefighters that were included or excluded from the analyses (data not shown). A total of 204 individual shifts, resulting in 126 pairs of consecutive shifts were included in the analysis. The average shift length was 11.0 ± 3.6 h. Firefighters' average total sleep time between consecutive shifts during wildfire suppression deployments was 6.1 ± 1.7 h.

The number of minutes and the proportion of time spent in each physical activity intensity across each shift is shown in Table 4.2. Firefighters, on average, engaged in physical activity of at least LPA for 87.7% of their shift.

The associations between the number of minutes spent in each physical activity intensity, the activity energy expenditure, and the total activity counts between pairs of shifts is shown in Table 4.3. Two significant associations were found between pairs of consecutive shifts. Every additional minute of LPA in a given shift was associated with 0.12 min more of LPA and 0.46 min more of MPA in the following shift. No other significant associations were observed between pairs of consecutive shifts. The interaction terms revealed no significant moderating effect of sleep duration on any associations.

Table 4.1: Self-reported demographics taken from self-reported answers on the General Health Questionnaire.

	Mean ± Standard Deviation	Range
Age (years)	39.6 ± 11.6	19–65
Body mass index (kg/m^2)[a]	27.7 ± 4.9	20–37
Firefighting experience (years)	10.8 ± 10.3	0–48
Total career multi-day deployments (number)	20 ± 32	0–150
Typical wildfire suppression deployment sleep (hours)	5.9 ± 1.2	4–9
Normal sleep (hours)	7.4 ± 1.2	3–9
Sleep quality[b]	2.5 ± 1.0	1–5

Note: (n=40); [a] Calculated from self-reported height and weight measurements in the General Health Questionnaire (ACSM 2010); [b] Sleep quality was assessed using a 5-point Likert Scale, where 1 = 'very good', 2 = 'good', 3 = 'average', 4 = 'poor', and 5 = 'very poor', as previously used by Paech et al. (2010).

Table 4.2: Average number of minutes and the proportion of time spent in each physical activity intensity per shift.

	Number of minutes	Proportion (%)
Intensity (METs)		
SED (≤ 1.5)	77 (58)	12.0 (9.8)
LPA (1.5–2.99)	432 (150)	65.6 (10.6)
MPA (3.0–5.99)	141 (75)	22.0 (11.6)
VPA (≥ 6.0)	1 (2)	0.1 (0.3)

Note: data presented as mean (± standard deviation); METs, metabolic equivalent; SED, sedentary time; LPA, light intensity physical activity; MPA, moderate intensity physical activity; VPA, vigorous intensity physical activity.

Table 4.3: Associations between time (minutes) spent in different physical activity intensities, activity energy expenditure and total counts between pairs of shifts.

	β (95% CI)	P Value
$SED_{S1} \rightarrow SED_{S2}$	–0.29 (–0.73 to 0.15)	0.203
$LPA_{S1} \rightarrow LPA_{S2}$	0.12 (0.02 to 0.23)	0.025*
$MPA_{S1} \rightarrow MPA_{S2}$	–0.24 (–0.8 to 0.32)	0.407
$AEE_{S1} \rightarrow AEE_{S2}$	–0.05 (–0.30 to 0.20)	0.708
$C_{S1} \rightarrow C_{S2}$	–0.11 (–0.49 to 0.26)	0.557
$SED_{S1} \rightarrow LPA_{S2}$	–0.08 (–0.17 to 0.01)	0.093
$SED_{S1} \rightarrow MPA_{S2}$	–0.33 (–0.74 to 0.08)	0.116
$LPA_{S1} \rightarrow SED_{S2}$	0.46 (–0.19 to 0.93)	0.060
$LPA_{S1} \rightarrow MPA_{S2}$	0.46 (0.01 to 0.90)	0.048*
$MPA_{S1} \rightarrow SED_{S2}$	–0.08 (–0.64 to 0.48)	0.777
$MPA_{S1} \rightarrow LPA_{S2}$	–0.03 (–0.15 to 0.09)	0.624

Note: data presented as parameter estimate (95% confidence interval); Adjusted for age, sex, firefighting experience, wear time, and body mass index; β, parameter estimate; CI, confidence interval; S1, shift one; S2, shift two; SED, sedentary time; LPA, light intensity physical activity; MPA, moderate intensity physical activity; AEE, activity energy expenditure; C, total counts. * denotes significance, $P < 0.05$.

Discussion

This study examined associations between time spent in various physical activity intensities during one shift and time spent in these intensities in the following shift during a multi-day wildfire using objective measures. Contrary to our hypotheses, the findings suggest that the more time firefighters spent in LPA during one shift, the greater their LPA and MPA levels were during the following shift. Furthermore, sleep duration between shifts did not moderate firefighters' physical activity levels.

Positive associations were found between time spent in LPA in one shift and LPA and MPA accumulated during the following shift. During any given shift, every additional 60 min spent in LPA was associated with 7.2 min more LPA and 27.6 min more MPA in the following shift. This observation is consistent with 'activity synergy', whereby participation in one active behaviour has been observed to increase activity at other times (Goodman et al. 2011). These data suggest that firefighters' have the capacity to increase their physical activity intensity if the wildfire situation requires. A finding not consistent with 'activity synergy' is the positive association observed between LPA and SED, which while approaching, did not reach statistical significance ($P = 0.060$). It is possible that this is a spurious finding and further research is needed to explore the association between LPA and SED across shifts. There were no other significant positive or negative associations observed, suggesting firefighters are able to maintain their physical activity levels from one shift to the next. While the type of data collected in the current study makes it difficult to determine the precise mechanisms, it is possible that firefighters self-pace their work efforts. Indeed, North American wildland firefighters' accelerometry-measured energy expenditure rarely exceeded 8 $kcal.min^{-1}$ and tended to oscillate between 4 and 6 $kcal.min^{-1}$ during a single wildfire suppression shift (Heil 2002). Heil (2002) postulated that wildland firefighters may pace themselves as they have prior knowledge that their shift duration will last between 10–16 h (Heil 2002). Furthermore, self-pacing would allow firefighters to maintain physical activity engagement over multiple shifts during a wildfire suppression deployment and may be reflective of energy conservation strategies. While data on wildfire environmental conditions was not collected, firefighters' physical activity requirements will likely change across successive shifts as each wildfire event is variable in duration, severity, terrain, smoke, and heat exposure. Overall, the current data suggests that firefighters are able to maintain and/or increase their work intensity across successive shifts despite likely variability in environmental conditions. This is a positive finding for agencies in assisting with workforce productivity estimates as the data suggests that for day-shift deployments additional personnel may not be required if wildfire suppression activity levels can be maintained across successive shifts.

To date, research conducted across single or multiple shifts has been used to characterise average physical activity levels (Heil 2002; Cuddy et al. 2007; Raines et al. 2012; Raines et al. 2013; Cuddy et al. 2015). In the current study, 12%, 66%, and 22% of firefighting work was spent in SED, LPA, and MPA, respectively. A negligible 0.1% was spent in VPA. These findings are in contrast to previous Australian research, using the same physical activity intensity cut points, where a larger proportion of time 50–62% was spent in SED, compared to 32–43% in LPA and 2–3% in MPA (Raines et al. 2012; Raines et al. 2013). This discrepancy could be explained by differences in monitor placement locations. Previous work has positioned the activity monitor on the xiphoid process (Raines et al. 2012; Raines et al. 2013) or jacket chest pocket (Heil 2002; Cuddy et al. 2007). The central location of devices in previous studies may be less sensitive to certain tasks performed during fire suppression, such as statically holding a fire hose to extinguish flames. Advancements in monitoring devices have resulted in smaller and more compact models, enabling physical activity to be measured at the wrist. Previous studies utilised central regions as earlier accelerometry models were too large to wear on the wrist, and thus had the potential to interfere with firefighters' work (Daniel Heil, personal communication). Given firefighting work often occurs in hot temperatures requiring firefighters to remove their jacket, monitor compliance may be improved by wrist worn devices. Furthermore, using one device to measure sleep and physical activity could augment the collection of valid physiological data while minimising cost and participant burden. More research is needed to establish firefighter physical activity levels during shifts using common monitor placement to ensure comparability between studies. Moreover, physical activity data, collected from descriptive field studies, are often used to develop laboratory research and/or simulation protocols. Thus, it is important that the measurement of firefighters' physical activity levels is accurate and consistent between studies and that data is collected using valid, reliable methods.

The current study is the first to examine moderating effects of sleep duration on physical activity intensities across successive shifts. Notably, in the current study, the observed average sleep duration (6.1 ± 1.7 h) was comparable to previous subjective reports (Gaskill & Ruby 2004; Cater et al. 2007) but significantly less than the current recommendations of 7–9 h for optimal cognitive functioning (Bonnet & Arand 1995; Ferrara & De Gennaro 2001). Previous research has indicated that the impact of restricted sleep on physical activity levels is equivocal (Fullagar et al. 2014). The contradictory findings arise, at least in part, from confounding variables such as calorie restriction (Nindl et al. 2002) and the different physical work parameters (Opstad et al. 1978; Haslam 1984; Rodgers et al. 1995) utilised between studies. Recent work has suggested that in a controlled laboratory environment, a 4-h sleep opportunity did not impact firefighters' performance on firefighting tasks compared to a control group who received an 8-h sleep opportunity (Vincent et al. 2015). However, sleep restricted firefighters were less physically active across a simulated shift, which was attributed to behavioural adaptations made during rest periods where passive rest (such as sitting still and lying down) was preferred over active rest activities (such as walking) (Vincent et al. 2015). A limitation of the current study is that the timing and duration of breaks were not recorded. Further interrogation of firefighters' pacing and energy conservation strategies would enable fire agencies to understand the operational capabilities of firefighters, and inform policy on the frequency of rest breaks during deployments. This may involve quantitatively describing the pattern of work behaviour in more detail e.g., understanding the nature of the tasks performed. Further research is also required on how firefighters' self-pace within a shift.

To determine more accurately the proportion of time spent in each physical activity intensity such research should utilise activity monitors that collect second by second accelerometry data. In addition, qualitatively establishing what information firefighters may assist in establishing how firefighters' self-pace throughout a work shift. It is also possible that the number of days of sleep restriction in the current study did not allow for observable adverse changes to firefighters' physical activity levels. Therefore, experimental studies are needed to examine how firefighters respond to sleep restriction over prolonged periods (> 2 nights of sleep restriction), and under controlled conditions where the sleep restriction is more severe (< 4 h per night).

This study utilised a sample of 40 volunteer firefighters, resulting in the analysis of 126 pairs of shifts collected objectively during different wildfires (i.e., various durations, intensities etc.) across Southern Australia. The analyses used in the current study involved an advanced modelling procedure which accounted for individual-level covariates (age, sex, body mass index, wear time, firefighting experience). However, there are several limitations of this study that should be acknowledged. Collecting data during wildfire events is extremely difficult and presents unique challenges for researchers. These include, but are not limited to, briefing and fitting firefighters with monitors during an emergency event in a way that does not compromise the firefighters' work or researcher safety. Furthermore, wildfires are unpredictable, therefore it is challenging to recruit firefighters for research purposes when there is no certainty of whether they will be called upon to attend a wildfire event. Thus, data collection for the current study took two years, which is comparable to other wildland firefighting research (Ruby et al. 2002; Rodríguez-Marroyo et al. 2012).

While the sample of the current study is comparable relative to existing firefighting research, it is possible that the study is underpowered when examining the influence of potential moderators on physical activity levels. For example, it is possible that firefighters' with varying years of experience may adopt different pacing strategies. Indeed, experience has been shown to alter pacing strategies in sporting contexts (Mauger et al. 2009; Green et al. 2010; Micklewright et al. 2010) and influence metabolic efficiency during manual handling tasks (Salvendy & Pilitsis 1974; Poole & Ross 1983) which may also have pacing implications. Future research, with much larger samples to accommodate a suite of moderators (e.g., age, sex, body mass index, fitness, caffeine, previous activity, hydration, diet) could, accordingly, also explore relationships between worker experience and pacing across a whole shift or between shifts of wildfire suppression.

Conclusion

The findings from this study suggest that firefighters are able to maintain and/or increase their physical activity levels across successive shifts. Sleep duration did not moderate firefighters' physical activity levels. Further research is needed to understand firefighters' pacing and energy conservation strategies and how performance on certain work tasks may be affected during deployments especially under multi-stressor environmental conditions.

Acknowledgements

We would like to acknowledge the Bushfire Co-operative Research Centre for providing logistical support for this project. We would like to thank all the firefighters that generously volunteered their time to participate in this research. Dr. Nicola D Ridgers is supported by an Australian Research Council Discovery Early Career Researcher Award (DE120101173). We acknowledge Eoin O'Connell for the development of the customised Excel macro.

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Chapter 5: Study Three

Sleep restriction during simulated wildfire suppression: effect on physical task performance

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Citation

Vincent G, Ferguson SA, Tran J, Larsen B, Wolkow A & Aisbett B. 2015. Sleep restriction during simulated wildfire suppression: effect on physical task performance. *PLoS One,* 10, e0115329.

The information presented in this chapter has been published in PLoS One and is presented as per the accepted manuscript. The manuscript is attached in Appendix B1.

Abstract

Objectives: To examine the effects of sleep restriction on firefighters' physical task performance during simulated wildfire suppression.

Methods: Thirty-five firefighters were matched and randomly allocated to either a control condition (8-hour sleep opportunity, n=18) or a sleep restricted condition (4-hour sleep opportunity, n=17). Performance on physical work tasks was evaluated across three days. In addition, heart rate, core temperature, and worker activity were measured continuously. Rate of perceived and exertion and effort sensation were evaluated during the physical work periods.

Results: There were no differences between the sleep-restricted and control groups in firefighters' task performance, heart rate, core temperature, or perceptual responses during self-paced simulated firefighting work tasks. However, the sleep-restricted group were less active during periods of non-physical work compared to the control group.

Conclusions: Under self-paced work conditions, 4 h of sleep restriction did not adversely affect firefighters' performance on physical work tasks. However, the sleep-restricted group were less physically active throughout the simulation. This may indicate that sleep-restricted participants adapted their behaviour to conserve effort during rest periods, to subsequently ensure they were able to maintain performance during the firefighter work tasks. This work contributes new knowledge to inform fire agencies of firefighters' operational capabilities when their sleep is restricted during multi-day wildfire events. The work also highlights the need for further research to explore how sleep restriction affects

physical task performance during tasks of varying duration, intensity, and complexity.

Introduction

Australian firefighters regularly work shifts of up to 15 h per day over several days during wildfire suppression (Cater et al. 2007; Phillips et al. 2007). Wildfire incidents are often long in duration, and certain deployments may require firefighters to travel considerable distances from their home location. During such deployments, fire personnel sleep in temporary accommodation near the fireground between consecutive shifts (Aisbett et al. 2012). Fireground conditions such as heat, light, smoke, noise, and unfamiliar surroundings may contribute to an inadequate sleeping environment, which may compromise sleep quantity and quality (Cater et al. 2007; Cuddy et al. 2007). Accordingly, firefighters have subjectively reported obtaining 3–6 h sleep per night during wildfire suppression deployments (Gaskill & Ruby 2004; Cater et al. 2007). Short sleeps, long working hours, and consecutive shifts have all been associated with an increased risk of accidents (Edkins & Pollock 1997; Åkerstedt 2000; Folkard & Tucker 2003). While the effects of multiple days of sleep restriction on cognitive function are well established (Belenky et al. 2003; Van Dongen et al. 2003), less is known about its effects on physical task performance. In response to an emergency event, wildfire personnel must perform physical work (Phillips et al. 2012). If task performance and/or the underlying physiology are compromised due to poor sleep, this may adversely impact firefighters' health and safety and the collective emergency response.

Although there is a lack of robust empirical data detailing the effects of sleep restriction on firefighters' physical work performance, insights can be gained from sustained military operations (Murphy et al. 1984; Legg & Patton 1987; Patton et al. 1989) and laboratory studies (Symons et al. 1988; Rodgers et al. 1995). Early military studies assessed physical performance following periods of sleep restriction ranging from 3.0–5.3 h per night, over 5–9 days. Preservation of self-paced work output but decrements in upper body 30-s mean power were observed during simulated combat scenarios (Murphy et al. 1984; Legg & Patton 1987; Patton et al. 1989). Others have observed that physical work output involving short-term maximal efforts was maintained under periods of complete sleep deprivation (Symons et al. 1988; Rodgers et al. 1995). Yet in contrast, declines in self-paced work rate have been reported in low- to moderate-intensity tasks performed during 48 h of total sleep deprivation (Rodgers et al. 1995). This decline was attributed to reduced motivation levels due to either task repetition in a laboratory environment, an increase in perceived exertion, or a combination of both factors (Rodgers et al. 1995). To our knowledge, no study has examined the effect of sleep restriction on the performance of intermittent, variable-intensity manual handling work over multiple days, which is typical of wildland firefighting (Phillips et al. 2012).

The aforementioned military and laboratory studies have employed experimental protocols with varying designs. In particular, the duration of the sleep restriction period, work parameters (task type, intensity and duration), and calorie restriction all differ between studies. This makes it difficult to accurately quantify the effect of sleep restriction on workers' physical task performance and physiology and to extrapolate these findings to wildfire personnel. Moreover, implementing controlled field studies is not often feasible as wildfire conditions can be dangerous to both firefighters and researchers. Wildfire conditions such as heat, smoke, and varying terrain are additional confounders which may make it challenging to accurately determine the influence of sleep restriction on physical task performance. In addition, the work performed by personnel within this dynamic environment is variable (Rodríguez-Marroyo et al. 2011) and therefore not standardised within- or between-individuals across a multi-day wildfire. Therefore, the aim of the current study was to determine the effect of sleep restriction on firefighters' physical task performance, physiology, and perceptual responses during simulated multi-day wildfire suppression. This study employed a rigorously controlled laboratory protocol implementing a valid work task simulation (Ferguson et al. 2011) to quantify the effects of sleep restriction on physical task performance.

Materials and Methods

Participants and screening

Thirty-five volunteer and career firefighters (30 males, 5 females) were recruited, from Australia's state fire agencies (Victoria, South Australia, New South Wales, Tasmania). The sample size was estimated by a magnitude based-statistical power analysis (Hopkins 2006) using an averaged effect size of 0.3 ± 0.2 from relevant firefighting research (Budd et al. 1997; Havenith & Heus 2004) and an $\alpha = 0.05$ and $\beta = 0.80$. Individual participants were matched, in order of priority, by sex, age, and body mass index (BMI) to reduce variation between conditions and then were randomly allocated to either the control condition (CON; n = 18) or the sleep-restricted condition (SR; n = 17). Participants provided written informed consent, completed a general health questionnaire (ACSM 2010) to ensure they were able to complete vigorous exercise without medically supervised exercise testing, and were screened for diagnosed sleep disorders. Ethical approval was obtained from the Deakin University Human Research Ethics Committee and the Human Research Ethics Committee of CQUniversity, and written informed consent was provided by all participants before the commencement of the study.

Participants were instructed to maintain their normal sleep behaviour prior to entering the study. Participants wore an activity monitor for two days pre-simulation (*Actical,* MiniMitter/Respironics, Bend, OR) on their non-dominant wrist and completed a sleep diary to evaluate their pre-simulation sleep hours and timing of sleep periods. Activity monitors were set to sample in 1-min epochs, with a sensitivity of < 40 counts per epoch to distinguish between sleep and wake states (Darwent et al. 2008).

Participants' age, height, and weight were recorded prior to testing. Height was measured without shoes using a stadiometer (Fitness Assist, Wrexham, England). Semi-nude body mass was measured using an electronic scale (A and D, Japan). Participants wore their own firefighting personal protective clothing throughout the simulation. This included a two-piece jacket and trouser set made from Proban cotton fabric (Protex, Australia), suspenders, boots, gloves, helmet, and goggles (amounting to ~5 kg). The participant characteristics of the CON and SR conditions are shown in Table 5.1.

Experimental protocol

Participants were required to attend the laboratory for four days and the study condition (CON or SR) was blinded from the participants prior to arrival. Participants arrived at the testing facility at 1800 h on the pre-study day and were familiarised with all daily procedures. Throughout the testing period, participants followed a strict daily schedule including work bouts, meal times, and sleep periods. The day was divided into two-hour work blocks, with each block comprising 55 min of physical work, 20–25 min of physiological testing, 20–25 min of cognitive testing, and a 15–20 min rest period. Participants did not receive feedback or encouragement from researchers when performing the physical work. The suite of cognitive procedures as well as daily measures of well-being were administered as part of another study and will be reported elsewhere (not part of this thesis). Participants were instructed that their caffeine consumption and cigarette smoking could continue as it normally would during a wildfire suppression deployment, but that these behaviours were restricted to the rest periods which occurred for 15–20 min within each two-hour period. When compared to habitual caffeine consumption, there were no differences between the groups in caffeine intake across the simulation.

The simulated environment was kept at a moderate temperature (18–20^{o}C) throughout the testing period. Room temperature was maintained through the use of split cycle air-conditioners (Daikin Industries Ltd, Japan). Ambient air temperature was monitored throughout testing using a wireless temperature and

Table 5.1: Characteristics of firefighters in the control and sleep restricted conditions.

	CON	SR
n	18	17
Age (y)	39 ± 16	39 ± 15
Body mass (kg)	85.1 ± 17.7	93.8 ± 20.2
Height (m)	1.78 ± 0.08	1.78 ± 0.07
BMI ($kg \cdot m^{-2}$)	26.7 ± 4.8	29.6 ± 5.5
Service (y)	9 ± 9	10 ± 6
Male:Female	15:3	15:2

Note: data presented as mean ± standard deviation; CON, control; SR, sleep restricted; BMI, body mass index.

humidity data logger (HOBO® ZW_003, One Temp Pty Ltd, Australia), data receiver (HOBO ZW_RCVR, One Temp Pty Ltd, Australia), and associated software (HOBO Pro Software, One Temp Pty Ltd, Australia).

On day one firefighters completed three two-hour work circuits: one familiarisation work block (1230–1430 h), then two subsequent work blocks (1430–1630 h; 1630–1830 h). Day one occurred prior to the sleep intervention providing each individual with a baseline against which all subsequent measures of each outcome variable were compared. Days two and three began at 0800 and on both days, the firefighters performed five two-hour work circuits (0800–1000 h, 1000–1200 h, 1230–1430 h, 1430–1630 h and 1630–1830 h). As such, the baseline value was labelled as Circuit 0 and every subsequent circuit performed labelled sequentially (Circuit 1-10). Breakfast (0630–0700 h), lunch (1200–1230 h), and dinner (1830–1900 h) were at the same time on all three days.

Daily fluid consumption was precisely recorded to monitor participants' hydration status as hyper- and hypo-hydration can impact physical performance (Sawka 1992). Participants were able to drink room temperature water ad libitum from marked, supplied bottles. Each day participants were provided with two sachets of carbohydrate supplement which they could add to their water at any time. Breakfast, lunch, and dinner meal items were based on food normally available to firefighters during wildfire suppression. Participants were also provided with a "ration pack" containing a variety of food items similar to those available during wildfire suppression. All meal and snack food items were nominated in consultation with subject matter experts from Australasian fire authorities. Types and quantities of ingested food were recorded throughout the protocol. There was no difference in fluid and total energy intake between the groups.

To replicate sleeping conditions during a wildfire suppression deployment (Cater et al. 2007), participants slept on camp beds in the simulated environment. The pre-study day involved an adaptation night consisting of an 8-h sleep opportunity for both conditions. On day two and three, the CON condition was assigned an 8-h sleep opportunity from 2200 h to 0600 h whereas those in the SR condition were assigned a 4-h sleep opportunity from 0200 h to 0600 h. Both conditions were constantly observed by research personnel to prevent them from falling asleep outside of their designated sleeping period. Between dinner (1900 h) and the beginning of the sleep opportunity (CON; 2200 h and SR; 0200 h) participants engaged in sedentary leisure activities (i.e., read a book, watch a movie).

The physical work circuit

The firefighting circuit was developed using a job task analysis (Phillips et al. 2012) of wildfire suppression tasks and verified by panels of firefighter subject matter experts (Ferguson et al. 2011). The tasks involved simulated actions, fitness components, and movements performed during wildfire suppression (Phillips et al. 2012; Phillips et al. 2015). These tasks were chosen on the basis of being the longest, most intense, or most frequent tasks performed during wildfire suppression work (Phillips et al. 2015). They were also considered the most physically demanding and operationally important (Phillips et al. 2012).

The six physical tasks include: charged hose advance, blackout hose work, hose rolling, lateral repositioning, rake, and static hold.

Five minutes were allocated to each task, with task-specific work-to-rest ratios within each 5-min block in accordance with the work-to-rest ratios observed for each task in live fire suppression conditions (Phillips et al. 2015). Some tasks were only performed once in each 55-min block, whereas others were performed multiple times according to their recorded frequency during live fire suppression (Phillips et al. 2015). Participants completed the tasks in an ordered circuit; each participant began the circuit at one of five task stations (charged hose advance, blackout hose work, hose rolling, lateral repositioning, or rake), but rotated through each subsequent task in the same order irrespective of start point. The static hold task was always the last task performed in the circuit and by all participants concurrently. This allowed participants to perform some tasks at the same time. CON and SR participants were matched on age, then sex, and BMI and then randomly allocated into the five circuit start points. This process prevented potential clustering of specific demographic variables into any one of the five circuit start points. Each participant began at the same individually-assigned start point during all physical work bouts. Task performance was evaluated for each 5-min work block completed for each task, as discussed in further detail below.

1. *Charged hose advance*

Each participant dragged a 2-m rubber hose (38-mm diameter, with branch) attached to a 15-kg weighted tyre up and back for 8 m along a carpeted surface, marked at 2-m increments. The hose was filled with rice to simulate a charged hose (i.e., pressurised with water). This task simulates forward movement with a charged hose towards the fire front (Phillips et al. 2012). This task was undertaken with a work-to-rest ratio of 65 s work to 55 s rest, which was completed twice within a 5-min period, with one 5-min work bout performed during the 55-min circuit. The participant was instructed to stop completely at the end of each work period, at which point task performance was recorded as distance covered (to the nearest 2-m marker).

2. Blackout hose work

Each participant dragged a 2-m rice-filled rubber hose (38-mm diameter, with branch), attached to a 15-kg weight bag around a 2.5-m x 2.5-m square, stopping at each corner for a period of 3 s timed by a metronome. This task simulated the stop start movements firefighters perform when extinguishing smouldering debris, during post-fire clean up (Phillips et al. 2012). This task was undertaken with a work-to-rest ratio of 90 s work to 60 s rest, which was completed twice within the 5-min period, with two 5-min work bouts performed during the 55-min circuit. The participants walked clockwise during the first work bout and anticlockwise during the second work bout to incorporate both left and right manoeuvres. The participants were instructed to stop at the end of each work period where their total distance was recorded to the nearest corner of the square.

3. Hose rolling

The participants were instructed to roll-up a 8-m rubber hose (38-mm diameter, 16-m length hose folded in half, with branch) beginning at the folded end of the hose and moving along the length of the hose rather than pulling the hose towards them. This task simulated rolling up a hose and therefore had to be rolled to operational standard (a tight coil with edges aligned). This task was undertaken with a work-to-rest ratio of 60 s work to 60 s rest, which was completed twice during the 5-min period, with one 5-min work bout performed during the 55-min circuit. The hose was taped 0-, 2-, 4-, 6-, and 8-m intervals to aid in recording distance.

4. Lateral repositioning

The participant walked the arc (11 m) of a 3.5-m radius semi-circle carrying a 3.5-m rice filled rubber hose (38-mm diameter, with branch). The hose was anchored by a chain to a stand positioned in the middle of the semi-circle allowing the hose to freely rotate. Two platforms (68 x 28 x 15 cm) were positioned at ¼ and ¾ distance markers of the semicircular arc, with one platform placed length ways and the other placed cross ways. Participants walked over the step placed cross ways and stepped up with two feet onto and then off the step placed length ways. This task simulated walking with a charged hose over obstacles such as tree roots and other debris commonly found on the fireground (Phillips et al. 2012). This task was undertaken with a work-to-rest ratio of 30 s work to 30 s rest, which was completed four times during the 5-min period, with four 5-min work bouts performed during the 55-min circuit. Task performance was measured as distance travelled during each work period, rounded to the nearest quarter (2.75 m) completed.

5. Rake

Participants were instructed to rake the contents of a 2-m x 0.9-m box filled with 29 kg of 1-cm tyre crumb and large tyre pieces. The tyre crumb simulated ground debris that is cleared when creating a mineral earth fire break (Phillips et al. 2012). Two identical boxes were placed side by side and participants alternated between the boxes after successfully raking the contents from one side to the other. Participants utilised a 35-cm dual-sided rakehoe (Cyclone Industries, Australia) to complete this task. This task was undertaken with a work-to-rest ratio of 90 s work to 60 s rest, which was completed twice during the 5-min period, with one 5-min work bout performed during the 55-min circuit. Task performance was measured by the area of material moved (m^2) (i.e., the amount of material moved from one side of the box to the other).

6. Static hold

The participant was instructed to hold a 3.5-m rice-filled rubber hose (38-mm diameter, with branch) attached to a stand with a looped elasticised rope providing resistance when held off the ground. A laser was positioned at the end of the hose so that participants could aim the hose towards a target placed 1.5 m above the ground. This task simulated holding a charged hose to direct water or other extinguishing material towards a fire, while stationary (Phillips et al. 2012). The participants could hold the hose at their waist or over their shoulder with their chosen front foot placed completely over the line marked at 4.8 m from the centre point of the hose stand. The participants were instructed to hold the hose for the entire 5-min period. If a participant dropped the hose, the laser went out of the target for more than 2 s, or the participant could not hold the position for 5 min, the failure time was recorded. This task was performed once during the 55-min circuit.

Heart rate

Daily heart rate was recorded using the Team Polar (Polar Team[2], Kempele, Finland) heart rate system from 0630 to 1800 h on all testing days. Heart rate was logged every 5 s, with data downloaded daily and analysed using the Polar Team 2 Pro Software (Polar, Kempele, Finland). Relative average and peak heart rate was predicted using $HR_{max} = 207 - (0.7 \times \text{age})$ (Gellish et al. 2007) to individualise the cardiovascular response due to the large spread in age (18–61 years) across the sample. Average and peak heart rates are analysed during the physical work circuit, the rest period, and during each physical task performed.

Core temperature

Participants ingested a core temperature capsule (Jonah, Minimitter, Oregon) prior to sleep each evening (2130 h), in order to allow adequate time for the capsule to pass through the stomach to the small intestines (Lee et al. 2000). Intestinal temperature (via ingested capsules) was preferred over rectal thermometry, as it is a valid but less invasive index of core temperature (Byrne & Leong 2007). Core temperature was recorded continuously on a data logger (VitalSense, Minimitter, Bend, Oregon) throughout the testing period.

Rating of perceived exertion and effort sensation scale

Participants were asked to report a rating of perceived exertion (RPE, on a scale of 6–20) (Borg 1982) after each work bout (i.e., every 5 min). After the completion of each physical work circuit participants were asked to report their physical effort using a modified Borg scale where effort < 100% is reported

(Abbiss et al. 2011). Participants were asked 'how much of yourself did you give'? Items ranged from 0% 'gave no effort at all' to 100% 'gave absolutely everything, nothing left'.

Worker activity

An activity monitor (*Actical,* MiniMitter/Respironics, Bend, OR) was worn on the participants' non-dominant wrist (dominance was defined as the participants' preferred writing hand) throughout the simulation to assess activity. Whole body motion in a three dimensional plane was measured at 1-min intervals. Data was downloaded using Actical software (version 3.10, MiniMitter/Respironics, Bend, OR) and expressed as total counts.

Sleep monitoring: Polysomnography

Polysomnography (PSG) was utilised during the four study nights to assess sleep architecture (Rama et al. 2006; Carskadon & Dement 2011). PSG arrangement and recording began each night at 2100 h for both conditions. Standard PSG equipment (Compumedics E Series, Melbourne) was arranged as follows: EEG (Oz and Cz positions); EOG (outer canthi of each eye); EMG (masseter and facial muscles); the earth electrode on the right clavicle. All signals were recorded using gold Grass electrodes with initial impedances below 10 kΩ. The PSG recordings were scored according to standard criteria of AASM (Iber et al. 2007) in 30-s epochs. Each epoch was assigned a stage of sleep (Stages 1-3, REM) or wake by a blinded scorer using Profusion 3 software (Compumedics E Series, Melbourne, Australia). From each sleep period, participants' total sleep time was calculated. Participants were continuously monitored throughout the study to ensure napping did not occur.

Statistical analyses

All statistical analyses were carried out using Stata 12.0 (StataCorp, Texas, USA). Exploratory data analysis was conducted to determine whether the data met parametric assumptions of normality and homoscedasticity. Each individual's performance scores were normalised to reflect changes from their individual specific baseline (as previously mentioned, pre-intervention task performance on day one of the simulation). Participant characteristics, total sleep hours, energy intake, hydration status, and caffeine consumption were normally distributed, thus one-way analyses of variance (ANOVA) were used to determine between-group differences. For all other variables, using Generalised Linear Latent and Mixed Models (GLLAMMs) were constructed using the generalised linear latent and mixed models software (*gllamm;* version 2.3.20). This modelling procedure has previously been employed in sleep literature (Van Dongen et al. 2003; Ingre et al. 2004) and is increasingly preferred over traditional repeated-measures ANOVA, as GLLAMMs better account for the serial correlation of data points over time (Molenberghs & Verbeke 2001). The *gllamm* also provides valid estimates in the presence of missing data, and uses maximum likelihood estimation with adaptive quadrature for more reliable parameter estimates than adaptive quadrature (Rabe-Hesketh et al. 2002). Readers are encouraged to seek out the comprehensive reviews of these procedures by Rabe-Hesketh (Rabe-Hesketh et al. 2002; Rabe-Hesketh et al. 2005), and a detailed comparison of linear mixed models and ANOVAs in sleep research (Van Dongen et al. 2004).

Mixed effects models incorporate *fixed* effects that determine the influence of the experimental conditions (e.g., assignment to a CON or SR condition), alongside *random* effects that considers each individual as having a unique response to the intervention (e.g., inter-individual differences in response to periods of sleep restriction) (Dinges 2004; Van Dongen et al. 2004). Therefore, mixed models enable the distinction of between-subject (i.e., inter-individual) from within-subject (i.e., intra-individual) effects. The framework recommended by Singer (1998) guided the construction of mixed models to iteratively investigate the fixed effects of Condition, Circuit, and the interaction of Condition × Circuit, with random intercepts and random slopes that varied at the Participant-level. All dependent variables exhibited a Gaussian distribution, thus the identity link function was specified (Kachman 2000). The CON and SR conditions were coded 0 and 1, respectively. Therefore, a positive β value for the effect of Condition indicates CON > SR and a negative β value indicates SR > CON. For Circuit effects, a positive β value indicates an increase over successive circuits and a negative β value indicates a decrease. The random effects express the variance due to the inter-individual differences at baseline (random intercept) and over time (random effect of Circuit). Selection of the optimal model for each outcome variable was informed by comparing Akaike weights between candidate models as per the procedure outlined by (Burnham & Anderson 2002). If the Akaike weights between two competing models had similar probabilities of being the best model, the model with the fewest number of parameters was preferred in accordance with the principle of parsimony. The final parameter estimates are reported in-text as β coefficient ± standard error of the estimate (SE), P value. Statistical significance was set at $P < 0.05$ and all data are presented as means ± standard deviations unless otherwise stated.

Results

There was no difference between CON and SR in participants' age, body mass, body mass index, height, or years of service ($P \geq 0.110$; Table 5.1). There were no differences in ambient temperature (CON 19.2 ± 1.1°C; SR 19.6 ± 1.6°C; $P = 0.220$) or humidity (CON 55.8 ± 6.3%; SR 55.9 ± 6.8%; $P = 0.980$) between conditions.

Sleep hours

There were no differences between the two conditions in mean sleep duration obtained in the two days prior to the simulation ($P \geq 0.283$), nor on the pre-study adaptation night (CON 6.3 ± 0.9 h; SR 6.4 ± 0.7 h; $P = 0.726$. During the two experimental nights, mean sleep duration was lower in the SR (3.6 ± 0.3 h) condition compared to CON (6.9 ± 0.4 h; $P < 0.001$).

Physical task performance

Daily mean performance on each physical task is shown in Table 5.2. For all physical tasks, the fixed effect of Condition did not significantly improve upon the amount of variance explained by simpler models. Random slope models best explained variances in physical task performance (Table 5.3).

Table 5.2: Daily physical task performance during the physical work circuit.

Task	Condition	Day 1 (Baseline)	Day 2	Day 3
Charged hose advance (m)	CON	107.8 ± 24.1	111.2 ± 26.1	116.6 ± 30.2
	SR	99.9 ± 12.3	104.4 ± 16.1	108.0 ± 17.6
Blackout (m)	CON	169.4 ± 14.5	168.0 ± 15.9	166.8 ± 16.1
	SR	167.9 ± 16.0	167.0 ± 17.1	167.4 ± 18.6
Hose-rolling (m)	CON	18.7 ± 4.8	21.6 ± 5.6	24.8 ± 7.5
	SR	16.9 ± 3.6	19.0 ± 3.9	20.5 ± 5.0
Lateral Repositioning (m)	CON	631.4 ± 92.1	657.9 ± 86.1	689.8 ± 91.1
	SR	650.5 ± 76.7	656.5 ± 76.8	676.7 ± 73.3
Rake (m^2)	CON	5.0 ± 1.4	5.5 ± 1.5	5.6 ± 1.5
	SR	4.6 ± 0.6	4.9 ± 0.8	5.1 ± 0.8

Note: data presented as mean ± standard deviation; CON, control; SR, sleep restricted.

Table 5.3: Generalised linear mixed model parameter estimates for physical task performance variables.

	Lateral Repositioning	Hose rolling	Rake	Charged hose advance	Black out hose
<u>Fixed effects</u>					
Intercept	2.05 (1.26)	1.31 (4.50)	8.17 (2.13)	2.71 (1.49)	-0.88 (0.90)
<u>Random effects</u>					
Intercept	37.40 (12.16)	484.95 (169.75)	115.55 (46.88)	110.03 (9.30)	26.27 (10.49)
Circuit	2.14 (0.57)	26.77 (7.36)	7.20 (2.20)	20.54 (17.97)	0.37 (0.20)
Residual	19.67 (1.67)	330.06 (27.94)	163.15 (13.83)	3.69 (1.21)	35.39 (3.02)

Note: data presented as: β parameter estimate (standard error).

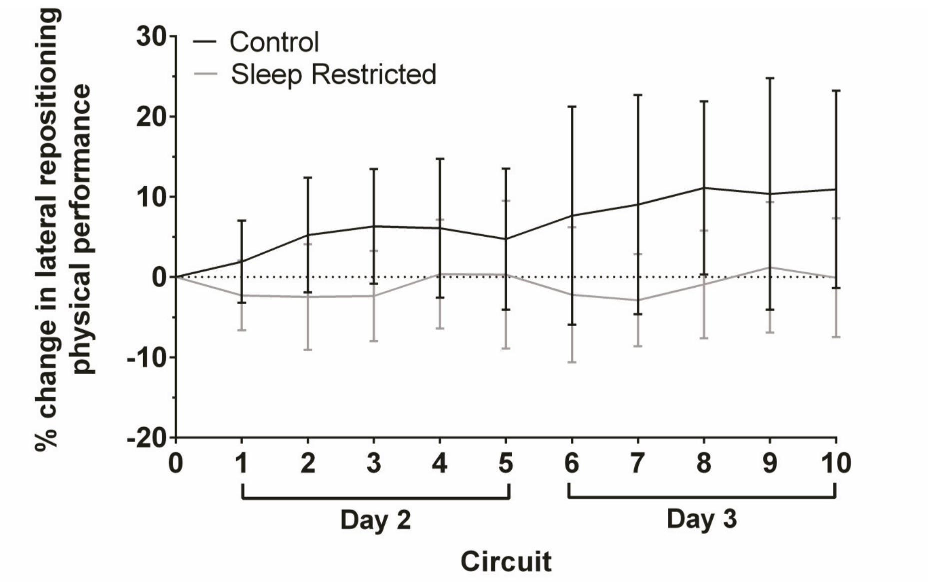

Figure 5.1: Lateral repositioning task performance during the multi-day simulation.

Note: the considerable inter-individual variability within both control and sleep restricted groups at each time point, as denoted by the error bars (± 1 standard deviation).

Figure 5.1 demonstrates the inter-individual variability in lateral repositioning task performance, indicative of the same pattern observed for the other tasks. Participants in both conditions successfully completed the 5-min static hold hose task during every two-hour period throughout the simulation, and therefore these data will not be reported.

Heart rate and core temperature

There was no effect of Circuit, Condition, or Condition × Circuit for average heart rate (%HR_{max}) across the two-hour work circuit ($P \geq 0.480$) or during the physical work component ($P \geq 0.490$) or rest period ($P \geq 0.270$). There was no effect of Circuit, Condition, or Condition × Circuit for peak heart rate (%HR_{max}) across the two-hour work circuit ($P \geq 0.800$) or during the physical work component ($P \geq 0.940$) or rest period ($P \geq 0.420$). Heart rate was also analysed for each individual physical task. For almost all tasks, the intercept-only and random slope models best explained variances in average and peak heart rate (Table 5.4). Peak heart rate during the black out hose task was best explained by the model including a single fixed effect for Circuit ($\beta = -0.21 \pm 0.08$; $P < 0.05$). For core temperature, the greatest relative likelihood was achieved by the full model with significant fixed effects for Condition ($\beta = -0.15 \pm 0.07$; $P < 0.05$) and Condition × Circuit ($\beta = 0.02 \pm 0.01$; $P < 0.05$).

Rating of perceived exertion and effort sensation scale

The intercept-only and random slope models best explained variances in rating of perceived exertion during the lateral repositioning, hose rolling, black out hose, and static hold tasks (Table 5.5). An interaction of Condition × Circuit

Table 5.4: Generalised linear mixed model parameter estimates for average and peak heart rate for each physical task.

	Lateral Repositioning		Hose rolling		Rake		Charged hose advance		Black out hose		Static hold	
	Average	Peak	Average	Peak	Average	Peak	Average	Peak	Average	Peak	Average	Peak
<u>Fixed effects</u>												
Intercept	62.80 (1.34)	72.17 (1.62)	64.29 (1.37)	75.62 (1.58)	70.63 (1.29)	80.24 (1.36)	72.64 (0.53)	83.01 (1.75)	62.31 (1.43)	70.26 (1.60)	59.24 (1.46)	66.32 (1.49)
Circuit										0.21 (0.08)		
<u>Random effects</u>												
Intercept	61.91 (15.04)	89.28 (21.85)	67.08 (17.12)	85.64 (22.05)	54.99 (14.27)	57.80 (15.46)	71.17 (6.78)	100.25 (25.61)	65.24 (16.43)	82.58 (20.22)	77.78 (19.99)	80.64 (20.91)
Circuit			0.18 (0.08)	0.23 (0.10)	0.28 (0.10)	0.28 (0.11)	0.17 (0.07)	0.22 (0.10)	0.11 (0.05)		0.28 (0.10)	0.40 (0.14)
Residual	11.14 (0.84)	23.62 (1.79)	14.24 (1.13)	18.68 (1.49)	13.70 (1.09)	21.10 (1.69)	17.34 (1.36)	21.38 (1.70)	9.96 (0.79)	22.13 (1.67)	13.63 (1.09)	20.80 (1.66)

Note: data presented as β parameter estimate (standard error).

Table 5.5: Generalised linear mixed model parameter estimates for perceptual measures for each physical task.

	Lateral Repositioning	Hose rolling	Rake	Charged hose advance	Black out hose	Static hold
<u>Fixed effects</u>						
Intercept	11.39 (0.13)	11.94 (0.19)	13.87 (0.29)	14.08 (0.36)	12.14 (0.15)	12.95 (0.26)
Condition			0.29 (0.40)	0.95 (0.50)		
Circuit		0.08 (0.01)	0.02 (0.02)	0.06 (0.03)		
Condition × *Circuit*			0.08 (0.03)	0.09 (0.04)		
<u>Random effects</u>						
Intercept	0.61 (0.15)	0.97 (0.25)	1.18 (0.30)	1.76 (0.45)	0.78 (0.20)	2.21 (0.55)
Residual	0.25 (0.02)	0.72 (0.05)	0.73 (0.06)	1.23 (0.09)	0.38 (0.03)	0.89 (0.07)

Note: data presented as β parameter estimate (standard error).

was observed for rake and charged hose (Table 5.5). While this may suggest that those in the control group perceived these tasks to be more difficult over the course of the simulation, the parameter estimates were very small in magnitude and thus require cautious interpretation. The random slope model best explained variance in effort sensation ($\beta = 78.83 \pm 1.80$; $P < 0.05$).

Work activity

Total activity counts were summed for each two-hour work circuit. The two-hour work circuit was also divided into two major components: the physical work circuit and the rest period. The conditional growth model with random slopes best explained variance in activity throughout the two-hour work circuit (fixed effect of Condition: $\beta = 11.92 \pm 2.25$; $P < 0.05$; random effect of Circuit: $\beta = 1.22 \pm 0.58$). This was also the case for the physical work circuit (fixed effect of Condition: $\beta = 5.02 \pm 1.99$; $P < 0.05$; random effect of Circuit: $\beta = 3.24 \pm 0.97$). A main effect for Condition ($\beta = 20.50 \pm 4.34$; $P < 0.001$) was also evident during the rest period. These results indicate that the CON participants recorded greater activity during work and rest periods compared to the SR participants, and that activity counts during work periods increased over the course of the simulation. The percentage change in total activity counts relative to baseline across each two-hour work circuit is shown in Figure 5.2.

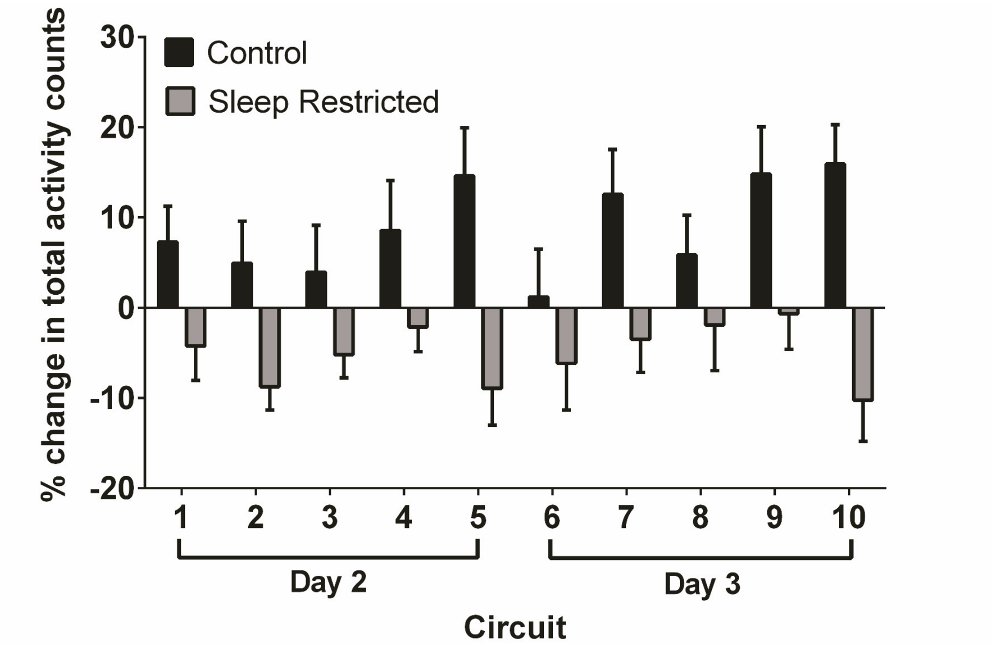

Figure 5.2: Percentage change in total activity counts relative to baseline across each two-hour work circuit.

Note: data presented as mean ± standard deviation.

Discussion

This study examined the effects of 4 h of sleep restriction on firefighters' physical task performance, physiology, and perceptual responses during multi-day simulated wildfire suppression. The findings suggest that physical task performance was unaffected by 4 h of sleep restriction. Heart rate, core temperature, and perceptual responses to these tasks were also largely unaffected by sleep restriction. However, sleep-restricted participants were significantly less active throughout the simulation compared to control participants.

Sleep restriction did not impact upon firefighters' physical work performance during multi-day simulated wildfire suppression. In addition, sleep restriction had limited effects on the physiological and perceptual measures, further supporting the assertion that there was no real difference in task performance. There were no observable differences between the groups in relative average and peak heart rate throughout the simulation. This finding is consistent with previous work, where resting average heart rate remained unchanged during partial sleep restriction (Dettoni et al. 2012). Moreover, sub-maximal exercising heart rate was also unchanged following total sleep deprivation periods of 36 and 64 h (Martin 1981; Plyley et al. 1987). Our findings indicate that core temperature was lower in the control group and decreased for all participants across the simulation. However, the parameter estimates are very small and therefore do not likely reflect a meaningful difference or change. This finding is consistent with previous investigations that have observed either no change (Lorenzo et al. 1995; Cajochen et al. 2001) or a only very small decrease (Meney et al. 1998; Vaara et al. 2009) in body temperature following sleep restriction. While the tasks that were included in the simulation were highly representative of those performed during actual fire suppression (Ferguson et al. 2011; Phillips et al. 2012), it is possible that these physical tasks were not sensitive enough to detect changes in task performance following sleep restriction; further research is needed to test this assertion. However, the decision to select tasks that may be more sensitive to sleep restriction must be balanced against the intent to maintain a representative design (Araujo et al. 2007), which is important to ensure that experimental observations can be generalised to a real wildfire suppression deployment. We contend that, if inadequate task sensitivity was the primary reason that performance decrements were not detected, the sleep restriction protocol should have had observable effects on other measures (i.e., the physiological and perceptual responses).

Effort sensation and RPE were also largely unaffected by sleep restriction. Previous research has noted an increase in RPE following total sleep deprivation (Rodgers et al. 1995) and sleep restriction (Ryman et al. 1989). However, the physical performance tasks in these investigations were of a significantly longer duration than the tasks used in the current study. Myles (1985) concluded that total sleep deprivation had no effect on RPE following short-duration tasks (30 s), but that increases in RPE were observed when tasks were of a longer duration (15–50 min). The tasks in the current study were short and interspersed with rest periods, and the sleep restriction was less severe than the aforementioned protocols. The work tasks and work schedule in the current study, designed to simulate fireground work, resulted in no effect of 4 h of sleep restriction on RPE.

The literature seems to indicate that long-duration self-paced tasks may be impaired by sleep restriction (Myles & Romet 1987; Rodgers et al. 1995), but maximal task performance can be maintained (Symons et al. 1988; Rodgers et al. 1995). This suggests that task characteristics – intensity, duration, volume of active musculature, continuous or discontinuous, self-paced or externally paced – may moderate the effect of sleep restriction on physical work performance. Researchers investigating cognitive performance have concluded that the cognitive tasks most sensitive to sleep loss are long in duration, demand continuous attention, and have low predictability (Gillberg & Åkerstedt 1998). In addition, performance feedback has been shown to improve task performance by augmenting motivation levels in a serial reaction time task after one-night of total sleep deprivation (Caldwell & Ramspott 1998). On this basis, we suggest that the domain-specific nature of tasks may have been inherently interesting to firefighters and that the variable intensities, frequent task rotation, and repeated rest breaks may have enabled firefighters to maintain physical task performance despite sleep restriction. Future research is required to investigate the impact of restricted sleep on isolated firefighting tasks performed consistently over a prolonged period (e.g., creating a fire break), and in the context of urgent, high-intensity work (e.g., protecting a home), where self-pacing may not be practicable.

Despite no between-group differences in self-paced task performance, decrements to worker activity in the sleep-restricted participants were evident during the rest periods. The between-condition difference was particularly pronounced during the rest periods; total activity counts were 20.5% greater for the control group compared to the sleep-restricted group. Given that no concurrent declines in task performance were apparent, it appears that sleep-restricted participants down-regulated their activity during periods when movement was not essential for task completion, i.e., during the rest periods provided between tasks within the physical work circuit or between circuits. It is plausible that the sleep restricted participants may have decreased their incidental activity during the rest periods. However, since activity was recorded in 1-min epochs and some of the tasks in the physical work circuit were shorter than this duration, the sampling rate did not allow more precise delineation between the work and rest components within each physical task.

It is unclear whether the sleep-restricted participants were actively adapting their behaviour, or whether reduced worker activity was observed following subconscious adaptations as a result of the fatigue induced by restricted sleep. In support of the former interpretation, competitive sporting literature suggests that the most important parameter for establishing pacing strategies is knowledge of the end-point of an activity (St Gibson et al. 2006; Mauger et al. 2009). In the current study, participants were aware of the demands expected of them (i.e., how many work circuits, task order, duration of task performance, and their opportunity for rest). Understanding these expectations may have allowed participants to modulate their behaviour so that the allocation of resources could be prioritised to the completion of the physical work tasks. However, if the sleep-restricted participants deliberately down-regulated their activity during the rest periods, it is not known whether this contributed to the preservation in physical task performance or simply occurred concurrently. Furthermore, we cannot conclude whether physical task performance would continue to be maintained if tasks were more frequent, of higher intensity, or if the protocol was extended. Nevertheless, the activity data suggest that, despite the lack of performance differences between groups, the intervention had some influence on the sleep-restricted group. While potential explanations for this finding are discussed above, further research is required to explain how firefighters regulate their work behaviour throughout a multi-day wildfire suppression deployment. This may involve describing the pattern of work behaviour in more detail, determining what information firefighters use to regulate their work behaviour and if these laboratory observations translate onto the fireground. This information is essential for fire agencies, especially when developing policy that informs shift lengths and the frequency of rest breaks during wildfire suppression deployments.

Conclusion

This is the first study to investigate the effects of sleep restriction on firefighters' physical task performance. Our results indicate that two nights of 4 h sleep restriction did not adversely affect firefighters' performance of self-paced, physical work tasks. However, the sleep restricted group was less physically active, which could reflect behavioural adaptations made during rest periods, e.g., passive rest (such as sitting still and lying down) preferred over active rest activities (such as walking). Future research should examine how firefighters respond to sleep restriction over prolonged periods (> 2 nights of sleep restriction), under conditions where the sleep restriction is more severe (< 4 h per night), and when performing longer duration and/or high-intensity tasks. In addition, a greater understanding of how firefighters regulate their work behaviour patterns throughout a multi-day wildfire is essential. Further understanding of the effects of sleep restriction on firefighters' physical task performance will enable fire agencies to manage their crews for improved health, safety, and productivity on the fireground.

Acknowledgements

The authors would like to acknowledge the Bushfire Co-operative Research Centre for providing financial and logistical support for this project. We would also like to thank all the firefighters that generously volunteered their time to participate in this research.

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Chapter 6: General Discussion

6.1 Introduction

This chapter will present the major findings of each study in this thesis. The novel contribution of the thesis and the implications of these findings will be discussed. Directions for future research will then be provided.

6.2 Major Findings

The current thesis provides novel foundational evidence describing the interplay between firefighters' sleep, physical activity, and physical task performance during real and simulated multi-day wildfire suppression. This was achieved by conducting three studies; two in the field (during actual wildfire suppression), and one in the laboratory (a simulated wildfire suppression deployment).

The existing literature assessing firefighters' sleep during wildfire suppression is limited and utilises exclusively self-report measures (Gaskill & Ruby 2004; Cater et al. 2007). Given the known adverse effects of sleep on various physiological and psychological processes, there was a need to objectively quantify wildland firefighters' sleep and the specific shift characteristics that may moderate sleep duration. Study 1 (Chapter 3) was the first to describe firefighters' sleep behaviour during multi-day wildfire suppression using objective measures. This work provides empirical evidence that firefighters' sleep was restricted during multi-day wildfire suppression compared to non-fire days. Self-reported levels of pre- and post-sleep fatigue were also greater on fire days compared to non-fire days. However, subjective sleep quality, latency, efficiency, and number of times woken did not differ significantly between fire and non-fire days. Collectively, these data suggest that sleep quality during multi-day wildfire suppression was maintained. Total sleep time was reduced during wildfire suppression deployments when firefighters' slept in tents or vehicles, shift lengths were greater than 14 h, or shifts started between 0500–0600 h. Therefore, given that sleep quantity was reduced on fire days, modifying specific characteristics of work shifts, such as sleep location, shift length, and shift start time, may improve firefighters' sleep quantity during wildfire suppression.

As Study 1 found sleep was impaired, it was important to establish whether sleep duration influenced firefighters' physical activity levels during real wildfire suppression, as reduced physical activity could risk firefighters' health and safety. Study 2 (Chapter 4) was the first to examine the associations between firefighters' physical activity levels between consecutive shifts and the impact of sleep on physical activity patterns in this way. The data presented suggests that the sleep duration between shifts does not moderate firefighters' shift-to-shift physical activity levels. Notably, the findings also indicated that while physical activity levels likely change between shifts (as each wildfire has variable characteristics), firefighters' were able to maintain, and in some cases increase, their physical activity levels between consecutive shifts.

Studies 1 and 2 utilised validated objective measures to examine firefighters' sleep behaviour and physical activity levels during actual wildfire suppression. However, it is difficult to determine physical task performance on firefighting work tasks in field settings. This is due, in part, to the wildfire environment, which inherently contains confounding variables (e.g., heat and/or smoke exposure), making it difficult to accurately ascertain how restricted sleep directly impacts firefighters' performance on physical work tasks. Therefore, Study 3 (Chapter 5) implemented a valid, high-fidelity, work task simulation, to quantify the effects of sleep restriction on firefighters' physical task performance, physiology, and perceptual responses. In the main, wildland firefighters perform neither explosive, one-off maximal efforts nor long duration self-paced work, which have been the overwhelming focus of the existing literature (Rodgers et al. 1995; Fullagar et al. 2014). As such, dedicated research was required to quantify the implications for sleep deprived workers repeatedly performing intense (but not maximal) short duration tasks across a 12-h wildfire suppression shift. Under self-paced work conditions, 4 h of sleep restriction did not adversely affect firefighters' physical task performance on work tasks, or their physiological and perceptual responses, compared to those firefighters who received an 8-h sleep opportunity. The domain-specific nature of the firefighting tasks, such as variable intensities, frequent task rotation, and repeated rest breaks, may have enabled firefighters to maintain physical task performance despite being sleep restricted. Interestingly, the sleep-restricted group were less physically active during periods of non-physical work compared to the control group, indicating they may have conserved effort during periods of rest to ensure they were able to maintain performance on firefighting work tasks.

6.3 Novel Contribution to the Literature and Implications

During wildfire suppression deployments firefighters' can sleep at home or away (e.g., motels, tents, vehicles). Since the majority of the wildland firefighting population are volunteers, who also have other regular jobs, this study provided a unique opportunity to investigate the effects of sleep at home under different working conditions. The findings of Study 1 (Chapter 3) suggest that sleep is reduced at home on fire-days compared to non-fire days. Thus, characteristics of the wildfire environment and job demands likely impact sleep quantity. For example, many firefighters self-reported difficulty in 'winding down' after their shift, which could possibly contribute to them obtaining less sleep. Therefore, sleep quantity for a given rest period may be more adversely affected in occupations which have a high level of work pressure, for example emergency service workers and military personnel.

Furthermore, Study 2 and Study 3 observed that sleep duration did not impact firefighters' physical activity levels and physical task performance, respectively, which may have implications for how work shifts are structured during wildfire suppression and other physically demanding occupations. Therefore, fatigue risk management strategies should focus on cognitive rather than physical aspects of firefighting performance. In situations where these factors cannot be modified, fire agencies should identify those firefighters at the greatest fatigue-related risk and implement appropriate controls to manage this risk, so these workers can still work, as necessary, to support the wildfire suppression effort.

The findings of Study 2 indicated that firefighters' were able to maintain their physical activity levels across successive shifts. These data may have implications for how workers' productivity is managed in other physically demanding occupational settings (e.g., military operations) that include multi-day shifts. For example, if workers are to maintain physical activity levels across successive shifts, additional personnel may not need to deployed, thereby reducing the financial costs associated with increased worker numbers. Reduced worker numbers may also decrease the exposure to highly hazardous working environments, such as those faced during wildland firefighting and other emergency service work. However, decisions to maintain worker numbers would need to be made in the context of the overall risk of the operation. Moreover, workers' knowledge of the work required the next day can often be stressful, creating apprehension, potentially contributing to reduced sleep (Kecklund & Åkerstedt 2004; Åkerstedt et al. 2007). If workers are aware that their physical activity levels and physical task performance can be maintained, this could also enable workers to obtain greater sleep in between shifts. Finally, with increasing advances in physical activity monitoring, feedback on physical activity levels during a shift and sleep behaviour between shifts could be provided to workers in real time. Therefore, physical activity monitoring represents a potential valuable addition to the existing paradigm of fatigue monitoring used in many occupations.

Study 3 observed that sleep restricted firefighters reduced their physical activity levels during rest breaks across multiple days of simulated wildfire suppression work. Therefore, during a wildfire, it is possible that a sleep-deprived firefighter may be less likely to perform other activities (e.g., returning to the staging area to eat or drink), which could consequently adversely impact upon their health and safety. It is also conceivable, that the reduced physical activity during rest breaks mitigated adverse effects of sleep restriction and allowed firefighters to maintain physical task performance (Tucker 2003). If true, fire agencies should encourage firefighters to take regular rest breaks and, where feasible, rotate work tasks throughout multi-day deployments, especially when firefighters' sleep is restricted.

Submaximal physical work is fundamental to many physically demanding occupations (Rodgers et al. 1995). Study 3 provides a valuable addition to the limited existing literature investigating the effects of sleep restriction on submaximal physical performance, suggesting that this type of physical task performance remains unaffected. For other physically demanding occupations these results suggest that workers are still able to physically 'get the job done' even if sleep restricted.

6.4 Future Directions

The results of this thesis have raised several questions that warrant further attention. The key areas for future research are discussed below.

Australia's wildland volunteer and career firefighting cohort comprises males and females, ranging in age from 18–65 y, with differing levels of firefighting experience and fitness (McLennan 2004). Due to resource and recruitment constraints, it was outside the scope of this thesis to determine how demographic factors impacted firefighters' sleep, physical activity, or physical task performance. For example, sex and age have previously been shown to impact both sleep quantity and quality (Reyner et al. 1995). In all studies within this thesis, these characteristics were adjusted and/or accounted for in the statistical analyses (Studies 1 and 2) or via group matching procedures (Study 3). Therefore, future studies should investigate whether there are differential impacts of demographic factors on the interaction between sleep, physical activity, and physical task performance.

During a wildfire, 24-h suppression work is performed by fire crews to protect life and property. Thus, 50% of firefighting shifts occur at night. All previous wildland firefighting research, including the studies conducted as part of this thesis, have focussed on day time wildfire suppression work. There is currently no research assessing the impact of night-shift deployments or different times of day on firefighters' physical activity levels, physical task performance, or sleep behaviour. More generally, there is also a paucity of research describing the impact of night-shift work or time of day on physical activity levels and physical task performance in physically demanding occupations (Folkard & Tucker 2003). A review of four studies noted declines in worker productivity and performance efficiency during night work (Folkard & Tucker 2003), whilst sleep after night work is often shorter and more disturbed than after day work (Åkerstedt 1998). Further, components of physical performance, such as muscular strength, short-term power output, self-selected work rate and prolonged submaximal exercise are influenced by time of day (Drust 2005). Before any changes to shift structures are implemented, all aspects of wildfire suppression operations, including the impact of night work and time of day, should be investigated. This could be achieved objectively by measuring firefighters' sleep and physical work during night shift deployments or different times of day. For example, conducting the simulated laboratory protocol (Chapter 5) using night time shifts and day time sleeps.

This thesis found that firefighters decreased their physical activity levels during periods when movement was not required for task completion. Further interrogation of firefighters' pacing and energy conservation strategies throughout a multi-day deployment would assist fire agencies in determining their operational capabilities. Such research could establish whether pacing and energy conservation is consciously or subconsciously regulated. The proposed 'activitystat' hypothesis suggests that when physical activity is increased or decreased in one domain, there will be a compensatory change in another domain, in order to maintain an overall stable level of physical activity or energy expenditure over time (Rowlands 1999). However, further research is needed to explore whether this relationship persists in physically demanding work environments. This may involve quantitatively describing the pattern of work behaviour in more detail and/or qualitatively establishing what information firefighters use to self-pace throughout a work shift. To investigate the former, patterns of physical activity accumulation within a work shift (i.e., the frequency and duration of the bouts of different physical activity intensities) could provide insight into how firefighters manage their physical activity levels during a shift. It is also unknown whether the observation that firefighters reduced their physical activity during rest periods was related to the design of the simulation, as firefighters did not have other responsibilities between tasks (e.g., since meal times were structured, firefighters' did not have to return to the staging area). Therefore, research investigating whether sleep deprived firefighters decrease their physical activity during rest periods throughout actual wildfire suppression, as observed in the simulated environment (Study 3), is also warranted.

In emergency situations it may not always be possible for firefighters to obtain an adequate sleep opportunity. For example, on any given deployment, shift lengths may be extended due to a lack of replacement personnel, potentially truncating a firefighter's sleep opportunity. In these circumstances, appropriate fatigue countermeasures, such as more frequent rest breaks (Tucker 2003) or increased rotation of work tasks, should be implemented. Understanding the efficacy and feasibility of these strategies before implementation is essential for fire agencies, especially when re-evaluating policy that informs shift lengths, and the frequency of rest periods during multi-day wildfire suppression deployments.

More broadly, further research is required to investigate how physical task characteristics (e.g., intensity, duration, volume of active musculature required, continuous or discontinuous, self-paced or externally paced) may differentially moderate the effect of sleep restriction. Such findings would likely have wider applications beyond wildland firefighting, as these physical task characteristics are fundamental to many physically demanding occupations (Rodgers et al. 1995). Further understanding the complex and poorly understood bi-directional relationship between physical activity and sleep also warrants further attention (Atkinson & Davenne 2007). For example, if physical work positively influences sleep quality, then the quantity of sleep obtained between work shifts may become less important. Controlled laboratory studies that simulate a physically demanding work shift and subsequent measures of sleep quality using polysomnography could further elucidate this relationship.

It is important to note that the findings of Study 1 indicate that obtaining less than 4 h of sleep during wildfire suppression is rare (8%). Therefore, firefighters' physical activity levels may be less affected in the field as a result of obtaining more hours of sleep than during the simulation (Study 3). Future research investigating the impact of various sleep durations on physical activity and physical task performance is required. Further, it is possible that the duration of sleep restriction in Studies 2 and 3 may not have been long enough to elicit changes in physical activity or physical task performance. Each jurisdiction has a unique policy surrounding the maximal number days a firefighter can perform wildfire suppression. For example, in Australia deployments commonly last 3–5 days (Cater et al. 2007; Phillips et al. 2007) whereas in the United States deployments can last up to 14 days (Heil 2002; Ruby et al. 2002; Ruby et al. 2003), which may result in prolonged sleep restriction. There is also no current research evaluating the effect of repeated deployments on firefighters' physical activity levels or physical task performance. Therefore, experimental studies are needed to examine how firefighters respond to sleep restriction over prolonged periods (> 2 nights of sleep restriction), and across repeated wildfire suppression deployments. Furthermore, future research should investigate firefighters' post-deployment behaviour such as nap frequency and return to work multi-day deployments are completed. Epidemiological approaches investigating the long-term impact of wildfire deployments on firefighter health is also warranted. This may include analysing data from annual health assessments or investigating aspects of work behaviour such as, length of firefighting service or number of times a firefighter responds to an emergency call.

6.5 Conclusion

During wildfire suppression, firefighters are exposed to a multitude of adverse risk factors, which may have significant ramifications for workplace performance, health, and safety (Aisbett et al. 2012). Restricted sleep represents a potentially modifiable risk factor within this occupation, which has received little research to date. The collective findings of this thesis suggest that while firefighters' sleep is restricted (Study 1), it does not appear to adversely affect physical task performance (Study 3) during simulated wildfire suppression. Furthermore, sleep duration did not impact upon physical activity during real wildfire suppression (Study 2). However, under conditions of severe sleep restriction (4 h), physical activity was reduced during periods not essential for task completion during simulated wildfire suppression (Study 3). This thesis represents a novel contribution to the scientific literature in understanding the relationships between sleep, physical activity, and physical task performance. For fire agencies to continue to defend local communities against wildfire, it is critical that a high level of investment in preserving the health and safety of firefighting personnel is maintained. This includes implementing strategies to improve and manage firefighters' sleep and reduce any adverse impacts on firefighters' work.

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Appendices

Human Research Ethics

Deakin Research Integrity
70 Elgar Road Burwood Victoria
Postal: 221 Burwood Highway
Burwood Victoria 3125 Australia
Telephone 03 9251 7123 Facsimile 03 9244 6581
research-ethics@deakin.edu.au

Memorandum

To: Dr Brad Aisbett
School of Exercise and Nutrition Sciences
B
cc: Grace Elizabeth Vincent

From: Deakin University Human Research Ethics Committee (DUHREC)

Date: 15 November, 2012

Subject: 2012-300
Sleeping on the fireground: An assessment of quantity and quality during multi-day fire suppression
Please quote this project number in all future communications

The application for this project was considered at the DU-HREC meeting held on 12/11/2012.

Approval has been given for Grace Elizabeth Vincent, under the supervision of Dr Brad Aisbett,School of Exercise and Nutrition Sciences, to undertake this project from 15/11/2012 to 15/11/2016.

The approval given by the Deakin University Human Research Ethics Committee is given only for the project and for the period as stated in the approval. It is your responsibility to contact the Human Research Ethics Unit immediately should any of the following occur:

- Serious or unexpected adverse effects on the participants
- Any proposed changes in the protocol, including extensions of time.
- Any events which might affect the continuing ethical acceptability of the project.
- The project is discontinued before the expected date of completion.
- Modifications are requested by other HRECs.

In addition you will be required to report on the progress of your project at least once every year and at the conclusion of the project. Failure to report as required will result in suspension of your approval to proceed with the project.

DUHREC may need to audit this project as part of the requirements for monitoring set out in the National Statement on Ethical Conduct in Human Research (2007).

Human Research Ethics Unit
research-ethics@deakin.edu.au
Telephone : 03 9251 7123

PLAIN LANGUAGE STATEMENT AND CONSENT FORM

TO: Participant

Plain Language Statement

Date: 1 January 2013

Full Project Title: Sleeping on the fireground: An assessment of quantity and quality during multi-day fire suppression

Principal Researcher: Dr. Brad Aisbett

Associate Researchers: A/Professor Sally Ferguson; Miss Grace Vincent

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Thank-you for expressing interest in this project. You are invited to participate in a study investigating sleep habits on the fireground during multi-day fire suppression.

Purpose:

The aim of the current study is to determine firefighters' sleep quantity and quality throughout campaign fires and prescribed burns.

Methods:

Participation in this project will involve wearing an activity monitor on your wrist (exactly like a wristwatch) for a period of four weeks (or in the case of planned burns 3-days pre, during and 3-day post deployment). Activity monitors are small lightweight devices (weigh 17.5g, size 2.8x2.7x1.0 cm) that monitor human movement. While performing firefighting work we also ask that you wear an additional activity monitor in the pocket of your firefighting jacket. These two devices will determine the quantity of your sleep and work during fire suppression. We also ask that you complete a sleep and work diary throughout the four weeks period. This should take approximately 3 minutes to fill out each day. Example questions include: how long was your work shift? How long did it take you to travel to work? How hard was your work day? Questions like what was the difficulty of fire containment will only be answered on days you are working on the fireground.

Activity monitors will allow a more accurate assessment of sleep behaviour during multi-day fire suppression than previous work which has utilised retrospective reporting of sleep hours. This descriptive field study will recruit 100 firefighters who are employed or volunteer for fire agencies in Australia. You will wear activity monitors to provide information on time in bed, total sleep time, sleep efficiency and work activity. In conjunction, you will be administered with a sleep and work dairy which will provide information on the factors that contribute to sleep quantity and quality i.e., comfort, time of sleep, sleep location etc. A greater understanding of firefighters' sleep behaviour will inform agencies of the risks associated with work hours and sleep/wake patterns. We do not anticipate any additional risks to your normal working conditions by wearing these two monitors.

Risks and benefits:

By assessing the sleeping behaviour of firefighters on the fireground a greater understanding of firefighter fatigue and work demands can be assessed. This will assist those who plan deployments to more accurately define the capabilities of firefighters on the fireground. By understanding this behaviour fire agencies can regulate (whenever possible) the management of their crews to preserve their health, safety and productivity on the fireground and providing ongoing protection for the nation against the annual threat of bushfires. It is not expected that this project will directly benefit participants. However, the results of this work will inform policy makers on sleep hours and considerations of optimal sleeping arrangements of firefighters during a campaign fire.

Expected benefits to wider community:

Research dedicated to understanding the impact that firefighters' working environment, and sleep conditions is fundamental if fire agencies are going to implement policies to preserve the health and safety of their crew. The proposed research will provide an evidence-based from which Australian firefighting agencies can make informed decisions about management of risk associated with firefighters' work hours, workload and working conditions.

Privacy and confidentiality:

Your privacy and confidentiality will be preserved through a number of measures. Participant's interest and participation in the research will not be anonymous, and it will probably not even be completely confidential given the activity monitors and the completion of sleep and work diary is in a public setting. Firstly, your interest and participation in, or withdrawal from will be largely anonymous. As you will be wearing an activity monitor others will know your identity. We ask, however, that all participants do not disclose the identity of any other participant without that individual's explicit consent. Secondly, your results and identity will be stored separately, such that the researchers will only refer to your data by your unique identifier code. Your data will be stored securely for a period of six years after the final publication of results, as per University guidelines. Thirdly, should you choose to withdraw from the research, after receipt of your revocation of consent form (attached), your data and personal records will be destroyed immediately should you specifically demand it. If not specified the data will be retained without analysis for a period of five years to ensure data integrity. Fourthly, your fire agency will have no record of your decision to participate in, or withdraw from the proposed research.

Dissemination of the research results:

The results from the proposed research will be presented in either a) oral presentation to fire industry or scientific audiences, b) written, peer-reviewed scientific journal articles, or c) Bushfire Co-Operative Research Centre (CRC) Firenote research briefings. In each case, only mean results will be reported and, as such, no individual results or identities will be revealed.

Ethical considerations:

Should you wish to no longer participate in the study during any stage, your decision will in no way negatively affect your relationship with researchers to the School of Exercise and Nutrition Sciences. Furthermore, The Australasian Fire Authorities Council and your fire agency will have no knowledge of your participation or results.

Should you decide to withdraw from the research project during data collection, your personal information and any research data collected to that point will be removed from any data that is analysed and reported. This data will be retained for the specified period of time unless you specify that the data is to be destroyed immediately. If data aggregation and analysis has commenced you can no longer withdraw from the study. Your decision to withdraw from the study will in no way affect your position within your organisation as either a staff member, incumbent, volunteer or contractor as all the information collected will be non-identifiable.

Research monitoring:

All research will be monitored by principal investigators Dr Brad Aisbett, Associate Professor Sally Ferguson and Miss Grace Vincent.

Sources of research funding:

The proposed research is funded for three-years by the Bushfire CRC. Specifically, the project is part of the Occupational Health and Safety project, within the Managing the Threat program of the Bushfire CRC extension. The Bushfire CRC extension is funded by the Federal Government and by cash and in-kind contributions from organisations that form the Australasian Fire Authorities Council.

Should you have any questions, please contact

Grace Vincent
School of Exercise and Nutrition Sciences
Deakin University
Burwood VIC 3125
Phone: 03 9244 5013 Fax: 03 9244 6017
Email: gvincent@deakin.edu.au

Complaints

If you have any complaints about any aspect of the project, the way it is being conducted or any questions about your rights as a research participant, then you may contact:

The Manager, Office of Research Integrity, Deakin University, 221 Burwood Highway, Burwood Victoria 3125, Telephone: 9251 7129, Facsimile: 9244 6581; research-ethics@deakin.edu.au
Project ID: 2012-300

PLAIN LANGUAGE STATEMENT AND CONSENT FORM

TO: Participants

Consent Form

Date: 16/10/12

Full Project Title: Sleeping on the fireground: An assessment of quantity and quality during multi-day fire suppression

Principal Researcher: Dr. Brad Aisbett

Associate Researchers: A/Professor Sally Ferguson

Miss Grace Vincent

I have read and I understand the attached Plain Language Statement.

I freely agree to participate in this project according to the conditions in the Plain Language Statement.

I have been given a copy of the Plain Language Statement and Consent Form to keep.

The researcher has agreed not to reveal my identity and personal details, including where information about this project is published, or presented in any public form.

Participant's Name (printed) …………………………………………………….

Signature ………………………………………Date …………………………

Should you wish to return your consent form (and have lost your reply-paid envelope), please send the forms to:

Grace Vincent
School of Exercise and Nutrition Sciences
Deakin University
Burwood VIC 3125
Phone: 03 9244 5013 Fax: 03 9244 6017
Email: gvincent@deakin.edu.au

PLAIN LANGUAGE STATEMENT AND CONSENT FORM

TO: Participants

Revocation of Consent Form

(To be used for participants who wish to withdraw from the project)

Date: 1/09/2015

Full Project Title: Sleeping on the fireground: An assessment of quantity and quality during multi-day fire suppression

Principal Researcher: Dr. Brad Aisbett

Associate Researchers: A/Professor Sally Ferguson
Miss Grace Vincent

I hereby wish to WITHDRAW my consent to participate in the above research project and understand that such withdrawal WILL NOT jeopardise my relationship with Deakin University or my fire agency.

Participant's Name (printed) ……………………………………………………….

Signature …………………………………………Date…………………………

Please mail or fax this form to:

Grace Vincent
School of Exercise and Nutrition Sciences
Deakin University
Burwood VIC 3125
Phone: 03 9244 5013 Fax: 03 9244 6017
Email: gvincent@deakin.edu.au

Fighting fires and fatigue

Occupational and environmental factors impacting firefighter performance

STUDY BOOKLET **Weeks 1-4**

Participant name:

Participant number:

Watch ID:

1

Important Contacts

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Bradley Smith (08) 8378 4528
b.p.smith@cqu.edu.au 0412 630 675

2

About You

Please complete this section before you begin your sleep/work diary

Name: ______________________________

1. Age__________

2. Date of Birth ________________

3. Height (cm) ________________

4. Weight (kg) ________________

5. What state do you currently reside? __________________

6. Gender Male □ Female □

7. Domestic status

- Married/ Living with partner □
- Separated/Divorced □
- Widowed □
- Single □

8. Do you consume caffeinated products (eg coffee, tea, cola, energy drinks, chocolate bars etc)

Yes □ No □

If YES, adding all of these together, how many items do you consume each day? ______________

3

9. Do you describe yourself as a:

- Non-smoker (I have never smoked regularly) □
- Occasional smoker (I do not smoke everyday) □
- Ex-smoker (I used to smoke but not anymore) □
- Regular smoker (I smoke one or more cigarettes per day) □

10. Are you, or have you ever been involved in shift work

Yes □ No □

If YES, when were you involved in shiftwork, and for how long? ____

____

____

11. Are you currently employed?

Yes □ No □

12. How often do you work?

Full time □ Part-time □ Casual □ Seasonal □ Self-employed □

4

Firefighting history

13. Years of firefighting experience (volunteer/salaried)____________

14. What agency are you currently affiliated with? ________________

15. Please approximate the number of campaign deployments you have completed over your entire employment?

____

16. On average how many hours of sleep (each night) do you obtain during campaign deployments? ___________________

17. What are some of the contributing factors to getting limited sleep during campaign deployments? _________________

____

____

____

____

5

Normal sleep

18. How many hours of sleep do you need to feel rested? _________________

19. How satisfied are you with the amount of sleep you get

<u>Very dissatisfied</u> 1 2 3 4 5 6 7 8 9 10 <u>Very Satisfied</u>

20. Overall, how would you rate the quality of your sleep

Very poor □ Poor □ Fair □ Good □ Very good □ Excellent □

21. Have you ever been diagnosed with a sleeping problem

Yes □ No □

If YES, please describe ____

____

22. How often do you take naps?

Never □ Once a week □ 2-3 times a week □ 4-5 times a week □ Daily □

23. One hears about 'morning' and 'evening' people. Which one of these do you consider yourself to be

- Definitely a morning type □
- More a morning type than an evening type □
- More an evening type than a morning type □
- Definitely an evening type □

6

24. How likely are you to doze off or fall asleep in the following situations?

0 = Would never doze

1 = Slight chance of dozing

2 = Moderate chance of dozing

3 = High chance of dozing

a) Sitting and reading ___________

b) Watching TV ___________

c) Sitting, inactive in a public place (e.g. cinema or meeting) ___________

d) As a passenger in a car for an hour without a break ___________

e) Lying down to rest in the afternoon when possible ___________

f) Sitting and talking to someone ___________

g) Sitting quietly after lunch not having had alcohol ___________

h) In a car when you stop at traffic for a few minutes ___________

Thank you for taking the time to fill out this questionnaire

7

Instructions for Activity Monitors

Thank you for participating in this study. The lessons we learn about your sleep patterns during fire suppression will give us an idea of your sleep before, during and after work on the fireground. To enable us to monitor your sleep, you will need to: (i) wear your wrist activity monitor at all times (ii) wear your shirt pocket activity monitor **during fire suppression activities** (put in your firekit so it is not forgotten) and (iii) keep a sleep/work diary.

It is essential that you wear the wrist monitor **ALL the time except when swimming or showering**. The activity monitor is water resistant but not waterproof. The activity monitor can be worn in the rain. **Remember to put the activity monitor back on after showering**. It is also very important that you complete **the sleep/work diary daily** as the information on the monitors cannot be analysed without this information. An activity monitor is a small device worn like a wristwatch that continuously records body movement. It is important that you always wear the activity monitor on the same wrist **(non-dominant)**. Take the activity monitor off if there is a chance that it could be damaged BUT don't forget to put it back on! ****Please take care of the Activity Monitor** replacement value = $3,000**

8

Sleep/Work Diary

In this booklet, you will find your sleep and work diary. The main purpose of the diary is to record the times when you are attempting to sleep. This information will be used in conjunction with data from the activity monitor to determine when you fell asleep and woke up.

Instructions

- **** It may be best to put your sleep diary next to your bed with a pen to ensure completion ****

- You will need to complete sections of this diary at two times during the day **'At bedtime'** and **'In the morning'. Please try to keep to these times as much as possible to aid in the accuracy of our results.**

Please fill out all times in 24-h time or make am/pm very clear especially if you are working nightshift

WORK SECTION (1-8)	**Fill out ONLY during fire suppression**
SLEEP SECTION (9-19)	**Complete DAILY**

9

Work Diary

Note: *Please only complete questions 1-8 if you are performing fire suppression work during that day.*

Date: The date you worked performing fire suppression activities

1. Where was your work located? The location of your work

2. How long did it take you to travel to work? Your travel time to your work location

3. Did you drive? Yes or No

4. What time did work start? The time that work started (do not include travel time to work)

5. What time did work end? The time work ended (do not include travel time after work has finished)

6. Please rate the difficulty of work? On the scale please indicate how hard your work was for that day

7. Please select fire danger level? Rate the severity of the fire on the scale

8. Please describe your work day: Provide a description of your work day ie: key tasks, intensity of work.

10

Sleep Diary

Note: *Please complete this section DAILY (regardless of whether you are performing fire suppression activities)*

Date: The date where you are going to sleep

9. Did you nap today? Please indicate whether you napped during the day. If YES, please complete the start and finish times of your nap.

10. Where are you sleeping? Please indicate where you slept, ie: At home (H), Motel/Hotel (M), Tent (T) or Other (O). If Other, please describe your sleeping location for example: *On a mattress in a school gym*

11. What is your pre-sleep fatigue level? Rate your pre-sleep level of fatigue using a scale of 1 to 7.

12. What time did you go to bed? The time that you attempted to sleep. Don't include time spent reading, watching TV, etc

13. How long did it take you to fall asleep? The time you thought it took you to fall asleep

14. What time did you wake up? The time you woke up

15. How much actual sleep did you obtain? What your length of sleep was

11

16. How many times did you wake during the night? Please indicate this on the scale. This include all times you woke during the night including toilet breaks.

17. What is your post-sleep fatigue level? Rate your post-sleep level of fatigue using a scale of 1 to 7.

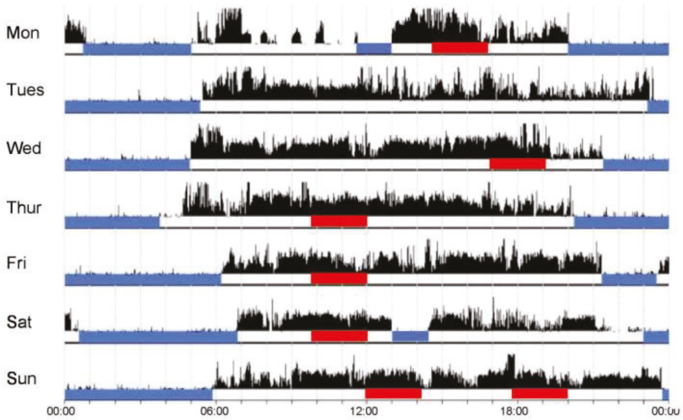
18. What was your sleep quality? The quality of your sleep compared to a 'normal' sleep period.

19. What was your sleep comfort? The comfort of your sleep compared to a 'normal' sleep period.

Notes: If you would like to provide additional comments or notes about any sleep period 'Notes' pages at the back of this booklet.

12

Example of Data



13

This figure shows an example of the type of data that you will collect:

- The figure represents 7 days of data.
- Each line represents a day of data, from midnight to midnight.
- The **blue** horizontal bars represent bed times we will get these from your diary.
- The **black** vertical bars represent the level of movement we will get these from your activity monitor.
- By combining the information from your sleep diary and activity monitor, we will use special software to determine (i) what time you went to sleep, (ii) what time you woke up, (iii) how much sleep you got, and (iv) how good or bad your sleep was.
- At the end of the sleep audit, you will get a report about your sleep/wake patterns.

14

	24 hour	12 hour
Morning (AM)	1:00	1:00am
	2:00	2:00am
	3:00	3:00am
	4:00	4:00am
	5:00	5:00am
	6:00	6:00am
	7:00	7:00am
	8:00	8:00am
	9:00	9:00am
	10:00	10:00am
	11:00	11:00am
Afternoon/Evening (PM)	12:00	12:00pm
	13:00	1:00pm
	14:00	2:00pm
	15:00	3:00pm
	16:00	4:00pm
	17:00	5:00pm
	18:00	6:00pm
	19:00	7:00pm
	20:00	8:00pm
	21:00	9:00pm
	22:00	10:00pm
	23:00	11:00pm
	24:00	12:00am

15

SLEEP AND WORK DIARY BEGINS HERE

16

SLEEP AND WORK DIARY

At Bedtime **Date:** 17/4/2013

WORK (*only complete questions 1-8 if you were involved in fire suppression activities today)*

1. Where was your work located? Yarra Valley
2. How long did it take you to travel to work? *hh:mm* 1:30
3. Did you drive? *Please circle* YES NO
4. What time did work start? *hh:mm* 09:00
5. What time did work end? *hh:mm* 17:30
6. Please rate the difficulty of your work below

6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
No exertion at all		Extremely light		Very light		Light		Somewhat hard		Hard (heavy)		Very hard		Extremely hard	Maximal exertion

7. Please select the fire danger level

Level 1 *Level 2* *Level 3*

8. Please describe your work day? Patrolling, blacking out. 2 hours of rakehoe work towards the end of day. Very tired.

17

At Bedtime (please complete questions 9-19 daily)

Date: 17/4/2013

9. Did you nap today? *Please Circle* YES NO

If yes, at what was your nap time?
A. Nap 1 start time __________ Nap 1 end time __________
B. Nap 2 start time __________ Nap 2 end time __________

10. Where are you sleeping? *H=Home, M=Motel, T=tent, O=Other (please describe)*

H *M* *T* *O* ***Describe:*** Swag with sleeping bag

11. What is your pre-sleep fatigue level?

1	2	3	4	5	6	7
Fully alert, wide awake	Very lively, responsive, not at peak	Okay, somewhat fresh	A little tired, less than fresh	Moderately tired, let down	Extremely tired, very difficult to concentrate	Completely exhausted, unable to function effectively

18

In the morning **Date: 18/04/2013**

EXAMPLE

12. What time did you go to bed (i.e the time you turned off the lights) *hh:mm* 21:30

13. How long did it take you to fall asleep? *hh:mm* 0:10

14. What time did you wake up? *hh:mm* 06:30

15. How much actual sleep did you obtain? *hh:mm* 9:00

16. How many times did you wake during the night? *0 1 2 3 4 5+*

17. What is your post-sleep fatigue level?

1	2	3	4	5	6	7
Fully alert, wide awake	*Very lively, responsive, not at peak*	*Okay, somewhat fresh*	*A little tired, less than fresh*	*Moderately tired, let down*	*Extremely tired, very difficult to concentrate*	*Completely exhausted, unable to function effectively*

18. What was your sleep quality?

1	2	3	4	5
Very good	*Good*	*Average*	*Poor*	*Very Poor*

19. What was your sleep comfort?

1	2	3	4	5
Very good	*Good*	*Average*	*Poor*	*Very Poor*

Notes: _Had trouble sleeping – too hot and uncomfortable

19

At Bedtime **Date:** _______________

WORK *(only complete questions 1-8 if you were involved in fire suppression activities today)*

1. Where was your work located? _________________________________

2. How long did it take you to travel to work? *hh:mm*_________________

3. Did you drive? *Please circle* YES NO

4. What time did work start? *hh:mm*___________

5. What time did work end? *hh:mm*___________

6. Please rate the difficulty of your work below

6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
No exertion at all	*Extremely light*		*Very light*		*Light*		*Somewhat hard*		*Hard (heavy)*		*Very hard*		*Extremely hard*	*Maximal exertion*

7. Please select the fire danger level

Level 1 *Level 2* *Level 3*

8. Please describe your work day? ____

____

20

At Bedtime (please complete questions 9-19 daily)

Date: _______________

9. Did you nap today? ***Please Circle*** **YES** **NO**

If yes, at what was your nap time? **A. Nap 1 start time** _________________ **Nap 1 end time** ______________
B. Nap 2 start time _________________ **Nap 2 end time** ______________

10. Where are you sleeping? ***H=Home, M=Motel, T=tent, O=Other (please describe)***

H *M* *T* *O* ***Describe:*** ____

11. What is your pre-sleep fatigue level?

1	2	3	4	5	6	7
Fully alert, wide awake	*Very lively, responsive, not at peak*	*Okay, somewhat fresh*	*A little tired, less than fresh*	*Moderately tired, let down*	*Extremely tired, very difficult to concentrate*	*Completely exhausted, unable to function effectively*

21

In the morning **Date:** _______________

12. What time did you go to bed (i.e the time you turned off the lights) ***hh:mm*** _________

13. How long did it take you to fall asleep? ***hh:mm*** __________________

14. What time did you wake up? ***hh:mm*** __________________________

15. How much actual sleep did you obtain? ***hh:mm*** __________________

16. How many times did you wake during the night? *0* *1* *2* *3* *4* *5+*

17. What is your post-sleep fatigue level?

1	2	3	4	5	6	7
Fully alert, wide awake	*Very lively, responsive, not at peak*	*Okay, somewhat fresh*	*A little tired, less than fresh*	*Moderately tired, let down*	*Extremely tired, very difficult to concentrate*	*Completely exhausted, unable to function effectively*

18. What was your sleep quality?

1	2	3	4	5
Very good	*Good*	*Average*	*Poor*	*Very Poor*

19. What was your sleep comfort?

1	2	3	4	5
Very good	*Good*	*Average*	*Poor*	*Very Poor*

Notes: ____

22

At Bedtime **Date:** ______________

WORK ***(only complete questions 1-8 if you were involved in fire suppression activities today)***

1. Where was your work located? ______________________________

2. How long did it take you to travel to work? ***hh:mm***________________

3. Did you drive? ***Please circle*** **YES** **NO**

4. What time did work start? ***hh:mm***__________

5. What time did work end? ***hh:mm***___________

6. Please rate the difficulty of your work below

6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
No exertion at all	*Extremely light*		*Very light*		*Light*		*Somewhat hard*		*Hard (heavy)*		*Very hard*		*Extremely hard*	*Maximal exertion*

7. Please select the fire danger level

Level 1 *Level 2* *Level 3*

8. Please describe your work day? ____

____

23

PLOS | ONE

RESEARCH ARTICLE

Sleep Restriction during Simulated Wildfire Suppression: Effect on Physical Task Performance

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Abstract

Objectives

To examine the effects of sleep restriction on firefighters' physical task performance during simulated wildfire suppression.

Methods

Thirty-five firefighters were matched and randomly allocated to either a control condition (8-hour sleep opportunity, n = 18) or a sleep restricted condition (4-hour sleep opportunity, n = 17). Performance on physical work tasks was evaluated across three days. In addition, heart rate, core temperature, and worker activity were measured continuously. Rate of perceived and exertion and effort sensation were evaluated during the physical work periods.

Results

There were no differences between the sleep-restricted and control groups in firefighters' task performance, heart rate, core temperature, or perceptual responses during self-paced simulated firefighting work tasks. However, the sleep-restricted group were less active during periods of non-physical work compared to the control group.

Conclusions

Under self-paced work conditions, 4 h of sleep restriction did not adversely affect firefighters' performance on physical work tasks. However, the sleep-restricted group were less physically active throughout the simulation. This may indicate that sleep-restricted participants adapted their behaviour to conserve effort during rest periods, to subsequently ensure they were able to maintain performance during the firefighter work tasks. This work contributes new knowledge to inform fire agencies of firefighters' operational capabilities when their sleep is restricted during multi-day wildfire events. The work also highlights the need for further research to

Citation: Vincent G, Ferguson SA, Tran J, Larsen B, Wolkow A, Aisbett B (2015) Sleep Restriction during Simulated Wildfire Suppression: Effect on Physical Task Performance. PLoS ONE 10(1): e0115329. doi:10.1371/journal.pone.0115329

Academic Editor: Mathias Basner, University of Pennsylvania Perelman School of Medicine, UNITED STATES

Received: August 11, 2014

Accepted: November 21, 2014

Published: January 23, 2015

Data Availability Statement: Data is available via a stable public repository (figshare.com.): http://dx.doi.org/10.6084/m9.figshare.1258799.

Funding: This project was funded by the Bushfire Co-operative Research Centre, http://www.bushfirecrc.com/. The funders had no role in the design of the study, data collection, analysis or preparation of the manuscript. Funders have approved the manuscript to be published and provided assistance in participant recruitment.

Competing Interests: The authors have declared that no competing interests exist.

explore how sleep restriction affects physical performance during tasks of varying duration, intensity, and complexity.

Introduction

Australian firefighters regularly work shifts of up to 15 h per day over several days during wildfire suppression [1,2]. Wildfire incidents are often long in duration, and certain deployments may require firefighters to travel considerable distances from their home location. During such deployments, fire personnel sleep in temporary accommodation near the fireground between consecutive shifts [3]. Fireground conditions such as heat, light, smoke, noise, and unfamiliar surroundings may contribute to an inadequate sleeping environment, which may compromise sleep quantity and quality [1,4]. Accordingly, firefighters have subjectively reported obtaining 3–6 h sleep per night during wildfire suppression deployments [1,5]. Elements of shift work such as night work, long working hours, and consecutive shifts have all been associated with an increased risk of accidents [6–8]. While the effects of multiple days of sleep restriction on cognitive function are well established [9,10], less is known about its effects on physical task performance. In response to an emergency event, wildfire personnel must perform physical work [11]. If task performance and/or the underlying physiology are compromised due to poor sleep, this may adversely impact firefighters' health and safety and the collective emergency response.

Although there is a lack of robust empirical data detailing the effects of sleep restriction on firefighters' physical work performance, insights can be gained from sustained military operations [12–14] and laboratory studies [15,16]. Early military studies assessed physical performance following periods of sleep restriction ranging from 3.0–5.3 h per night, over 5–9 days. Preservation of self-paced work output but decrements in upper body 30 s mean power were observed during simulated combat scenarios [12–14]. Others have observed that physical work output involving short-term maximal efforts was maintained under periods of complete sleep deprivation [15,16]. Yet in contrast, declines in self-paced work rate have been reported in low- to moderate-intensity tasks performed during 48 h of total sleep deprivation [16]. This decline was attributed to reduced motivation levels due to either task repetition in a laboratory environment, an increase in perceived exertion, or a combination of both factors [16]. To our knowledge, no study has examined the effect of sleep restriction on the performance of intermittent, variable-intensity manual handling work over multiple days, which is typical of wildland firefighting [11].

The aforementioned military and laboratory studies have employed experimental protocols with varying designs. In particular, the duration of the sleep restriction period, work parameters (task type, intensity and duration), and calorie restriction all differ between studies. This makes it difficult to accurately quantify the effect of sleep restriction on worker physical task performance and physiology and to extrapolate these findings to wildfire personnel. Moreover, implementing controlled field studies is not often feasible as wildfire conditions can be dangerous to both firefighters and researchers. Wildfire conditions such as heat, smoke, and varying terrain are additional confounders which may make it challenging to accurately determine the influence of sleep restriction on physical task performance. In addition, the work performed by personnel within this dynamic environment is variable [17] and therefore not standardised within- or between-individuals across a multi-day wildfire. Therefore, the aim of the current study was to determine the effect of sleep restriction on firefighters' physical task performance, physiology, and perceptual responses during simulated multi-day wildfire suppression. This study employed a rigorously controlled laboratory protocol implementing a valid work task simulation [18] to quantify the effects of sleep restriction on physical performance.

Materials and Methods

Participants and screening

Thirty-five volunteer and career firefighters (30 males, 5 females) were recruited, from Australia's state fire agencies (Victoria, South Australia, New South Wales, Tasmania). The sample size was estimated by a magnitude based-statistical power analysis [19] using an averaged effect size of 0.3 ± 0.2 from relevant firefighting research [20,21] and an $\alpha = 0.05$ and $\beta = 0.80$. Individual participants were matched, in order of priority, by sex, age, and body mass index to reduce variation between conditions and then were randomly allocated to either the control condition (CON; n = 18) or the sleep-restricted condition (SR; n = 17). Participants provided written informed consent, completed a general health questionnaire [22] to ensure they were able to complete vigorous exercise without medically supervised exercise testing, and were screened for diagnosed sleep disorders. Ethical approval was obtained from the Deakin University Human Research Ethics Committee and the Human Research Ethics Committee of CQUniversity, and written informed consent was provided by all participants before the commencement of the study.

Participants were instructed to maintain their normal sleep behaviour prior to entering the study. Participants wore an activity monitor for two days pre-simulation (*Actical* MiniMitter/Respironics, Bend, OR) on their non-dominant wrist and completed a sleep diary to evaluate their pre-simulation sleep hours and timing of sleep periods. Activity monitors were set to sample in 1-min epochs, with a sensitivity of < 40 counts per epoch to distinguish between sleep and wake states [23].

Participants' age, height, and weight were recorded prior to testing. Height was measured without shoes using a stadiometer (Fitness Assist, Wrexham, England). Semi-nude body mass was measured using an electronic scale (A and D, Japan). Participants wore their own firefighting personal protective clothing throughout the simulation. This included a two-piece jacket and trouser set made from Proban cotton fabric (Protex, Australia), suspenders, boots, gloves, helmet, and goggles (amounting to ~5 kg). The participant characteristics of the CON and SR conditions are shown in Table 1.

Experimental protocol

Participants were required to attend the laboratory for four days and the study condition (CON or SR) was blinded from the participants prior to arrival. Participants arrived at the

Table 1. Characteristics of firefighters in the control and sleep restricted conditions.

	CON	SR
n	18	17
Age (y)	39 ± 16	39 ± 15
Body mass (kg)	85.1 ± 17.7	93.8 ± 20.2
Height (m)	1.78 ± 0.08	1.78 ± 0.07
BMI ($kg \cdot m^{-2}$)	26.7 ± 4.8	29.6 ± 5.5
Service (y)	9 ± 9	10 ± 6
Male:Female	15:3	15:2

Values are in mean ± SD; BMI, body mass index.

doi:10.1371/journal.pone.0115329.t001

testing facility at 6:00 p.m. on the pre-study day and were familiarised with all daily procedures. Throughout the testing period, participants followed a strict daily schedule including work bouts, meal times, and sleep periods. The day was divided into two-hour work blocks, with each block comprising 55 min of physical work, 20–25 min of physiological testing, 20–25 min of cognitive testing, and a 15–20 min rest period. The suite of cognitive procedures was administered as part of another study and will be reported elsewhere. Participants were instructed that their caffeine consumption and cigarette smoking could continue as it normally would during a wildfire suppression deployment, but that these behaviours were restricted to the rest periods which occurred for 15–20 min within each two-hour period. When compared to habitual caffeine consumption, there were no differences between the groups in caffeine intake across the simulation.

The simulated environment was kept at a moderate temperature (18–20°C) throughout the testing period. Room temperature was maintained through the use of split cycle air-conditioners (Daikin Industries Ltd, Japan). Ambient air temperature was monitored throughout testing using a wireless temperature and humidity data logger (HOBO ZW_003, One Temp Pty.Ltd, Australia), data receiver (HOBO ZW_RCVR, One Temp Pty Ltd, Australia), and associated software (HOBO Pro Software, One Temp Pty Ltd, Australia).

On day one firefighters completed three two-hour work circuits: one familiarisation work block (12:30–2:30 p.m.), then two subsequent work blocks (2:30–4:30 p.m.; 4:30–6:30 p.m.). Day one occurred prior to the sleep intervention providing each individual with a baseline against which all subsequent measures of each outcome variable were compared. Days two and three began at 8:00 a.m. and on both days, the firefighters performed five two-hour work circuits (8:00–10:00 a.m., 10:00 a.m.–12:00 p.m., 12:30–2:30 p.m., 2:30–4:30 p.m. and 4:30–6:30 p.m.). As such, the baseline value was labelled as circuit 0 and every subsequent circuit performed labelled sequentially (circuit 1–10). Breakfast (6:30–7:00 a.m.), lunch (12:00–12:30 p.m.), and dinner (6:30–7:00 p.m.) were at the same time on all three days.

Daily fluid consumption was precisely recorded to monitor participants' hydration status as hyper- and hypo-hydration can impact physical performance [24]. Participants were able to drink room temperature water ad libitum from marked, supplied bottles. Each day participants were provided with two sachets of carbohydrate supplement which they could add to their water at any time. Breakfast, lunch, and dinner meal items were based on food normally available to firefighters during wildfire suppression. Participants were also provided with a "ration pack" containing a variety of food items similar to those available during wildfire suppression. All meal and snack food items were identified in consultation with subject matter experts from Australasian fire authorities. Types and quantities of ingested food were recorded throughout the protocol. There was no difference in fluid and total energy intake between the groups.

To replicate sleeping conditions during a wildfire suppression deployment [1], participants slept on camp beds in the simulated environment. The pre-study day involved an adaptation night consisting of an 8-h sleep opportunity for both conditions. On day two and three, the CON condition was assigned an 8-h sleep opportunity from 10:00 p.m. to 6:00 a.m. whereas those in the SR condition were assigned a 4-h sleep opportunity from 2:00 a.m. to 6:00 a.m. Both conditions were constantly observed by research personnel to prevent them from falling asleep outside of their designated sleeping period. Between dinner (7:00 p.m.) and the beginning of the sleep opportunity (CON; 10:00 p.m. and SR; 2:00 a.m.) participants engaged in sedentary leisure activities (i.e. read a book, watch a movie).

The physical work circuit

The firefighting circuit was developed using a job task analysis [11] of wildfire suppression tasks and verified by panels of firefighter subject matter experts [18]. The tasks involved simulated actions, fitness components, and movements performed during wildfire suppression [11,25]. These tasks were chosen on the basis of being the longest, most intense, or most frequent tasks performed during wildfire suppression work [25]. They were also considered the most physically demanding and operationally important [11]. The six physical tasks include: charged hose advance, blackout hose work, hose rolling, lateral repositioning, rake, and static hold.

Five minutes were allocated to each task, with task-specific work-to-rest ratios within each 5-min block in accordance with the work-to-rest ratios observed for each task in live fire suppression conditions [25]. Some tasks were only performed once in each 55-min block, whereas others were performed multiple times according to their recorded frequency during live fire suppression [25]. Participants completed the tasks in an ordered circuit; each participant began the circuit at one of five task stations (charged hose advance, blackout hose work, hose rolling, lateral repositioning, or rake) but rotated through each subsequent task in the same order irrespective of start point. The static hold task was always the last task performed in the circuit and by all participants concurrently. This allowed participants to perform some tasks at the same time. CON and SR participants were matched on age, then sex, and body mass index and then randomly allocated into the five circuit start points. This process prevented potential clustering of specific demographic variables into any one of the five circuit start points. Each participant began at the same individually-assigned start point during all physical work bouts. Task performance was evaluated for each 5-min work block completed for each task, as discussed in further detail below.

Charged hose advance

Each participant dragged a 2-m rubber hose (38-mm diameter, with branch) attached to a 15-kg weighted tyre up and back for 8 m along a carpeted surface, marked at 2-m increments. The hose was filled with rice to simulate a charged hose (i.e., pressurised with water). This task simulates forward movement with a charged hose towards the fire front [11]. This task was undertaken with a work-to-rest ratio of 65 s work to 55 s rest, which was completed twice within a 5-min period, with one 5-min work bout performed during the 55-min circuit. The participant was instructed to stop completely at the end of each work period, at which point task performance was recorded as distance covered (to the nearest 2-m marker).

Blackout hose work

Each participant dragged a 2-m rice-filled rubber hose (38-mm diameter, with branch), attached to a 15-kg weight bag around a 2.5-m × 2.5-m square, stopping at each corner for a period of 3 s timed by a metronome. This task simulated the stop start movements firefighters perform when extinguishing smouldering debris, during post-fire clean up [11]. This task was undertaken with a work-to-rest ratio of 90 s work to 60 s rest, which was completed twice within the 5-min period, with two 5-min work bouts performed during the 55-min circuit. The participants walked clockwise during the first work bout and anticlockwise during the second work bout to incorporate both left and right manoeuvres. The participants were instructed to stop at the end of each work period where their total distance was recorded to the nearest corner of the square.

Hose rolling

The participants were instructed to roll-up a 8-m rubber hose (38-mm diameter, 16-m length hose folded in half, with branch) beginning at the folded end of the hose and moving along the length of the hose rather than pulling the hose towards them. This task simulated rolling up a hose and therefore had to be rolled to operational standard (a tight coil with edges aligned). This task was undertaken with a work-to-rest ratio of 60 s work to 60 s rest, which was completed twice during the 5-min period, with one 5-min work bout performed during the 55-min circuit. The hose was taped 0-, 2-, 4-, 6-, and 8-m intervals to aid in recording distance.

Lateral repositioning

The participant walked the arc (11 m) of a 3.5-m radius semi-circle carrying a 3.5-m rice filled rubber hose (38-mm diameter, with branch). The hose was anchored by a chain to a stand positioned in the middle of the semi-circle allowing the hose to freely rotate. Two platforms (68 × 28 × 15 cm) were positioned at ¼ and ¾ distance markers of the semicircular arc, with one platform placed length ways and the other placed cross ways. Participants walked over the step placed cross ways and stepped up with two feet onto and then off the step placed length ways. This task simulated walking with a charged hose over obstacles such as tree roots and other debris commonly found on the fireground [11]. This task was undertaken with a work-to-rest ratio of 30 s work to 30 s rest, which was completed four times during the 5-min period, with four 5-min work bouts performed during the 55-min circuit. Task performance was measured as distance travelled during each work period, rounded to the nearest quarter (2.75 m) completed.

Rake

Participants were instructed to rake the contents of a 2-m × 0.9-m box filled with 29 kg of 1-cm tyre crumb and large tyre pieces. The tyre crumb simulated ground debris that is cleared when creating a mineral earth fire break [11]. Two identical boxes were placed side by side and participants alternated between the boxes after successfully raking the contents from one side to the other. Participants utilised a 35-cm dual-sided rakehoe (Cyclone Industries, Australia) to complete this task. This task was undertaken with a work-to-rest ratio of 90 s work to 60 s rest, which was completed twice during the 5-min period, with one 5-min work bout performed during the 55-min circuit. Task performance was measured by the area of material moved (m^2) (i.e., the amount of material moved from one side of the box to the other).

Static hold

The participant was instructed to hold a 3.5-m rice-filled rubber hose (38-mm diameter, with branch) attached to a stand with a looped elasticised rope providing resistance when held off the ground. A laser was positioned at the end of the hose so that participants could aim the hose towards a target placed 1.5 m above the ground. This task simulated holding a charged hose to direct water or other extinguishing material towards a fire, while stationary [11]. The participants could hold the hose at their waist or over their shoulder with their chosen front foot placed completely over the line marked at 4.8 m from the centre point of the hose stand. The participants were instructed to hold the hose for the entire 5-min period. If a participant dropped the hose, the laser went out of the target for more than 2 s, or the participant could not hold the position for 5 min, the failure time was recorded. This task was performed once during the 55-min circuit.

Heart rate

Daily heart rate was recorded using the Team Polar (Polar Team^2, Kempele, Finland) heart rate system from 6:30 a.m. to 6:00 p.m. on all testing days. Heart rate was logged every 5 s, with data downloaded daily and analysed using the Polar Team 2 Pro Software (Polar, Kempele, Finland). Relative average and peak heart rate was predicted using $HR_{max} = 207 - (0.7 \times age)$ [26] to individualise the cardiovascular response due to the large spread in age (18–61 years) across the sample. Average and peak heart rates are analysed during the physical work circuit, the rest period, and during each physical task performed.

Core temperature

Participants ingested a core temperature capsule (Jonah, Minimitter, Oregon) prior to sleep each evening (9:30 pm), in order to allow adequate time for the capsule to pass through the stomach to the small intestines (Lee et al., 2000). Intestinal temperature (via ingested capsules) was preferred over rectal thermometry, as it is a valid but less invasive index of core temperature [27]. Core temperature was recorded continuously on a data logger (VitalSense, Minimitter, Bend, Oregon) throughout the testing period.

Rating of perceived exertion and effort sensation scale

Participants were asked to report a rating of perceived exertion (RPE, on a scale of 6–20; Borg, 1982) [28][28] after each work bout (i.e., every 5 min). After the completion of each physical work circuit participants were asked to report their physical effort using a modified Borg scale where effort $<$ 100% is reported [29]. Participants were asked 'how much of yourself did you give'? Items ranged from 0% 'gave no effort at all' to 100% 'gave absolutely everything, nothing left'.

Worker activity

An activity monitor (*Actical* MiniMitter/Respironics, Bend, OR) was worn on the participants' non-dominant wrist (dominance was defined as the participants' preferred writing hand) throughout the simulation to assess activity. Whole body motion in a three dimensional plane was measured at 1-min intervals. Data was downloaded using Actical software (version 3.10 MiniMitter/Respironics, Bend, OR) and expressed as absolute counts.

Sleep monitoring: Polysomnography

Polysomnography (PSG) was utilised during the four study nights to assess sleep architecture [30,31]. PSG arrangement and recording began each night at 9:00 p.m. for both conditions. Standard PSG equipment (Compumedics E Series, Melbourne) was arranged as follows: EEG (Oz and Cz positions); EOG (outer canthi of each eye); EMG (masseter and facial muscles); the earth electrode on the right clavicle. All signals were recorded using gold Grass electrodes with initial impedances below 10 kΩ. The PSG recordings were scored according to standard criteria of AASM [32] in 30-s epochs. Each epoch was assigned a stage of sleep (Stages 1–3, REM) or wake by a blinded scorer using Profusion 3 software (Compumedics E Series, Melbourne, Australia). From each sleep period, participants' total sleep time was calculated. Participants were continuously monitored throughout the study to ensure napping did not occur.

Statistical analyses

All statistical analyses were carried out using Stata 12.0 (StataCorp, Texas, USA). Exploratory data analysis was conducted to determine whether the data met parametric assumptions of normality and homoscedasticity. Each individual's performance scores were normalised to reflect changes from their individual specific baseline (as previously mentioned, pre-intervention task performance on day one of the simulation). Participant characteristics, total sleep hours, energy intake, hydration status, and caffeine consumption were normally distributed, thus one-way analyses of variance (ANOVA) were used to determine between-group differences. For all other variables, generalised linear mixed models (GLMMs) were constructed using the

Generalized Linear Latent and Mixed Model software (*gllamm;* version 2.3.20). This modelling procedure has previously been employed in sleep literature [9,33] and is increasingly preferred over traditional repeated-measures ANOVA, as GLMMs better account for the serial correlation of data points over time [34]. The *gllamm* also provides valid estimates in the presence of missing data, and uses maximum likelihood estimation with adaptive quadrature for more reliable parameter estimates than adaptive quadrature [35]. Readers are encouraged to seek out the comprehensive reviews of these procedures by Rabe-Hesketh [35,36], and a detailed comparison of linear mixed models and ANOVAs in sleep research [37].

Mixed effects models incorporate *fixed* effects that determine the influence of the experimental conditions (e.g., assignment to a CON or SR condition), alongside *random* effects that considers each individual as having a unique response to the intervention (e.g., inter-individual differences in response to periods of sleep restriction) [38,39]. Therefore, mixed models enable the distinction of between-subject (i.e, inter-individual) from within-subject (i.e, intra-individual) effects. The framework recommended by Singer [40] guided the construction of mixed models to iteratively investigate the fixed effects of Condition, Circuit, and the interaction of Condition × Circuit, with random intercepts and random slopes that varied at the Participant-level. All dependent variables exhibited a Gaussian distribution, thus the identity link function was specified [41]. The CON and SR conditions were coded 0 and 1, respectively. Therefore, a positive β value for the effect of Condition indicates CON > SR and a negative β value indicates SR > CON. For Circuit effects, a positive β value indicates an increase over successive circuits and a negative β value indicates a decrease. The random effects express the variance due to the inter-individual differences at baseline (random intercept) and over time (random effect of Circuit). Selection of the optimal model for each outcome variable was informed by comparing Akaike weights between candidate models as per the procedure outlined by [42]. If the Akaike weights between two competing models had similar probabilities of being the best model, the model with the fewest number of parameters was preferred in accordance with the principle of parsimony. The final parameter estimates are reported in-text as β coefficient ± standard error of the estimate (SE), *P* value. Statistical significance was set at $P \leq 0.05$ and all data are presented as means ± standard deviations unless otherwise stated.

Results

There was no difference between CON and SR in participants' age, body mass, body mass index, height, or years of service ($P \geq 0.110$; Table 1). There were no differences in ambient temperature (CON 19.2 ± 1.1°C; SR 19.6 ± 1.6°C; $P = 0.220$) or humidity (CON 55.8 ± 6.3%; SR 55.9 ± 6.8%; $P = 0.980$) between conditions.

Sleep hours

There were no differences between the two conditions in mean sleep duration obtained in the two days prior to the simulation ($P \geq 0.283$), nor on the pre-study adaptation night (CON 6.3 ± 0.9 h; SR 6.4 ± 0.7 h; $P = 0.726$. During the two experimental nights, mean sleep duration was lower in the SR (3.6 ± 0.3 h) condition compared to CON (6.9 ± 0.4 h; $P < 0.001$).

Physical task performance

Daily mean performance on each physical task is shown in Table 2. For all physical tasks, the fixed effect of Condition did not significantly improve upon the amount of variance explained by simpler models. Random slope models best explained variances in physical performance (Table 3). Fig. 1 demonstrates the inter-individual variability in lateral repositioning task performance, indicative of the same pattern observed for the other tasks. Participants in both

Table 2. Daily physical task performance during the physical work circuit.

Task	Condition	Day 1 (Baseline)	Day 2	Day 3
Charged hose advance (m)	CON	107.8 ± 24.1	111.2 ± 26.1	116.6 ± 30.2
	SR	99.9 ± 12.3	104.4 ± 16.1	108.0 ± 17.6
Blackout (m)	CON	169.4 ± 14.5	168.0 ± 15.9	166.8 ± 16.1
	SR	167.9 ± 16.0	167.0 ± 17.1	167.4 ± 18.6
Hose-rolling (m)	CON	18.7 ± 4.8	21.6 ± 5.6	24.8 ± 7.5
	SR	16.9 ± 3.6	19.0 ± 3.9	20.5 ± 5.0
Lateral Repositioning (m)	CON	631.4 ± 92.1	657.9 ± 86.1	689.8 ± 91.1
	SR	650.5 ± 76.7	656.5 ± 76.8	676.7 ± 73.3
Rake (m^2)	CON	5.0 ± 1.4	5.5 ± 1.5	5.6 ± 1.5
	SR	4.6 ± 0.6	4.9 ± 0.8	5.1 ± 0.8

doi:10.1371/journal.pone.0115329.t002

conditions successfully completed the 5-min static hold hose task during every two-hour period throughout the simulation, and therefore this data will not be reported.

Heart rate and core temperature

There was no effect of Circuit, Condition, or Condition × Circuit for average heart rate (%HR_{max}) across the two-hour work circuit ($P \geq 0.480$) or during the physical work component ($P \geq 0.490$) or rest period ($P \geq 0.270$). There was no effect of Circuit, Condition, or Condition × Circuit for peak heart rate (%HR_{max}) across the two-hour work circuit ($P \geq 0.800$) or during the physical work component ($P \geq 0.940$) or rest period ($P \geq 0.420$). Heart rate was also analysed for each individual physical task. For almost all tasks, the intercept-only and random slope models best explained variances in average and peak heart rate (Table 4). Peak heart rate during the black out hose task was best explained by the model including a single fixed effect for Circuit ($\beta = -0.21 \pm 0.08$; $P < 0.05$). For core temperature, the greatest relative likelihood was achieved by the full model with significant fixed effects for Condition ($\beta = -0.15 \pm 0.07$; $P < 0.05$) and Condition × Circuit ($\beta = 0.02 \pm 0.01$; $P < 0.05$).

Rating of perceived exertion and effort sensation scale

The intercept-only and random slope models best explained variances in rating of perceived exertion during the lateral repositioning, hose rolling, black out hose, and static hold tasks (Table 5). An interaction of Condition × Circuit was observed for rake and charged hose (Table 5). While this may suggest that those in the control group perceived these tasks to be more difficult over the course of the simulation, the parameter estimates were very small in

Table 3. Generalised linear mixed model parameter estimates for physical performance variables.

	Lateral Repositioning	Hose rolling	Rake	Charged hose advance	Black out hose
Fixed effects					
Intercept	2.05 (1.26)	1.31 (4.50)	8.17 (2.13)	2.71 (1.49)	−0.88 (0.90)
Random effects					
Intercept	37.40 (12.16)	484.95 (169.75)	115.55 (46.88)	110.03 (9.30)	26.27 (10.49)
Circuit	2.14 (0.57)	26.77 (7.36)	7.20 (2.20)	20.54 (17.97)	0.37 (0.20)
Residual	19.67 (1.67)	330.06 (27.94)	163.15 (13.83)	3.69 (1.21)	35.39 (3.02)

Data presented as: β parameter estimate (standard error).

doi:10.1371/journal.pone.0115329.t003

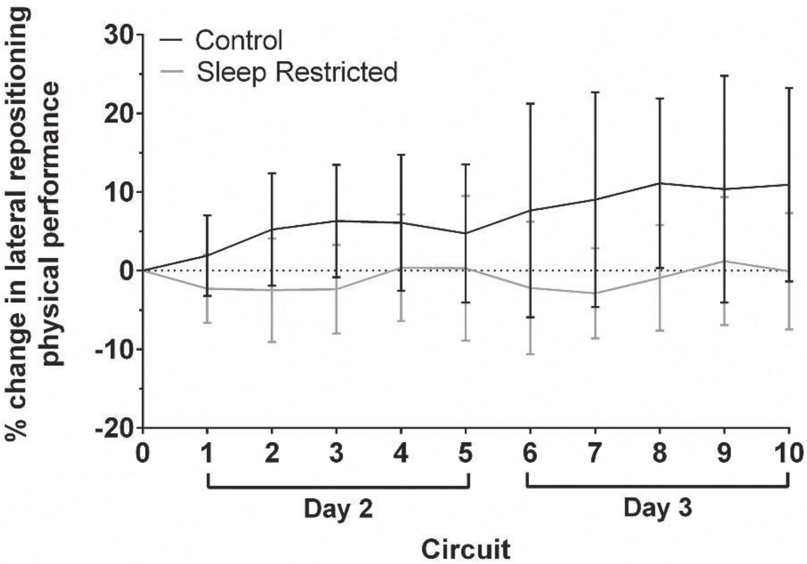

Figure 1. Lateral repositioning task performance during the multi-day simulation. Note the considerable inter-individual variability within both CON and SR groups at each time point, as denoted by the error bars (± 1 SD).

doi:10.1371/journal.pone.0115329.g001

magnitude and thus require cautious interpretation. The random slope model best explained variance in effort sensation ($\beta = 78.83 \pm 1.80$; $P < 0.05$).

Work activity

Total activity counts were summed for each two-hour work circuit. The two-hour work circuit was also divided into two major components: the physical work circuit and the rest period. The conditional growth model with random slopes best explained variance in activity throughout the two-hour work circuit (fixed effect of Condition: $\beta = 11.92 \pm 2.25$; $P < 0.05$; random effect of Circuit: $\beta = 1.22 \pm 0.58$). This was also the case for the physical work circuit (fixed effect of Condition: $\beta = 5.02 \pm 1.99$; $P < 0.05$; random effect of Circuit: $\beta = 3.24 \pm 0.97$). A main effect for Condition ($\beta = 20.50 \pm 4.34$; $P < 0.001$) was also evident during the rest period. These results indicate that the CON participants recorded greater activity during work and rest periods compared to the SR participants, and that activity counts during work periods increased over the course of the simulation. The percentage change in total activity counts relative to baseline across each two-hour work circuit is shown in Fig. 2.

Discussion

This study examined the effects of 4 hours of sleep restriction on firefighters' physical task performance, physiology, and perceptual responses during multi-day simulated wildfire suppression. The findings suggest that physical task performance was unaffected by 4 hours of sleep

Table 4. Generalised linear mixed model parameter estimates for average and peak heart rate for each physical task.

	Lateral Repositioning		Hose rolling		Rake		Charged hose advance		Black out hose		Static hold	
	Average	Peak	Average	Peak	Average	Peak	Average	Peak	Average	Peak	Average	Peak
Fixed effects												
Intercept	62.80 (1.34)	72.17 (1.62)	64.29 (1.37)	75.62 (1.58)	70.63 (1.29)	80.24 (1.36)	72.64 (0.53)	83.01 (1.75)	62.31 (1.43)	70.26 (1.60)	59.24 (1.46)	66.32 (1.49)
Circuit										0.21 (0.08)		
Random effects												
Intercept	61.91 (15.04)	89.28 (21.85)	67.08 (17.12)	85.64 (22.05)	54.99 (14.27)	57.80 (15.46)	71.17 (6.78)	100.25 (25.61)	65.24 (16.43)	82.58 (20.22)	77.78 (19.99)	80.64 (20.91)
Circuit			0.18 (0.08)	0.23 (0.10)	0.28 (0.10)	0.28 (0.11)	0.17 (0.07)	0.22 (0.10)	0.11 (0.05)		0.28 (0.10)	0.40 (0.14)
Residual	11.14 (0.84)	23.62 (1.79)	14.24 (1.13)	18.68 (1.49)	13.70 (1.09)	21.10 (1.69)	17.34 (1.36)	21.38 (1.70)	9.96 (0.79)	22.13 (1.67)	13.63 (1.09)	20.80 (1.66)

Data presented as: β parameter estimate (standard error).

doi:10.1371/journal.pone.0115329.t004

restriction. Heart rate, core temperature, and perceptual responses to these tasks were also largely unaffected by sleep restriction. However, sleep-restricted participants were significantly less active throughout the simulation compared to control participants.

Sleep restriction did not impact upon firefighters' physical work performance during multi-day simulated wildfire suppression. In addition, sleep restriction had limited effects on the physiological and perceptual measures, further supporting the assertion that there was no real difference in task performance. There were no observable differences between the groups in relative average and peak heart rate throughout the simulation. This finding is consistent with previous work, where resting average heart rate remained unchanged during partial sleep restriction [43]. Moreover, sub-maximal exercising heart rate was also unchanged following total sleep deprivation periods of 36 and 64 h [44,45]. Our findings indicate that core temperature was lower in the control group and decreased for all participants across the simulation. However, the parameter estimates are very small and therefore do not likely reflect a meaningful difference or change. This finding is consistent with previous investigations that have observed either no change [46,47] or a small decrease [48,49] in body temperature following sleep restriction. While the tasks that were included in the simulation were highly representative of those performed during actual fire suppression [11,18], it is possible that these physical tasks

Table 5. Generalised linear mixed model parameter estimates for perceptual measures for each physical task.

	Lateral Repositioning	Hose rolling	Rake	Charged hose advance	Black out hose	Static hold
Fixed effects						
Intercept	11.39 (0.13)	11.94 (0.19)	13.87 (0.29)	14.08 (0.36)	12.14 (0.15)	12.95 (0.26)
Condition			0.29 (0.40)	0.95 (0.50)		
Circuit		0.08 (0.01)	0.02 (0.02)	0.06 (0.03)		
Condition × Circuit			0.08 (0.03)	0.09 (0.04)		
Random effects						
Intercept	0.61 (0.15)	0.97 (0.25)	1.18 (0.30)	1.76 (0.45)	0.78 (0.20)	2.21 (0.55)
Residual	0.25 (0.02)	0.72 (0.05)	0.73 (0.06)	1.23 (0.09)	0.38 (0.03)	0.89 (0.07)

Data presented as: β parameter estimate (standard error).

doi:10.1371/journal.pone.0115329.t005

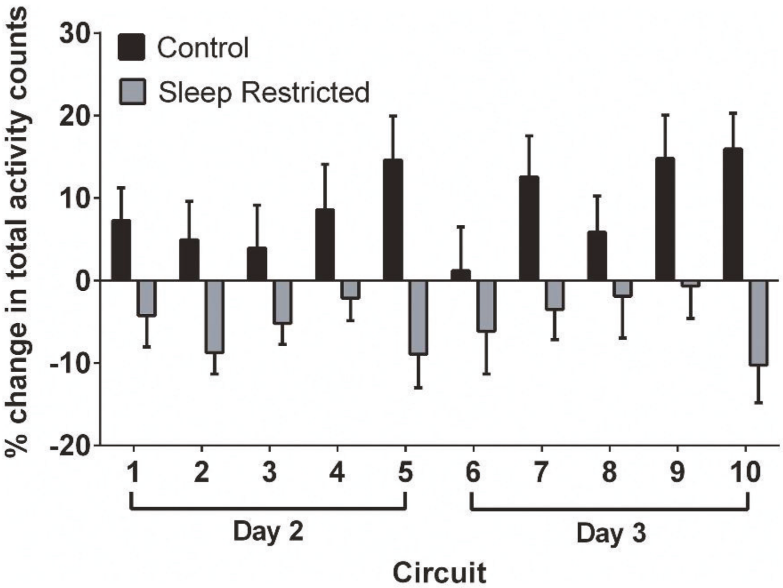

Figure 2. Percentage change in total activity counts relative to baseline across each two-hour work circuit.

doi:10.1371/journal.pone.0115329.g002

were not sensitive enough to detect changes in task performance following sleep restriction; further research is needed to test this assertion. However, the decision to select tasks that may be more sensitive to sleep restriction must be balanced against the intent to maintain a representative design [50], which is important to ensure that experimental observations can be generalised to a real wildfire suppression deployment. We contend that, if inadequate task sensitivity was the primary reason that performance decrements were not detected, the sleep restriction protocol should have had observable effects on other measures (i.e., the physiological and perceptual responses).

Effort sensation and RPE were also largely unaffected by sleep restriction. Previous research has noted an increase in RPE following total sleep deprivation [16] and sleep restriction [51]. However, the physical performance tasks in these investigations were of a significantly longer duration than the tasks used in the current study. Myles [52] concluded that total sleep deprivation had no effect on RPE following short-duration tasks (30 s), but that increases in RPE were observed when tasks were of a longer duration (15–50 min). The tasks in the current study were short and interspersed with rest periods, and the sleep restriction was less severe than the aforementioned protocols. The work tasks and work schedule in the current study, designed to simulate fireground work, resulted in no effect of 4 h of sleep restriction on RPE.

The literature seems to indicate that long-duration self-paced tasks may be impaired by sleep restriction [16,53], but maximal task performance can be maintained [15,16]. This suggests that task characteristics–intensity, duration, volume of active musculature, continuous or discontinuous, self-paced or externally paced–may moderate the effect of sleep restriction on physical work performance. Researchers investigating cognitive performance have concluded that the cognitive tasks most sensitive to sleep loss are long in duration, demand continuous attention, and have low predictability [54]. In addition, performance feedback has been shown to improve task performance by augmenting motivation levels in a serial reaction time task after one-night of total sleep deprivation [55]. On this basis, we suggest that the domain-specific nature of tasks may have been inherently interesting to firefighters and that the variable intensities, frequent task rotation, and repeated rest breaks may have enabled firefighters to maintain physical performance despite sleep restriction. Future research is required to investigate the impact of restricted sleep on isolated firefighting tasks performed consistently over a prolonged period (e.g., creating a fire break), and in the context of urgent, high-intensity work (e.g., protecting a home), where self-pacing may not be practicable.

Despite no between-group differences in self-paced task performance, decrements to worker activity in the sleep-restricted participants were evident during the rest periods. The between-condition difference was particularly pronounced during the rest periods; total activity counts were 20.5% greater for the control group compared to the sleep-restricted group. Given that no concurrent declines in task performance were apparent, it appears that sleep-restricted participants down-regulated their activity during periods when movement was not essential for task completion, i.e., during the rest periods provided between tasks within the physical work circuit or between circuits. It is plausible that the sleep restricted participants may have decreased their incidental activity during the rest periods. However, since activity was recorded in 1-min epochs and some of the tasks in the physical work circuit were shorter than this duration, the sampling rate did not allow more precise delineation between the work and rest components within each physical task.

It is unclear whether the sleep-restricted participants were actively adapting their behaviour, or whether reduced worker activity was observed following subconscious adaptations as a result of the fatigue induced by restricted sleep. In support of the former interpretation, competitive sporting literature suggests that the most important parameter for establishing pacing strategies is knowledge of the end-point of an activity [56,57]. In the current study, participants were aware of the demands expected of them, i.e., how many work circuits, task order, duration of task performance, and their opportunity for rest. Understanding these expectations may have allowed participants to modulate their behaviour so that the allocation of resources could be prioritised to the completion of the physical work tasks. However, if the sleep-restricted participants deliberately down-regulated their activity during the rest periods, it is not known whether this contributed to the preservation in physical task performance or simply occurred concurrently. Furthermore, we cannot conclude whether physical performance would continue to be maintained if tasks were more frequent, of higher intensity, or if the protocol was extended. Nevertheless, the activity data suggest that, despite the lack of performance differences between groups, the intervention had some influence on the sleep-restricted group. While potential explanations for this finding are discussed above, further research is required to explain how firefighters regulate their work behaviour throughout a multi-day wildfire deployment. This may involve describing the pattern of work behaviour in more detail, determining what information firefighters use to regulate their work behaviour and if these laboratory observations translate onto the fireground. This information is essential for fire agencies, especially when developing policy that informs shift lengths and the frequency of rest breaks during wildfire suppression deployments.

Conclusion

This is the first study to investigate the effects of sleep restriction on firefighters' physical performance. Our results indicate that two nights of 4 h sleep restriction did not adversely affect firefighters' performance of self-paced, physical work tasks. However, the sleep restricted group was less physically active, which could reflect behavioural adaptations made during rest periods, e.g., passive rest (such as sitting still and lying down) preferred over active rest activities (such as walking). Future research should examine how firefighters respond to sleep restriction over prolonged periods (> 2 nights of sleep restriction), under conditions where the sleep restriction is more severe (< 4 h per night), and when performing longer duration and/or high-intensity tasks. In addition, a greater understanding of how firefighters regulate their work behaviour patterns throughout a multi-day wildfire is essential. Further understanding of the effects of sleep restriction on firefighters' physical performance will enable fire agencies to manage their crews for improved health, safety, and productivity on the fireground.

Acknowledgments

The authors would like to acknowledge the Bushfire Co-operative Research Centre for providing financial and logistical support for this project. We would also like to thank all the firefighters that generously volunteered their time to participate in this research.

Author Contributions

Conceived and designed the experiments: BA SAF. Performed the experiments: GV BL AW. Analyzed the data: GV JT. Contributed reagents/materials/analysis tools: GV BA SAF AW BL JT. Wrote the paper: GV BA SAF AW BL JT.

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DEAKIN UNIVERSITY

Human Ethics Research

Office of Research Integrity
Research Services Division
70 Elgar Road Burwood Victoria
Postal: 221 Burwood Highway
Burwood Victoria 3125 Australia
Telephone 03 9251 7123 Facsimile 03 9244 6581
research-ethics@deakin.edu.au

Memorandum

To: Dr Brad Aisbett
School of Exercise and Nutrition Sciences

B

cc:

From: Deakin University Human Research Ethics Committee (DUHREC)

Date: 06 October, 2010

Subject: 2010-170
Awake, smoky and hot: Workplace stressors when fighting bushfires

Please quote this project number in all future communications

The application for this project was considered at the DU-HREC meeting held on 02/08/2010.

Approval has been given for Dr Brad Aisbett, School of Exercise and Nutrition Sciences, to undertake this project from 6/10/2010 to 6/10/2014.

The approval given by the Deakin University Human Research Ethics Committee is given only for the project and for the period as stated in the approval. It is your responsibility to contact the Human Research Ethics Unit immediately should any of the following occur:

- Serious or unexpected adverse effects on the participants
- Any proposed changes in the protocol, including extensions of time.
- Any events which might affect the continuing ethical acceptability of the project.
- The project is discontinued before the expected date of completion.
- Modifications are requested by other HRECs.

In addition you will be required to report on the progress of your project at least once every year and at the conclusion of the project. Failure to report as required will result in suspension of your approval to proceed with the project.

DUHREC may need to audit this project as part of the requirements for monitoring set out in the National Statement on Ethical Conduct in Human Research (2007).

Human Research Ethics Unit
research-ethics@deakin.edu.au
Telephone: 03 9251 7123

PLAIN LANGUAGE STATEMENT AND CONSENT FORM

TO: Participant

Plain Language Statement

Date: 1 September 2015

Full Project Title: Awake, smoky and hot: workplace stressors when fighting bushfires

Principal Researchers: Dr Brad Aisbett (Deakin University)
Associate Professor Sally Ferguson (CQUniversity)
Dr Sarah Jay (University of South Australia)

Associate Researcher(s): Dr Brad Smith (CQUni)
Mr Michael Crvin (CQUni)
Miss Madeline Spracjer (CQUni)
Miss Cara Lord (Deakin University)
Miss Brianna Larsen (Deakin University)
Miss Grace Vincent (Deakin University)
Mr Alex Wolkow (Deakin University)

Miss Sarah Jefferies (Deakin University)
Dr Luana Main (Deakin University)

Purpose:

The purpose of the proposed research is to investigate the individual and combined effects of heat, smoke and sleep restriction on firefighter performance during a simulated fireground tour.

Methods:

Participation in this project will involve a three-day campaign fire simulation at the Box Hill Town Hall, Melbourne. You will arrive by 1800 the first evening having kept a record of your sleep/wake/work patterns (by wearing a small monitor on your wrist and filling in a sleep diary) for the previous week. You will then spend the next four nights at the facility and undertake physical work tasks and computer-based tests every two hours during three, simulated, day-time shifts. During this time we will measure your blood pressure using an automated blood pressure machine, your level of dehydration (through assessment of your urine colour and concentration) and the volume of urine, your blood glucose (sugar) levels via a small fingertip sample of your blood and your stress hormones, through chewing on a cotton swab until it's very soggy and then spitting it into a tube. We will also assess your lung function which will involve breathing powerfully into a small machine; grip strength, where you will grip a machine as forcefully as you can and carbon monoxide exposure via two methods 1) breathing into a second type of machine and 2) having a fingertip oximiter attached to your finger for about a minute. Each sleep will be measured using a standard sleep recording procedure which requires small wires to be attached to your head and face. In addition, you will be asked to rate your effort, thermal sensation, motivation, feelings of hunger and food cravings at set times throughout the simulation. Following the simulation you will spend a 'recovery' night at the training college this will be followed by another 2 h bout of physical and computer-based testing before going home at approximately 1100 on Day Five. Prior to leaving the facility you will complete a one on one interview with a researcher (no longer than 15 min duration) about your experiences during the testing period. Finally, in the week following you will continue to record information about your sleep (timing, duration, quality) using the wrist monitor and sleep diary. You will participate in groups of five and be randomly allocated to one of eight different conditions involving various combinations of high heat, raised carbon monoxide levels and reduced total sleep time.

Demands:

The proposed research has been designed to approximate the demands placed on firefighters during suppression of multi-day bushfires. For this reason, you will be exposed to intermittent physically hard work, and cognitive tasks which challenge your attention, concentration and memory. Further, depending on the trial you participate in, you could be exposed to high day- and night-time temperatures, raised levels of carbon monoxide, or reduce sleep opportunities. Each of these environmental stressors is based on real fireground conditions.

In order to effectively assess your responses (physical, cognitive, subjective and physiological) to the experimental conditions you will be required to 'live' in the simulated environment and adhere to a strict schedule as dictated by the protocol. This means you will be instructed when to eat main meals, sleep and perform physical/cognitive task at specific times throughout each day. While cigarettes and caffeine will be permitted, you will be asked to consume them as you would during campaign bushfire suppression - this might mean smoking/drinking less than you would on a regular day. You will not be permitted to leave the facility nor will you be able to have visitors while you are there. You will however be able to maintain contact with family and friends through your mobile phone during non-testing times.

All food and drink will be provided for you during your visit, please do not bring your own food or drink onsite. If you have particular dietary requirements, please advise the researchers when you return your consent and medical forms to enable us to cater for you.

Potential risks to participants:

You will be performing strenuous physical exercise which has inherent risks such as musculoskeletal injury, heat stress, and sudden cardiac death. The risks are, however, very small due, in part, to the medical screening procedures used in the study where individuals with current musculoskeletal injuries or two or more risk factors for cardiovascular disease will be asked to seek medical authorisation before commencing testing. **All participants are encouraged to consider a medical check before participating in the research.** Further, the likelihood of these risks occurring is extremely low as the testing you will be undertaking is based on "real" work practices which you perform routinely when striving to curtail the spread of bushfire.

Exposure to hot working conditions can lead to heat stress, however, the conditions are similar to those faced during real fireground working conditions and as per fire agency guidelines, you will be provided with free access to food and fluid to manage your hydration status and limit your heat stress. Exposure to low levels of carbon monoxide (such as those proposed in this study) can be associated with headaches, dizziness and confusion. The current study will, however, be only using carbon monoxide levels that are consistent with those experienced on the fireground and are within Occupational Health and Safety guidelines for Australia and the United States of America. The levels of sleep restriction proposed for the current study are similar to those reported by firefighters during bushfire suppression. Though partial sleep deprivation is associated with impaired cognitive function which can lead to an increase in errors, your behaviours when partially sleep deprived will be closely monitored by the research team to ensure such errors do not lead to injury.

Expected benefits to wider community:

Research dedicated to understanding the impact that firefighters' working environment, namely temperature, air composition, and sleep periods is fundamental if fire agencies are going to implement policies to preserve the health and safety of their crew. The proposed research will provide an evidence-based from which Australian firefighting agencies can make informed decisions about management of risk associated with firefighters' work hours, workload and working conditions.

Privacy and confidentiality:

Your privacy and confidentiality will be preserved through a number of measures. Firstly, your interest and participation in, or withdrawal from will be largely anonymous. As you will be performing your testing within small groups of five, the other four members of your testing may, should you introduced yourself, know your identity. We ask, however, that all participants do not disclose the identity of any other participant without that individual's explicit consent. We will re-iterate the need to gain consent for revealing the identity of any other individual participant before testing commences. Secondly, your results and identity will be stored separately, such that the researchers will only refer to your data by your unique identifier code. Your data will be stored securely for a period of six years after the final publication of results, as per University guidelines. Thirdly, should you choose to withdraw from the research, your data and personal records will be destroyed immediately after receipt of your revocation of consent form (attached). Fourthly, your fire agency will have no record of your decision to participate in, or withdraw from the proposed research.

Dissemination of the research results:

The results from the proposed research will be presented in either a) oral presentation to fire industry or scientific audiences, b) written, peer-reviewed scientific journal articles, or c) Bushfire Co-Operative Research Centre (CRC) Firenote research briefings. In each case, only mean results will be reported and, as such, no individual results or identities will be revealed.

Research monitoring:

All research will be monitored by principal investigators Dr Brad Aisbett, Associate Professor Sally Ferguson and Dr Bradley Smith.

Payments to participants:

You will not be paid for your participation in the proposed research.

Sources of research funding:

The proposed research is funded by the three-year extension to the Bushfire CRC. Specifically, the project is part of the Occupational Health and Safety project, within the Managing the Threat program of the Bushfire CRC extension. The Bushfire CRC extension is funded by the Federal Government and by cash and in-kind contributions from organisations that form the Australasian Fire Authorities Council.

Should you have any questions, please contact

Dr Bradley Smith
Appleton Institute
Central Queensland University
Wayville SA 5034
Phone: 08 8378 4528 Mobile: 0412 630 675
Email : b.p.smith@cqu.edu.au

Complaints

If you have any complaints about any aspect of the project, the way it is being conducted or any questions about your rights as a research participant, then you may contact:

The Manager, Office of Research Integrity, Deakin University, 221 Burwood Highway, Burwood Victoria 3125, Telephone: 9251 7129, Facsimile: 9244 6581; research-ethics@deakin.edu.au
Please quote project number **[2010-*170]*.**

PLAIN LANGUAGE STATEMENT AND CONSENT FORM

TO: Participants

Consent Form

Date: 1/09/2015

Full Project Title: Awake, smoky and hot: Workplace stressors when fighting bushfires

Reference Number: [2010-*170].*

I have read and I understand the attached Plain Language Statement.

I freely agree to participate in this project according to the conditions in the Plain Language Statement.

I have been given a copy of the Plain Language Statement and Consent Form to keep.

The researcher has agreed not to reveal my identity and personal details, including where information about this project is published, or presented in any public form.

I give my specific consent to be filmed throughout testing and understand that the researchers may contact me again for my data to be used for other research purposes.

Participant's Name (printed)
……………………………………………………………………………………

Signature ……………………………………………Date …………………

Should you wish to return your consent form (and have lost your reply-paid envelope), please send the forms to:

Dr Brad Aisbett
School of Exercise and Nutrition Sciences
Deakin University
Burwood VIC 3125
Phone: 03 9244 6474 Fax: 03 9244 6017 Email:
brad.aisbett@deakin.edu.au

PLAIN LANGUAGE STATEMENT AND CONSENT FORM

TO: Participants

Revocation of Consent Form

(To be used for participants who wish to withdraw from the project)

Date: 1/09/2015

Full Project Title: Awake, smoky and hot: Workplace stressors when fighting bushfires

Reference Number: [2010-*170]*.

I hereby wish to WITHDRAW my consent to participate in the above research project and understand that such withdrawal WILL NOT jeopardise my relationship with Deakin University or Country Fire Authority.

Participant's Name (printed) …………………………………………………………………………………..

Signature ……………………………………………………Date …………

Please mail or fax this form to:

Dr Brad Aisbett
School of Exercise and Nutrition Sciences
Deakin University
Burwood VIC 3125
Phone: 03 9244 6474 Fax: 03 9244 6017 Email: brad.aisbett@deakin.edu.au

MEDICAL SCREENING QUESTIONNAIRE

Awake, Smoky and Hot Medical Screening Questionnaire

Name_______________________________________

1. What is your age?____________ years

2. Gender:

   Male ☐

   Female ☐

3. Domestic status:

   Married / Living with a partner ☐

   Separated / Divorced ☐

   Widowed ☐

   Single ☐

4. Do you have children living at home with you?

   Yes ☐

   No ☐

   If yes, how many? ______ and how old are they?

   1)_______ 2)_______ 3)_______ 4)_______ 5) _______

5. Do you consume caffeinated products (e.g., coffee, tea, cola, energy drinks, chocolate bars etc.)?

   Yes ☐

   No ☐

   If YES, adding all of these together, how many items do you normally consume each day?

   ____

6. Do you describe yourself as a:

    Regular smoker (I smoke one or more cigarettes per day) ☐

    Occasional (I do not smoke every day) ☐

    Ex-smoker (I have never smoked regularly) ☐

    Non-smoker (I have never smoked regularly) ☐

7. How often do you drink alcohol?

    Never ☐

    Less than once per week ☐

    Once or twice per week ☐

    Once every two days ☐

    Daily ☐

8. On a typical drinking occasion, how many drinks do you have?

    (One drink equals a glass of beer, a glass of wine or a shot of liquor).

    None ☐

    Less than 2 drinks ☐

    2-4 drinks ☐

    5-6 drinks ☐

9. Have you travelled overseas in the last four weeks?

    Yes ☐

    No ☐

    If YES, when and where did you travel?

    ____

    ____

10. Are you currently undertaking any form of regular exercise?

    Yes ☐

    No ☐

    If YES, briefly describe the type and amount (i.e., frequency, duration) of exercise you perform:

____

____

WORK

11. Are you, or have you ever been, involved in shift work?

Yes ☐

No ☐

If YES, when were you involved in shift work, and for how long?

12. Are you currently employed?

Yes ☐

No ☐

If YES, what is your current occupation?

____

13. How often do you work?

Full-time ☐

Part-time ☐

Casual ☐

Seasonal ☐

Self-employed ☐

FIREFIGHTING HISTORY

14. Years of firefighting experience (volunteer and/or salaried)?

____

15. How long have you been a member of the CFA?

____

16. What training have you completed?

____

17. Approximate number of campaign deployments?

____

18. When were you last called for a job to which you responded/attended?

____

HEALTH

19. Do you have a history of:	Yes	No	Don't Know
Serious accident, head injury or concussion?	☐	☐	☐
Epilepsy or other neurological disorders?	☐	☐	☐
Unexplained loss of consciousness?	☐	☐	☐
Migraine headaches?	☐	☐	☐
Respiratory problems?	☐	☐	☐
Chronic depression or another psychiatric problem?	☐	☐	☐
Cardiovascular disease (e.g., heart attack, stroke)?	☐	☐	☐
Blood disorder?	☐	☐	☐
Substance abuse?	☐	☐	☐
Recreational drug use?	☐	☐	☐

20. Has anyone ever told you that you?	Yes	No	Don't Know
Are overweight?	☐	☐	☐
Have high blood pressure?	☐	☐	☐
Have a heart murmur?	☐	☐	☐
Are asthmatic?	☐	☐	☐
Are diabetic?	☐	☐	☐

21. Have you ever had?	Yes	No	Don't Know
Chest pain, chest discomfort, chest tightness or chest heaviness?	☐	☐	☐
Shortness of breath out of proportion to exercise undertaken?	☐	☐	☐
Sensations of abnormally fast and/or irregular heart beat?	☐	☐	☐

Episodes of fainting, collapse or loss of consciousness?	☐	☐	☐
Abnormal bleeding or bruising?	☐	☐	☐

22. Have you ever suffered any musculoskeletal injury or had a disorder that has impaired your movement or functioning?

    Yes ☐

    No ☐

    Don't Know ☐

    If YES, please elaborate:

    ____

    ____

If you answered 'yes' to any parts of Questions 20, 21 and 22 above, please provide details regarding any restrictions or cautions that may need to be taken during the course of the study.

____

____

____

---

23. Do you have a cardiac pacemaker or other implanted electro-medical device?

    Yes ☐

    No ☐

    Don't Know ☐

    If YES, please elaborate:

    ____

    ____

24. Are you currently taking any medications?

    Yes ☐

    No ☐

    If YES, please list the medications:

____

____

25. Do you have any allergies (e.g., to any food, tapes or bandaids (adhesives), latex etc.)

Yes ☐

No ☐

If YES, please list the allergies:

____

____

26. Will you be having a medical procedure or travelling by aeroplane in the next month?

Yes ☐

No ☐

Don’t Know ☐

SLEEP

27. How many hours of sleep do you need to feel rested?

________ hours

28. How satisfied are you with the amount of sleep you get?

Very dissatisfied 1 2 3 4 5 6 7 8 9 10 Very Satisfied

29. Overall, how would you rate the quality of your sleep?

Very poor ☐

Poor ☐

Fair ☐

Good ☐

Very good ☐

Excellent ☐

30. Have you ever been diagnosed with a sleeping problem?

Yes ☐
No ☐

If YES, please describe

____

____

31. How often do you take naps?
(e.g., never, occasionally, once a day, twice a week)

____

32. How likely are you to doze off or fall asleep in the following situations, in contrast to feeling just tired? (This refers to your usual way of life in recent times. If you have not performed a listed activity, make a guess at what you are likely to do during that activity)
PLEASE TICK ONE BOX PER LINE

	Would never doze	Slight chance	Moderate chance	High chance
Sitting and reading	0 ☐	1 ☐	2 ☐	3 ☐
Watching TV	0 ☐	1 ☐	2 ☐	3 ☐
Sitting inactive in a public place (e.g., theatre, meeting)	0 ☐	1 ☐	2 ☐	3 ☐
As a passenger in a car for an hour without a break	0 ☐	1 ☐	2 ☐	3 ☐
Lying down in the afternoon when circumstances permit	0 ☐	1 ☐	2 ☐	3 ☐
Sitting and talking to someone	0 ☐	1 ☐	2 ☐	3 ☐
Sitting quietly after lunch <u>without</u> alcohol	0 ☐	1 ☐	2 ☐	3 ☐
In a car, while stopped for a few minutes in traffic	0 ☐	1 ☐	2 ☐	3 ☐

33. Please answer the following in relation to sleep timing

- Please read each question very carefully before answering.
- Please answer each question as honestly as possible.
- Answer ALL questions
- Each question should be answered independently of others. Do NOT go back and check your answers.

- What time would you get up if you were entirely free to plan your day?

  5:00 – 6:30 AM ☐
  6:30 – 7:45 AM ☐
  7:45 – 9:45 AM ☐
  9:45 – 11:00 AM ☐
  11:00 – 12 Noon ☐
  12 Noon – 5:00 AM ☐

- What time would you go to bed if you were entirely free to plan your evening?

  8:00 – 9:00 PM ☐
  9:00 – 10:15 PM ☐
  10:15 – 12:30 AM ☐
  12:30 – 1:45 AM ☐
  1:45 – 3:00 AM ☐
  3:00 AM – 8:00 PM ☐

- If there is a specific time at which you have to get up in the morning, to what extent do you depend on being woken up by an alarm clock?

  Not all dependent ☐
  Slightly dependent ☐
  Fairly dependent ☐
  Very dependent ☐

- How easy do you find it to get up in the morning (when you are not woken up unexpectedly)?

  Not all easy ☐

Not very easy ☐
Fairly easy ☐
Very easy ☐

- How alert do you feel during the first half-hour after you wake up in the morning?

  Not all alert ☐
  Slightly alert ☐
  Fairly alert ☐
  Very alert ☐

- How hungry do you feel during the first half hour after you wake up in the morning?

  Not all hungry ☐
  Slightly hungry ☐
  Fairly hungry ☐
  Very hungry ☐

- During the first half-hour after you wake up in the morning, how tired do you feel?

  Very tired ☐
  Fairly tired ☐
  Fairly refreshed ☐
  Very refreshed ☐

- If you have no commitments the next day, what time would you go to bed compared to your usual bedtime?

  Seldom or never later ☐
  Less than one hour later ☐
  1 – 2 hours later ☐
  More than two hours later ☐

- You have decided to engage in some physical exercise. A friend suggests that you do this for one hour twice a week and the best time for him is between 7:00 – 8:00 am. Bearing in mind nothing but your own internal “clock”, how do you think you would perform?

Would be in good form ☐
Would be in reasonable form ☐
Would find it difficult ☐
Would find it very difficult ☐

- At what time of day do you feel you become tired as a result of need for sleep?

8:00 – 9:00 PM ☐
9:00 – 10:15 PM ☐
10:15 PM – 12:45 AM ☐
12:45 – 2:00 AM ☐
2:00 – 3:00 AM ☐

- You want to be at your peak performance for a test that you know is going to be mentally exhausting and will last for two hours. You are entirely free to plan your day. Considering only your own internal “clock”, which ONE of the four testing times would you choose?

8:00 AM – 10:00 AM ☐
11:00 AM – 1:00 PM ☐
3:00 PM – 5:00 PM ☐
7:00 PM – 9:00 PM ☐

- If you got into bed at 11:00 PM, how tired would you be?

Not at all tired ☐
A little tired ☐
Fairly tired ☐
Very tired ☐

- For some reason you have gone to bed several hours later than usual, but there is no need to get up at any particular time the next morning.

Which ONE of the following are you most likely to do?

Will wake up at usual time, but will NOT fall back asleep ☐

Will wake up at usual time and will doze thereafter ☐

Will wake up at usual time but will fall asleep again ☐

Will NOT wake up until later than usual ☐

- One night you have to remain awake between 4:00 – 6:00 AM in order to carry out a night watch. You have no commitments the next day. Which ONE of the alternatives will suite you best?

  Would NOT go to bed until watch was over ☐

  Would take a nap before and sleep after ☐

  Would take a good sleep before and nap after ☐

  Would sleep only before watch ☐

- You have to do two hours of hard physical work. You are entirely free to plan your day and considering only your own internal "clock" which ONE of the following time would you choose?

  8:00 AM – 10:00 AM ☐

  11:00 AM – 1:00 PM ☐

  3:00 PM – 5:00 PM ☐

  7:00 PM – 9:00 PM ☐

- You have decided to engage in hard physical exercise. A friend suggests that you do this for one hour twice a week and the best time for him is between 10:00 – 11:00 PM. Bearing in mind nothing else but your own internal "clock" how well do you think you would perform?

  Would be in good form ☐

  Would be in reasonable form ☐

  Would find it difficult ☐

  Would find it very difficult ☐

- Suppose that you can choose your own work hours. Assume that you worked a FIVE hour day (including breaks) and that your job was interesting and paid by results). Which FIVE CONSECUTIVE HOURS would you select?

5 hours starting between 4:00 AM and 8:00 AM ☐
5 hours starting between 8:00 AM and 9:00 AM ☐
5 hours starting between 9:00 AM and 2:00 PM ☐
5 hours starting between 2:00 PM and 5:00 PM ☐
5 hours starting between 5:00 PM and 4:00 AM ☐

- At what time of the day do you think that you reach your "feeling best" peak?

5:00 – 8:00 AM ☐
8:00 – 10:00 AM ☐
10:00 AM – 5:00 PM ☐
5:00 – 10:00 PM ☐
10:00 PM – 5:00 AM ☐

- One hears about "morning" and "evening" types of people. Which ONE of these types do you consider yourself to be?

Definitely a "morning" type ☐
Rather more a "morning" than an "evening" type ☐
Rather more an "evening" than a "morning" type ☐
Definitely an "evening" type ☐

34. Do you have any other condition or injury not previously mentioned that the researchers should be aware of (i.e., that would prevent you from undertaking your normal duties)?

Yes ☐
No ☐

If YES, please describe

____

____

Thank you for taking the time to fill in this questionnaire

I believe the information I have provided to be true and correct.

SIGNED:______________________

DATE:________________________

This project is funded by the Bushfire CRC and CFA is in full support of this research

PHYSICAL WORK CIRCUIT ORDER

TIME (min) ↓	FF 1	FF 2	FF 3	FF 4	FF 5
0 – 5	LAT 1	BOH	LAT 2	CHA	RAKE
5 – 10	REST	LAT 1	BOH	LAT 2	CHA
10 – 15	HOSE	REST	LAT 1	BOH	LAT 2
15 – 20	LAT 2	HOSE	REST	LAT 1	BOH
20 – 25	BOH	LAT 2	HOSE	REST	LAT 1
25 – 30	LAT 1	BOH	LAT 2	HOSE	REST
30 – 35	RAKE	LAT 1	BOH	LAT 2	HOSE
35 – 40	CHA	RAKE	LAT 1	BOH	LAT 2
40 – 45	LAT 2	CHA	RAKE	LAT 1	BOH
45 – 50	BOH	LAT 2	CHA	RAKE	LAT 1
50 – 55	STAT	STAT	STAT	STAT	STAT

Key: LAT 1 = Lateral repositioning first 30s; LAT 2 = Lateral repositioning second 30s; BOH = Black out hose; HOSE = Hose-rolling; CHA = Charged hose advance; RAKE = Rake; STAT = Static hose hold

RPE SCALE

6	No exertion at all
7	
	Extremely light
8	
9	Very light
10	
11	Light
12	
13	Somewhat hard
14	
15	Hard (heavy)
16	
17	Very hard
18	
19	Extremely hard
20	Maximal exertion