OPERATIONAL READINESS OF RURAL FIREFIGHTERS DURING BUSHFIRE SUPPRESSION

FINAL PROJECT REPORT

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Cover:
Left – A firefighter undertaking a hose role task as part of the laboratory-based simulation. Photo by the Bushfire CRC.
Right – Firefighters at work in hot and smoky conditions. Photo by CFA Communities and Communication.

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Executive Summary

Background, Aim and Objectives

Devastating bushfires have crippled communities across the world in the past decade. Many predict that the severity and frequency of bushfire is on the rise. Hotter weather and more intense fires requiring longer shifts and more frequent deployments represent significant threats to the operational readiness of the volunteers and salaried staff of Australasia's fire and emergency services. Safeguarding workers' operational readiness relies, in part, on a robust, relevant evidence-base from which to build policies and procedures. Accordingly, the aim of the current project was to conduct industry-specific research to assist the fire industry to develop comprehensive policy, best practice guidelines, and training and educational materials to preserve the health and safety of their firefighters during multi-day bushfire suppression deployments. This aim was underpinned by targeting three specific objectives:

- Work with key fire industry informants to validate a three-day bushfire suppression tour simulation;
- Investigate the impact of, and interaction between, multiple fireground stressors (i.e., sleep disruption, heat and smoke) on firefighters' physiological responses, physical and cognitive work performance across a simulated three-day bushfire suppression tour;
- Present the research findings to key fire industry stakeholders to inform comprehensive policy, best practice guidelines, and training and educational materials for the preservation of firefighters' health and safety.

State of Knowledge

The decision to develop and validate a novel, four-day bushfire suppression was based primarily, on the limitations of the existing evidence-base. Previous research had focussed on understanding human responses to shortened sleep, exposure to smoke (and its constituent elements) and high temperatures. However, the data had often been collected using tasks, environments or durations that bear little resemblance to the working demands or conditions faced by Australasia's rural and regional firefighting force. The available evidence showed that high temperatures and shortened sleep consistently degraded physical and cognitive performance respectively. However, cognitive performance was rarely measured concurrently with exercise so it was unclear whether the adverse impact of shortened sleep would be moderated or exaggerated by the physical work firefighters' perform across a shift. Further, there was very little research to conclusively indicate

whether shortened sleep would adversely impact firefighters' physical work or whether heat exposure and concurrent physical work would impair cognitive function. Finally, very few studies have examined the impact(s) that the combination of shortened sleep and high temperatures has on physical or cognitive performance. The laboratory simulation study was accompanied by; novel investigations into the amount of sleep firefighters experienced during campaign bushfire deployments and the development of a prototype for assessing firefighters' physical operational readiness for bushfire suppression.

Progression of Research

A novel, laboratory-based simulation of the work completed on a typical fireground deployment was designed, refined, and evaluated through repeated consultation with members of the Australasian fire and emergency services. Once implemented, 91 rural firefighters (83% volunteer, 17% career) participated in the laboratory simulation studies. These participants spanned five state-based fire authorities and land management agencies. Their average age was 38 ± 14 years had served in a firefighting role for 11 ± 9 years. The study protocol spanned four days, including a study briefing, familiarisation of the tasks, and adaption to sleeping conditions (stretcher bed and sleep monitoring equipment) on the evening prior to testing, three consecutive day 'shifts', followed by a morning testing session on day four. Participants (maximum five per study) lived in a simulated environment for the duration of the study (including physical tasks, rest breaks, meals, and sleeping) and were asked to remain inside excluding when smoking or using amenities that were located outside. During the daytime, participants adhered to a strict schedule, completing 14, 2-hour testing sessions over four days. Each session consisted of 50 min of physical work designed to mimic fireground tasks followed by physiological testing lasting 20 min and a cognitive test battery lasting 20 min. Both the physical and cognitive tasks were developed using a combination of published research and close consultation with incumbent firefighters. Testing sessions were completed in full protective clothing. At the conclusion of the last physical task in each 50-min physical circuit, firefighters were tested on a series of physiological measures, including salivary cortisol. Heart rate, core and skin temperature were measured continuously through each day and night. Urine was collected across the duration of the study to measure firefighters' hydration status. On completion of each day, participants were provided dinner and allocated free time until bedtime (e.g., read book, watch movies). Sleep quality and quantity were measured each night using a sleep diary, wrist actigraphy, and polysomnography.

Research Results

The laboratory simulation, field and operational readiness prototype research produced a number of results. The key findings from each major area of study were;

- Researchers and agencies should promote and document end-user engagement when designing simulations;
- There was no adverse impact of consecutive nights of moderate sleep restriction on physical work, physiology or perceived exertion performed in temperate conditions;
- There was no adverse impact of consecutive nights of moderate sleep restriction on self-paced physical work, physiology or perceived exertion in hot conditions;
- Firefighters may have offset the adverse impact of high temperatures on their physical work by increasing their fluid intake before and during their work in hot conditions;
- Two consecutive nights of shortened sleep significantly increase firefighters' acute cortisol levels outside normal reference ranges;
- Shortened sleep in hotter temperatures was associated with less 'deep' sleep, compared to milder temperatures.
- When fatigued through shortened sleep, firefighters could identify their cognitive performance was declining, but could not identify the degree of their impairment;
- Firefighters' receive significantly less sleep and lower sleep efficiency when away on campaign deployment compared to sleeping at home.

Project Outputs

To date, the project has delivered 41 outputs to the Australasian Fire and Emergency Services sector. These outputs span; peer-review journal articles, industry-focused reports, conference oral and poster presentations, and invited seminars. In the coming months, a suite of scientific manuscripts will be submitted for peer-review and publication. The current and future outputs collectively represent a significant step forward in the available evidence-base agencies can use to promote and preserve the operational readiness of their personnel.

State of Knowledge - Now

The synthesis of laboratory and field research outputs revealed three priority areas for Australasia's fire and emergency services to consider. There issues are;

- When workers are sleep deprived and working in hot conditions, agencies should contemplate additional safety measures for workers performing tasks requiring hand-eye co-ordination and externally paced, but monotonous physical work;
- Firefighters' sleep is shortened on the fireground. Their sleep restriction is having adverse outcomes on their cognitive performance, self-assessment of their work, and their body's physiological stress reactions. To minimise these negative outcomes, the sector should, where possible, continue to quarantine an 8-h sleep (not just 'off work') opportunity between consecutive shifts;
- In mild temperatures (15 - 20°C), firefighters working to suppress bushfires are consuming approximately 300 mL of fluid (both water and carbohydrate-electrolyte solutions) per hour. In hotter temperatures (> 33°C) their intake almost doubles to approximately 600 mL per hour. In both temperature ranges, these self-paced drinking rates (together with snacks and meals) appear sufficient to maintain (and in some cases restore) firefighters' hydration levels. Agencies should consider these values when planning the logistics of fluid supply for their workers on deployments. Further, the sector should strive for a more uniform set of fluid intake recommendations that educate personnel on the benefits of self-paced drinking.

The current project also generated a number of new, industry-relevant research questions for further discussion, including;

- What are the interactions between sleep, physical and cognitive work when firefighters are completing night or afternoon shift cycles;
- Does self-paced drinking continue to preserve firefighters' physical work and physiological responses in very hot conditions (e.g., > 45°C);
- What are the sleeping (and next day performance) implications for sleeping in very hot (> 28°C) night time temperatures.

To help answer the next generation of 'operational readiness' research questions, the current project also left an enduring legacy. Specifically, the successful completion of five honours students, with five doctoral students (all with applied sleep or work physiology interests) to submit their theses in the next 12 months; an ongoing nexus with the Australasian Fire Authorities Council (AFAC) Worker Health and Safety Technical Group; and emergency service worker health and safety research hubs at Deakin University, Melbourne and Central Queensland University, Adelaide.

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1 Introduction

1.1 Overview

Australia is consistently ravaged by bushfire and over the last decade, bushfires in New South Wales, the Australian Capital Territory, South Australia, Tasmania, and Victoria have claimed lives, destroyed homes and crippled communities [1]. Volunteer and career firefighters safeguard Australians from the annual threat of bushfires. With the ever-increasing threat and severity of bushfire [2] the demands on Australia's fire and emergency service workers are at an all-time high.

On the fireground, firefighters face a number of occupational and environmental stressors. They can work long hours during both day and night shift, often with little rest between consecutive shifts [3]. Across each shift, firefighters are required to perform intermittent, intense physical labour [4, 5] often in hot [6] and smoky [7] conditions, whilst remaining alert and vigilant to make critical decisions in life threatening situations and/or amid the personal suffering of others [8].

For fire agencies, managing the health and safety of personnel during bushfire suppression requires information about the impact of a range of stressors. In isolation, factors such as heat, smoke (or its constituent elements), and sleep disruption can have a detrimental impact on cognitive and physical work capacity [9-12]. However, previous research has generally been conducted using tasks, environments or durations that bear little resemblance to the working demands and conditions faced by Australasia's rural firefighting force. Research using participants from the general population can provide valuable insights into basic human cognition and physiology, however, applied research using incumbent firefighters is required for two key reasons:

a) to capture the interactions between human physiology/cognition and job specific skills and expertise, and

b) aid the process of research adoption by optimising the face validity [13] of the evidence-base.

1.2 Project Aims and Objectives

To this end, the **Operational Readiness of rural firefighters during bushfire suppression** (referred to hereafter as Operational Readiness) project has undertaken a detailed investigation of fireground stressors and strains, particularly in the areas of sleep and work physiology. These investigations were made possible through development of a novel simulation of fireground work.

The specific aim of the project was to conduct industry-specific research to assist the fire industry to develop comprehensive policy, best practice guidelines and training and educational materials to preserve the health and safety of their firefighters during multi-day bushfire suppression deployments.

This aim was met through three specific **objectives**:

1. Work with key fire industry informants to validate a three-day bushfire suppression tour simulation;
2. Investigate the impact of, and interaction between, multiple fireground stressors (i.e., sleep disruption, heat and smoke) on firefighters' physiological responses, physical and cognitive work performance across a simulated three-day bushfire suppression tour;
3. Present the research findings (from 2, above) to key fire industry stakeholders to inform comprehensive policy, best practice guidelines, and training and educational materials for the preservation of firefighters' health and safety.

The project has delivered on all three objectives. The research findings are presented in section 4 and the associated outputs in section 5. As will be discussed in the report, while objective two was modified to exclude smoke conditions, the breadth of sleep and work physiology findings documented herein (Section 4 and 6) represents a significant step forward in the ongoing development of a robust, contemporary health and safety evidence-base for the Australasian fire and emergency services sector. In the case of objective three, the project team will continue to work with the Australasian fire and emergency services sector beyond the conclusion of the Bushfire Co-Operative Research Centre (CRC) extension program.

2 State of knowledge

The current project emerged, as such projects invariably do in applied research contexts, from a series of discussions between agencies, professional bodies, AFAC and the Bushfire CRC. The discussions centred on what it means for firefighters to be 'operationally ready'. Agencies face continued challenges in responding to emergency incidents while maintaining health, safety and well-being of their personnel. For volunteer and salaried firefighters responding to bushfires, the risks to health and safety come not only from the direct interaction with the fire, but from a multitude of other environmental and occupational sources. The current program of work sought to provide an evidence-base to assist agencies assess and make decisions about operational readiness for their workers.

Prior to this program of work, no study had assessed the integrative effect that multiple stressors have on work performance during bushfire suppression. The few studies that have attempted to quantify the impact of multiple stressors in controlled laboratory settings indicate that when combined, heat and sleep deprivation [14-16], and sleep deprivation and sustained exercise, have a detrimental effect on cognitive work [17, 18]. Very few studies have assessed the impact of multiple stressors on physical work performance or when work tasks involve both cognitive and physical elements as they do on the fireground.

Given the dearth of definitive research in these areas, the initial outputs from the Operational Readiness project (see Section 5) were focussed on capturing and critiquing the available evidence-base. The reader is referred to the following publications for a rigorous review of the state of knowledge;

- Aisbett B, Wolkow A, Sprajcer M, Ferguson SA. [19] '"Awake, smoky, and hot": providing an evidence-base for managing the risks associated with occupational stressors encountered by wildland firefighters' Applied Ergonomics; 43(5): 916 – 925', Impact Factor (IF): 1.467, http://www.sciencedirect.com/science/article/pii/S000368701200004X
- Jay SM, Aisbett B, Sprajcer M, Ferguson SA. [20] 'Sleeping at work: not all about location, location, location' Sleep Medicine Reviews (Available May 2nd, 2014), IF: 8.62, http://www.sciencedirect.com/science/article/pii/S1087079214000446

In the remainder of this section, the knowledge base before the Operational Readiness project is briefly presented, with key limitations identified. For comprehensive, but industry-focussed critiques of the background research and practice in the areas of simulation design, physical and cognitive performance, and sleep the reader is also referred to the following project outputs (matched to each of the proceeding sections and all available through the Bushfire CRC website);

Section 2.1

Ferguson et al. (2011) Design of a valid simulation for researching physical, physiological and cognitive performance in volunteer firefighters during bushfire deployment. http://www.bushfirecrc.com/sites/default/files/managed/resource/196-204_simulation_development_for_industry.pdf;

Section 2.2 & 2.3

Ferguson & Aisbett (2013) 'Awake, Smoky, and Hot - fighting fire without fire'. http://www.bushfirecrc.com/sites/default/files/managed/resource/ash_fire_note_111_final_low_res.pdf

Section 2.4

Jay et al. (2013) 'Sleep and the operational readiness of rural firefighters during bushfire suppression'
http://www.bushfirecrc.com/sites/default/files/managed/resource/sleeping_in_the_field_project_resource_final_0.pdf

2.1 Simulation Design

To investigate whether typical fireground occupational and environmental stressors adversely impacted firefighters' cognitive and physical work, the project team conceived and implemented a fireground simulation. Simulation involves the imitation or reproduction of situations or processes with the use of analogous settings and equipment. The accuracy or 'fidelity' of the simulation describes it's resemblance to the job and/or task [21]. Many different dimensions of fidelity are discussed in the literature. For example, equipment fidelity typically refers to whether the real technologies of work are recreated faithfully, and psychological fidelity typically refers to the degree of perceived realism from the perspectives of the participants within the simulation [22, 23]. Though simulation design and fidelity assessment are commonplace in training and learning, there are few examples of this approach being applied to research. In contrast to training, ultra-high fidelity simulations can threaten experimental control and any application of the ensuing results, and therefore may not be optimal for research [24]. To test the key outcome variables (e.g., physical and cognitive performance) in the Operational Readiness project, the **researchers needed to strike a balance between maximising the various dimensions of fidelity and the rigours of experimental control.**

2.2 Physical performance

Fighting bushfires is physical work [25]. Degradation in workers' physical performance can increase their individual risk of injury, put more pressure on other crew members, and/or slow the overall suppression effort [19]. Physical performance can be impaired by a number of occupational and environmental stressors, including high ambient temperatures [26, 27] and restricted sleep opportunities [28, 29]. Research using laboratory and field simulations of sport show that high temperatures can slow physical work-rates or shorten task performance [30]. The type of tasks simulated, including their intensity, movement patterns and durations, bear little resemblance to the fireground. Specifically, there was a dearth of studies examining physical work performance in hot temperatures across several days of long duration work. Similarly, there was almost no research examining the impact of sleep restriction on physical performance. The limited research comes from laboratory settings using short duration tasks which report no changes in ultra-short maximal efforts [29]. In contrast, long duration, self-paced performance was reported to change under conditions of sleep restriction or deprivation [28]. In the main, firefighters suppressing bushfires in Australia perform neither explosive, one-off maximal efforts nor long-duration self-paced work [31]. As such, dedicated study was required to quantify the implications for sleep-deprived workers repeatedly performing intense (but not maximal) short duration tasks across a 12-h shift. The Operational Readiness project, therefore, sought to **identify whether work performance on simulated firefighting tasks changes under conditions of high ambient heat and sleep restriction.**

2.3 Cognitive Performance

Firefighting also requires cognitive faculties [32] . Across a shift firefighters engage both simple (e.g., vigilance) and complex (e.g., decision making) cognitive tasks [33, 34]. Previous research shows that these functions, together with communication, hand-eye co-ordination and situational awareness, can be impaired by high ambient temperatures, shortened sleep, and long periods awake [17-19, 35, 36]. The evidence-base is comprised, nearly exclusively, of applied and laboratory studies where participants are <u>only</u> performing cognitive tasks. On the fireground, workers complete their cognitive functions during, after, and between prolonged and sometimes intense bursts of physical activity. The effects of physical activity on cognitive performance have been reported to be beneficial for both simple and complex tasks, but work duration can moderate this relationship [37, 38]. For instance, moderate intensity exercise can facilitate information processing, but if that work is prolonged, cognitive performance degrades [37, 38]. Further, participants often 'feel' that exercise can improve cognitive performance when their sleep is restricted, but their 'actual' performance is worse [39]. A mismatch between perceived and actual alertness, awareness or comprehension could have devastating effects on the fireground. The Operational Readiness project sought to **identify how subjective and objective cognitive performance between bouts of physical activity were affected by conditions of high ambient temperature and restricted sleep.**

2.4 Sleep

Firefighters on deployment are required to sleep in a range of different settings. In Australia, strike teams deployed to large incidents are accommodated in temporary camps or existing hotel/motel or caravan parks [3]. Though shared sleeping spaces, camp stretches and hot temperatures may intuitively impair sleep, the level to which sleep is restricted and whether the level of restriction is moderated by the preceding physical work and/or the location in which the sleep occurs is yet to be quantified. The current research does provide a platform for emergency service agencies to tailor their interventions (if necessary), depending on the environment. Preserving workers' sleep, may have short- (see sections 2.2 and 2.3) and long-term benefits to workers. Indeed, in other contexts, chronic sleep restriction has been associated with increased risk of diabetes, metabolic syndrome and cancer, particularly in combination with circadian disruption as experienced by shiftworkers [40]. Research helping agencies optimise the sleep of their workers could, accordingly, be integral to helping emergency services personnel preserve their long-term health. The Operational Readiness project, therefore, sought to **quantify, whether sleep is acutely impacted by high temperatures, shortened opportunities and varying locations.**

3 Progression of Research

For clarity and efficiency of presentation, the methods associated with the 'Awake, Smoky and Hot' trials have been summarised and will be presented in a consolidated format within section 3. In contrast, the methodology underpinning other parts of the research program, (namely simulation design, and applied sleep research) will be presented in summarised form as a part of the results (section 4).

3.1 Timeline of activity

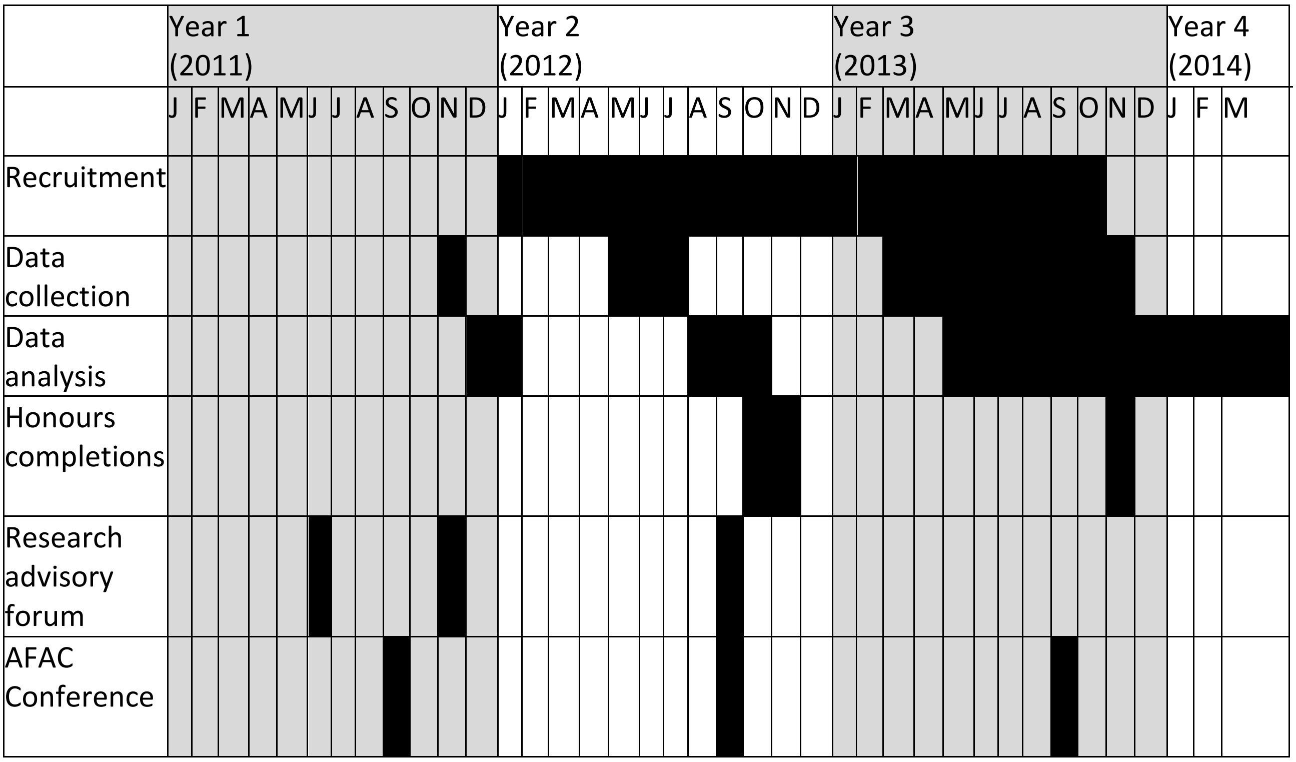


Figure 3.1 Project timeline (note testing could not take place over the fire season (December-March)

3.2 Participants, recruitment, study sites, and experimental conditions

A total of 91 rural firefighters (83% volunteer, 17% career) participated in the study, across four experimental conditions (see Table 3.1). Participants were recruited from five fire state and territory fire agencies across Australia (CFA, TFS, CFS, NSW RFS & Parks and Wildlife, ACT Parks and Wildlife). Participants were required to be between the ages of 18-70 years and excluded only if they had a current or pre-existing injury or condition preventing performance of fire ground duties, a diagnosed sleep disorder, or were pregnant. The majority of the sample were male

(87%), whilst the average age of the study sample was 38 ± 14 years. This mean age is slightly lower than data reported profiling Australian rural firefighters [41]. The average firefighting experience across the cohort was 11 ± 9 years.

Table 3.1 Overview of the study conditions, locations, and participant demographics.

	Control	**Awake**	**Hot**	**Awake & Hot**
Experimental conditions				
Physical activity (circuits)	14	14	14	14
Temperature (degrees)				
Day (6am-6pm)	18-20	18-20	33-35	33-35
Night (6pm-6am)	18-20	18-20	23-25	23-25
Sleep opportunity (hours)				
Adaption/Recovery (1&4)	8	8	8	8
Experimental nights (2&3)	8	4	8	4
Experiments completed				
Total (n=21)	7	6	5	3
Adelaide (n=11)	3	4	2	2
Melbourne (n=7)	3	0	3	1
Canberra (n=3)	1	2	0	0
Demographics				
Firefighters tested (n=91)	31	25	21	3
Withdrawals (n=7)	1	2	3	1
Males (n=79)	28	21	17	13
Females (n=12)	3	4	4	1
Age (M=38 ± 14)	39 ± 16	39 ± 14	35 ± 13	42 ± 16
BMI (M=28 ± 5)	27 ± 5	29 ± 5	27 ± 4	27 ± 4

3.3 Procedure

The project developed an innovative, laboratory-based simulation of a typical fire-ground tour (12-hour work shifts over three consecutive days; please refer to pages 23 - 26). The study protocol spanned four days, including a study briefing, familiarisation of the tasks, and adaption to sleeping conditions (stretcher bed and sleep monitoring equipment) on the evening prior to testing, and a morning testing session on day four. Participants (maximum five per study) lived in a simulated environment for the duration of the study (including physical tasks, rest breaks, meals, and sleeping) and were asked to remain inside except when smoking or using amenities that were located outside. During the daytime, participants adhered to a strict schedule, completing 14, 2-hour testing sessions over 4 days (Figure 3.2). Each session consisted of 50 min of physical work designed to mimic fire-ground tasks (Table 3.2; Section 3.4), followed by physiological testing lasting 20 min (Section 3.6) and a cognitive battery lasting 20 min (Table 3.3; Section 3.5). Testing sessions were completed in full protective clothing including helmets and gloves. On completion of each session participants had a 15-30 min break before beginning the next session. After dinner participants were allocated free time until bedtime (e.g., read book, watch movies). Sleep quality and quantity was measured each night using a sleep diary, wrist actigraphy, and polysomnography (Table 3.4). Testing occurred over three different field sites; Adelaide (CFS Training Centre, Brukunga, SA), Melbourne (Box Hill Town Hall, Box Hill, VIC), Canberra (Birrigai Outdoor School, Paddy's River, ACT). Video footage of the study can be accessed via You Tube: https://www.youtube.com/watch?v=q-KwY3KFuxE.

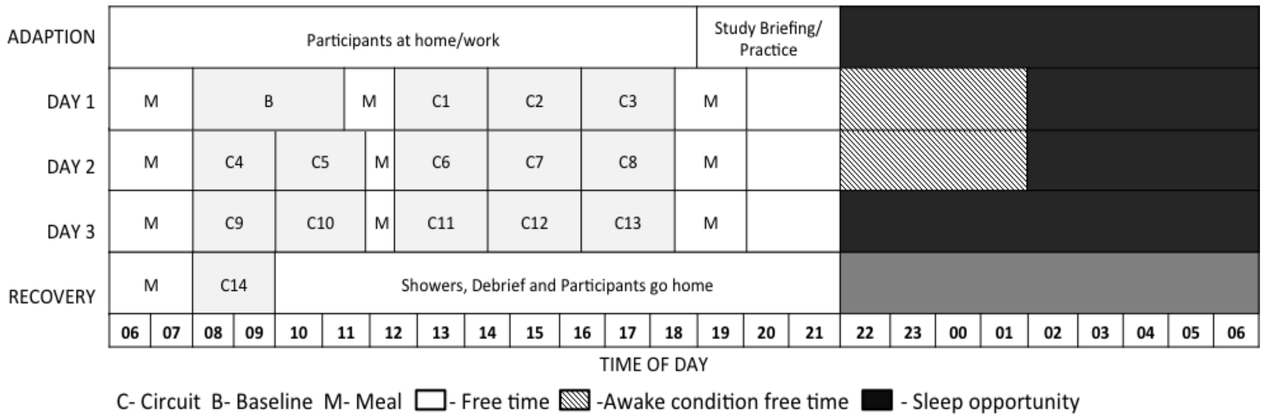


Figure 3.2 The study protocol outlining each testing circuit, scheduled meal times, free time, and sleep opportunity. Participants in the awake conditions were given an extended free time.

3.4 Physical performance battery

During a testing circuit, each firefighter was placed on a specific work-rest schedule, and rotated through a series of 5-min tasks. Tasks were designed to mimic real world tasks and work rates [31, 42]. Some tasks were therefore performed more frequently than others in each session. Participants were asked to complete tasks in a similar manner to how they would on the fire ground. No feedback was given regarding performance, time remaining in the task, or motivation/encouragement. As such, firefighters' work was truly self-paced. At the end of each task, participants were asked for a subjective assessment of exertion and temperature. For details on the design of the simulation see Ferguson et al. [43] (Section 5).

3.5 Cognitive performance battery

A series of five cognitive tasks were used to tap into the cognitive aspects of firefighters' work [44]. Firefighters were also required to report their subjective levels of fatigue and alertness, and to assess their own cognitive performance before and after testing (Table 3.3).

3.6 Physiological measurements

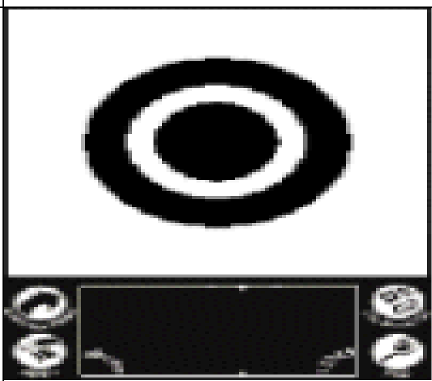
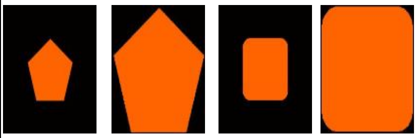
At the conclusion of the last physical task in the physical circuit, firefighters were tested on a series of physiological measures, including blood glucose and salivary cortisol. Heart rate was continually monitored using a wireless heart rate monitor strapped to the chest. Core body temperature was measured via ingested pills, and skin temperature via patches located on legs and arms (temperature data was detected and recorded on a portable VitalSense device). Urine was collected for the duration of the study (volume, colour, and hydration according to urine specific gravity-USG).

Table 3.2: Details of the physical task battery

Rake hoe		• Simulates raking a fire break • Task: Rake the contents of the box (tyre crumbs etc.) from one side to the other using a rake-hoe • Work-rest ratio: 90 s work, 60 s rest, 90 s work • Times completed per 50-min circuit: 1 • Measure: Number of completed boxes raked (movement of material from one side to the other). Number of strokes performed.
Lateral reposition		• Simulates walking around a fireground while carrying a hose and avoiding obstacles • Task: Hold weighted hose and walk in an 11-m arc, stepping over/on two obstacles • Work-rest ratio: 30 s work, 30 s rest × 4 • Times completed per 50-min circuit: 3 • Measure: Number of semi circles completed (later converted to distance covered).
Hose rolling		• Designed to simulate packing up a hose • Task: Required to roll up a 16-m folded (38-mm width) hose to operational standard. Must be rolled along the ground. • Work-rest ratio: 60 s work, 60 s rest, 60 s work • Times completed per 50 min circuit: 1 • Measure: Absolute number of hoses rolled during the allocated work period.
Charged hose advance		• Simulates dragging a charged hose • Task: Drag a weighted hose connected to a car tyre loaded with 10-kg bag over 8 m. Repeat • Work-rest ratio: 65 s work, 55 s rest, 65 s work • Times completed per 50-min circuit: 1 • Measure: Absolute number of completed hose drags from one end of the 8 m line to the other.

Black out hose work		• Simulates blacking out spot fires/hot spots • <u>Task</u>: Drag a 2-m weighted hose connected to a 15-kg bag around a 10-m square (4 × 2.5 m) pausing for 3 s at each corner. • <u>Work-rest ratio</u>: 90 s work, 60 s rest, 90 s work • <u>Times completed per 50-min circuit</u>: 2 • <u>Measure</u>: Number of full rotations around the square (later converted to distance covered).
Static hold		• Simulates holding a charged hose • <u>Task</u>: Stand holding the hose with one foot in front of the other keeping the 4.2-m long weighted hose off the ground • <u>Work-rest ratio</u>: 5 min work period (no rest) • <u>Times completed per 50-min circuit</u>: 1 • <u>Measure</u>: Time that the firefighter can hold the hose in the correct position (maximum of 5 min).
Subjective		• At the end of each of each circuit, fire fighters are asked to provide their: • Rating of perceived exertion (RPE-Scale). This is a scale between 6 (no exertion at all) to 20 (maximum exertion) • Thermal sensation. This asks how hot or cold they are on a scale from 0.0 (unbearably cold) to 8.0 (unbearably hot).

Table 3.3: Details of the cognitive test battery

Memory		• This task assesses long-term memory. • Participants must operate a CFS pager, and are then given 20 s to read a CFS issued pager message describing an incident. • They are then prompted to recall at least 3 aspects of the message directly after completing the PVT test (5-min delay). • Measure: Number of correct responses (/3)
Vigilance		• Assessed using the Psychomotor Vigilance Test (palm pilot version), a valid indicator of performance deficits attributable to fatigue and sleep loss. • Participant must press a button when a target appears on the screen. • Task duration: 5 min • Measure: Average reaction time (ms)
Complex attention		• Stroop test (4 min): Measure of speed processing and automaticity of reading. Part 1, participants press coloured key that matches the colour of the word. Part 2, press coloured key matching colour of the word (colour of word does not match the word) • Go/No-Go task (4 min 40 s): Measure of response inhibition. User must click when 3 items appear (go) but not when 1 item appears (no-go)
Hand-eye coordination		• Hand-eye co-ordination is tested using a tracking task (OSPAT). • Participants are required to keep a moving cursor on a central target using a mouse track ball. • The test takes 45 s to complete. • Measure: Score from 0-100.

Driving experience		• To simulate travel to and from the fire ground, participants are required to drive a car simulator at the start and end of the testing day (York Driving Simulator). Participants must follow all standard road rules. • Task duration: The simulator runs for 30 min each session. • Measure: deviation from centre line, accidents.
Subjective questionnaire		• Participants are asked to rate their performance (pre and post cognitive session), and also their level of fatigue, and alertness. • Mood is also collected at the end of each day (POMS). • Users either circle the most relevant item from a list, or place a mark on a scale.

Table 3.4: Details of the sleep measures used in the Operational Readiness laboratory simulation research study.

Poly-somnography (PSG)		• Each night, the sleep duration and quality were measured using polysomography, the gold standard measure of sleep • 10 electrodes were placed on the face and head, and connected to a portable device (Siesta Unit). • Sleep was monitored overnight, and later scored for total sleep duration, and stage of sleep.
Activity monitors		• Wrist actigraphy (Phillips ActicCal Respironics actiwatches) was used to measure sleep duration and quality for a duration of 14 days (2 days pre testing, 4 nights during testing, and 7 nights post testing) • A wristwatch, that detects movement, was worn on the non-dominant hand.

4 Research Results

Given the breadth of the Operational Readiness project, with a focus spanning simulation design, applied sleep research, work physiology and health, the results will be presented as sequential synopses. Each synopsis contains a brief outline of project background and/or methods, the major finding or findings (What was found?), the context of these findings in the broader picture of research or industry application (The Bigger Picture) and concluding with a statement of future directions for either researchers or end-users (Where to from here?). The aim of this approach is to allow readers to quickly glean the take-home messages from each area. For readers seeking a more in-depth analyses and discussion of the data, the authors will be submitting scientific manuscripts for peer-review and, ultimately publication in the months ahead. The bibliographic details for these proposed manuscripts are included as appropriate within each research synopsis. In Section 6 - '**State of Knowledge – Now**', the authors synthesize the findings as they pertain to the operational readiness of Australasia's emergency service workers and identify practical applications and some immediate research priorities.

4.1 Engaging end-users in simulation design - I

When working to suppress bushfires, Australasia's fire and emergency service workers face a number of risks. Beyond the obvious (e.g. burnover, radiant heat), firefighters can also endure cognitive fatigue from extended wakefulness and disrupted sleep [45]. Further, they risk physical fatigue from heat stress and dehydration [25]. Understanding the individual and interactive effects of these occupational and environmental challenges is essential for effective human resource management on and off the fireground. The evidence-base for such decisions is limited to laboratory studies with little relevance to bushfire suppression or observational field research where the relative impact of various fireground stressors (e.g., fatigue, heat) cannot be easily identified.

To aid fire and emergency agencies manage various fireground stressors, a large-scale (three-day) simulation was conceived. The key stages in simulation development and the processes that were used for design, data collection, trial/refinement and evaluation will be outlined in the following sections.

4.1.1 What was found?

Simulation design: The challenge with any simulation is to balance experimental rigour against face validity [24] and, accordingly, end-user acceptance [13]. To reconcile these viewpoints, the researchers conceived work shifts and tasks (both physical and cognitive) that closely resembled fireground duties, and could be performed in a tightly controlled manner. These early designs were presented using the Bushfire CRC Research Advisory Forum and AFAC Worker Health and Safety Technical Group (WHSTG) meetings for initial stakeholder feedback.

Data Collection: The physical task parameters (e.g., frequency, intensity, duration and type of tasks) were derived from published work [31, 42]. To isolate core cognitive functions, the researchers undertook a modified applied cognitive task analysis [46] with local, rural fire brigade members who identified communication, decision-making, vigilance, concentration, and maintaining awareness as core constructs. Environmental constraints (e.g., temperatures) were established by published research [47, 48] and agency reports from major fire incidents, and occupational standards (e.g., shift lengths, protective clothing and equipment, and food/fluid provisions) were set from agency policies and procedures.

Trial and Refinement: Video footage of the task prototypes where presented to a meeting of the WHSTG. At this meeting, the rake hoe task intensity was increased, a hose rolling task was added and obstacles were included during hose lateral repositioning task. Thereafter, two further 'small-scale' simulations were completed lasting one and two days respectively. During each simulation, researchers recorded their observations of participants (volunteer firefighters). Feedback from the simulations, together with that collected from the firefighters during formal, post-simulation de-briefing sessions was incorporated into the final simulation design.

Evaluation: A group of nine subject matter experts, comprising two experienced rural firefighters, together with pairs of experts in human factors, cognitive psychology and a trio of physiology experts were engaged to evaluate the realism/fidelity of the simulation. The purpose of choosing this multi-disciplinary group was to ensure no inherent biases were brought to the evaluation from the perspective of a single disciplinary standpoint. This group was shown footage of the simulation and were able to trial physical and cognitive tasks. They completed visual analogue scales to rate the level of fidelity across psychological, physiological, equipment, and environmental domains. As shown in Figure 4.1, the fidelity of the psychological, physiological, and equipment was considered very high (> 75/100) on either average or median scales. Within these domains, team work and stressors return much lower scores. Similarly, the fidelity of the audio aspects of equipment realism, and visual aspects of the environment were not rated highly (e.g., < 40 / 100). These lower ratings were, however, part of the accepted trade-off as the research focussed on individual (rather than team) work, and was completed in a temperature controlled room, with non-powered (e.g., quiet) proxies of the actual equipment firefighters use during suppression duties.

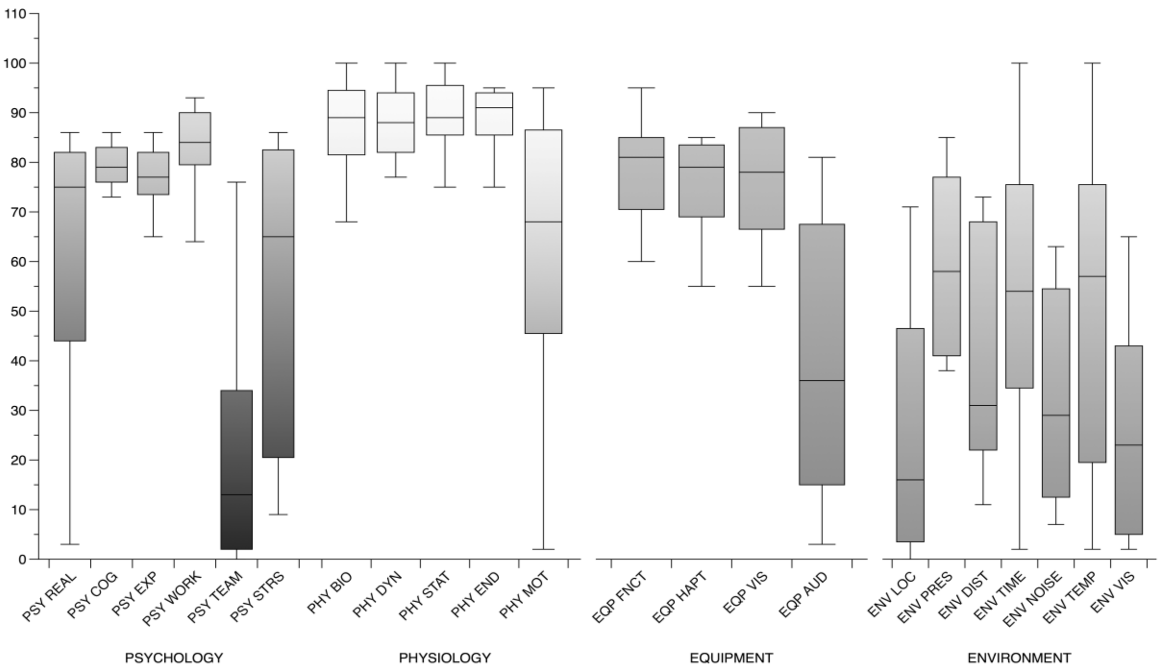


Figure 4.1 Box Plots for Overall ratings of Simulation Fidelity. NB: Boxes indicate 1st and 3rd inter-quartile range, bisected by a line indicating the median score. Whiskers indicate the range of scores. NB: for a complete list of the abbreviations used in Figure 4.1, please refer to Appendix 1.

4.1.2 The Bigger Picture

Engaging members of the Australasian fire and emergency services community through the simulation development will promote acceptance of the physiological and cognitive findings arising from this work. Indeed, previous research in the workplace has shown that workers feel more ownership of outcomes when they were involved with the process [49]. Research conducted with high face validity (i.e., tasks that look like the work) has also been purported to enhance uptake [13]. Anecdotally, presentations of the simulation and ensuing findings to agency representatives at brigade and leadership level has shown increased levels of acceptance, relative to more ‘laboratory’ science outcomes.

4.1.3 Where to from here?

The level of engagement required to develop the simulation was exhaustive. This was a conscious decision and may not always be the most convenient method for researchers developing similar protocols. The researchers would strongly advocate however, that researchers engage in at least some level of formal consultation (and document this process) to aid with both end-user uptake, but also to address questions from scientific peers in relation to the application/validity of the work. The engagement with the sector in the design of the simulation, and the documentation of the processes has allowed for uptake and adoption of the protocol by both aligned and external research groups. The physical work circuit has been modified to work with Dutch firefighters to explore the consequences of changing their personal protective clothing. Similarly, the physical circuit forms the backbone of the criterion validity assessment for a physical selection test prototype for Australian rural firefighters. The data presented here will comprise part of the peer-review manuscript;

- Thomas M, Ferguson SA, Balakrishnan G, Aisbett B *‘Fidelity in a Complex Firefighting Simulation: Considerations for Maximising the Quality of Experimental Design’* <u>Submitted to Applied Ergonomics</u>

4.2 Sleep

Sleep was recorded for 85 volunteer and career firefighters across four consecutive nights. Firefighters were assigned to one of four experimental groups described in Table 4.1. All groups were provided an 8-hour sleep opportunity on both the adaptation and recovery nights in 18-20^{o}C (Nights 1 and 4 of the protocol). On the experimental nights, both the length of the sleep opportunity, and the ambient temperature were varied. On Experimental Nights 1 and 2 the control group (n=27) were provided 8-hour sleep opportunities in 18-20^{o}C (Control); the Hot group (n=19) were provided 8-hour sleep opportunities in 23-25°C (Hot); the sleep restricted group (n=25) were provided 4-hour sleep opportunities in 18-20°C (Awake); the sleep restricted heat group (n=13) were provided 4-hour sleep opportunities in 23-25°C (Awake & Hot). Initial analysis of the sleep data obtained using PSG identified a number of participants with potential sleep disordered breathing problems. To date, 23 individuals have been identified (Control=3; Awake=10; Hot=2; Awake & Hot=8) and have been advised to seek medical advice.

4.2.1 What was found?

Total sleep time was reduced in the sleep restricted groups. The average amount of sleep obtained in the 8-hour groups was 390 minutes (not including the adaptation night). The average total sleep time in the 4-hour groups was approximately 215 minutes.

Total sleep time was not affected by an increased ambient temperature, either in the 8-hour sleep opportunities, or the 4-hour sleep opportunities. However, there were some differences seen in the structure of sleep. As would be expected in shortened sleep periods, there was a higher percentage of Stage 3 sleep (as a proportion of total sleep time) in the sleep restricted groups. Stage 3 NREM sleep is also known as deep sleep and occurs earlier in the sleep period [50]. Interestingly, the sleep restricted group sleeping in the heat had less Stage 3 sleep as a percentage of total sleep time than the sleep restricted group in 18-20°C conditions.

The other difference seen in sleep structure was in REM sleep. The first night of sleep restriction was associated with a 35% reduction in REM sleep in the Awake & Hot group compared to the Hot group (Figure 4.4). This is likely to be related to the increased percentage of NREM stage 3 sleep in sleep restricted groups (Figure 4.3).

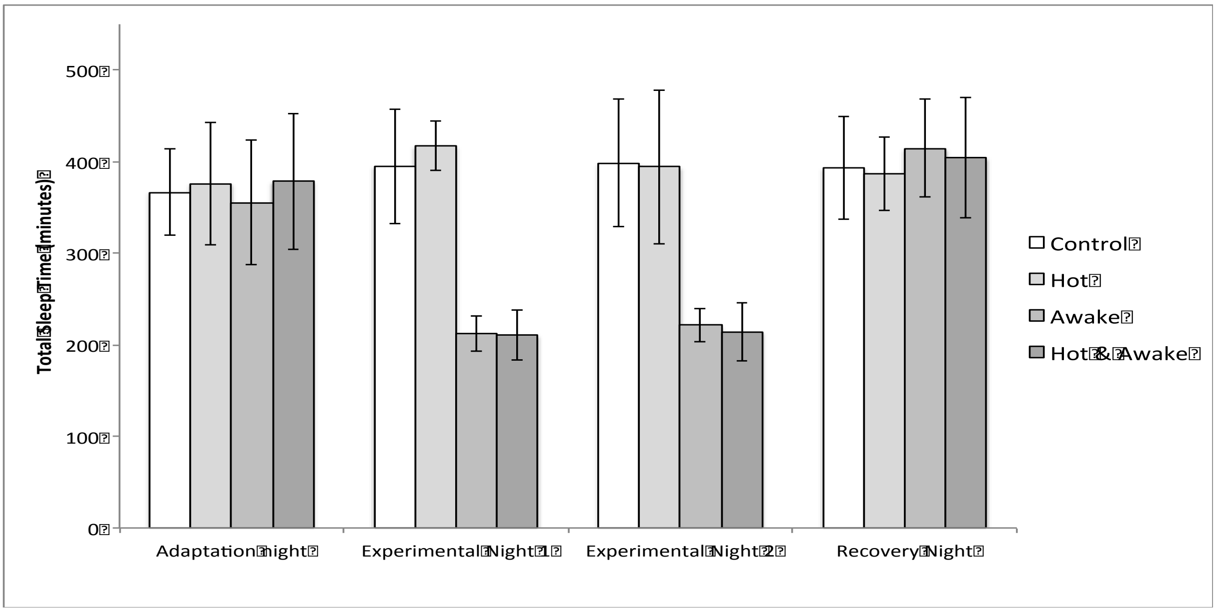


Figure 4.2 Mean total sleep time (minutes) for each night of the simulation for the Control, Hot, Awake and Awake & Hot groups.

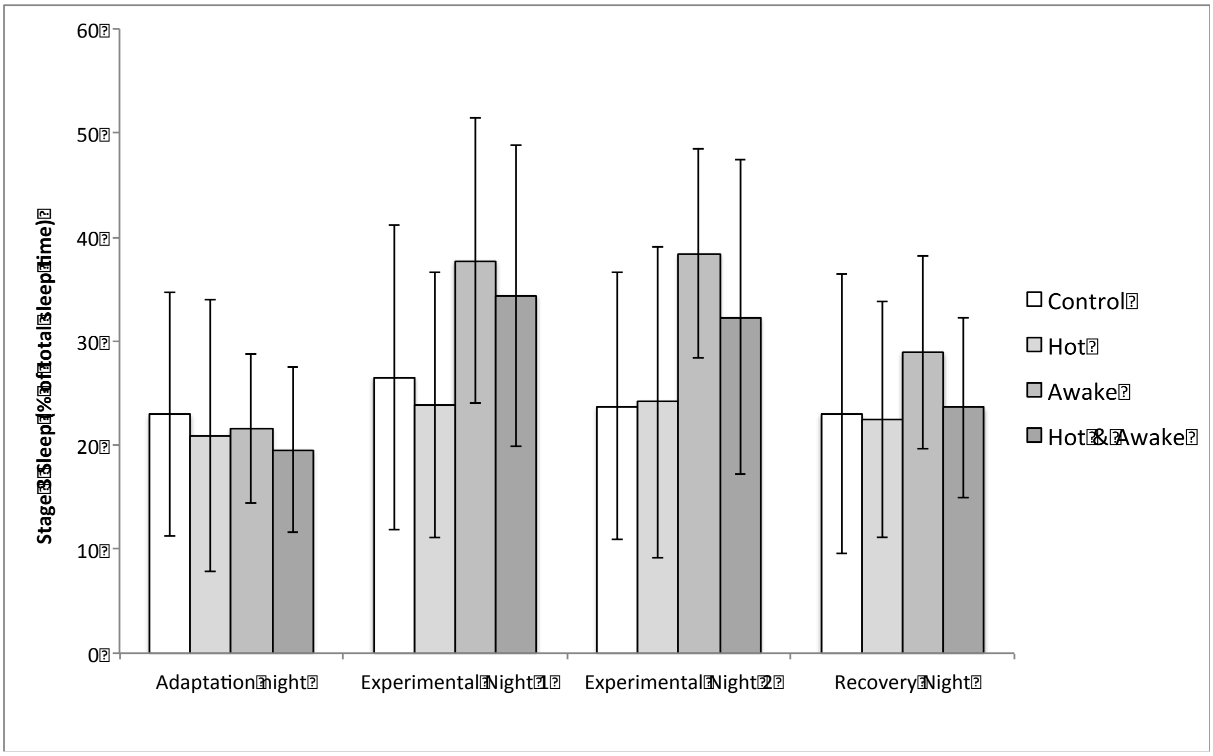


Figure 4.3 Mean percentage of Stage 3 sleep for each night of the simulation for the Control, Hot, Awake, Awake & Hot groups.

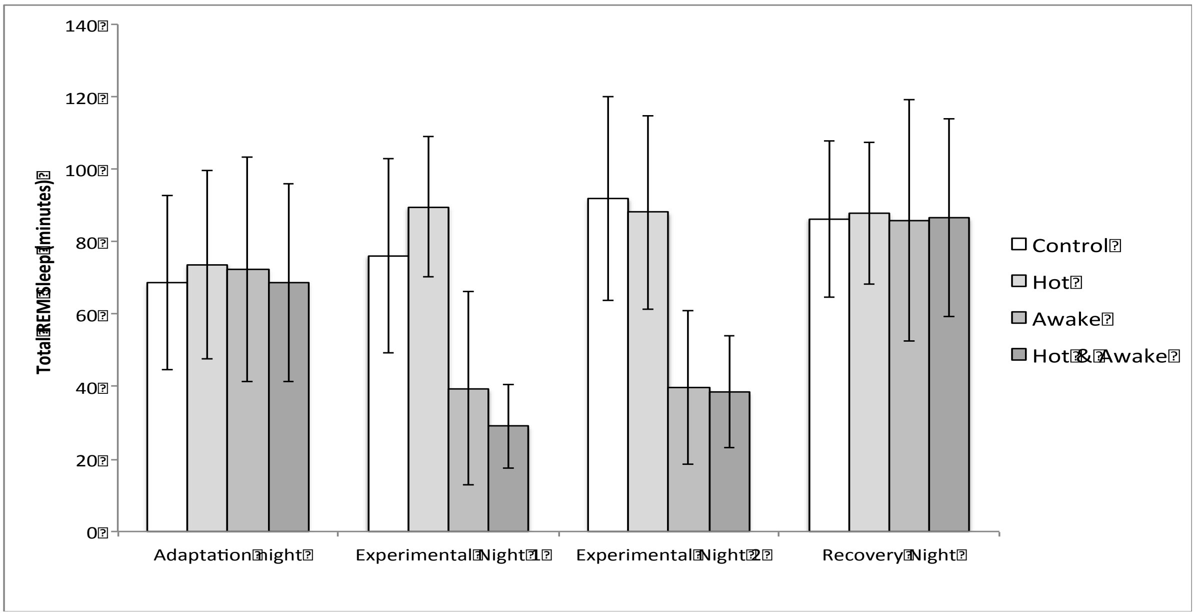


Figure 4.4 Mean percentage of REM sleep for each night of the simulation for the Control, Hot, Awake, Awake & Hot groups.

4.2.2 The Bigger Picture

This is one of the first studies to examine the sleep of firefighters using PSG under simulated field operational conditions. The PSG system allows examination of not only global markers of sleep quantity and quality but also assessment of changes in sleep structure [50]. Previous studies have either used self-reports of sleep and/or activity [3, 51]. While these measures do provide some indication of sleep quantity and quality, they are not sufficiently sensitive to detect changes in sleep structure. Given the importance of specific sleep stages for waking function [50] (3947), an understanding of the deviations from normal sleep structure is important for understanding and managing risk of performance impairment. Somewhat reassuringly, under ambient temperature conditions of 23-25^{o}C in the current study, sleep was largely preserved. The current findings do suggest that firefighters sleeping in higher ambient temperatures may experience less deep sleep as a percentage of total sleep time when sleep is restricted. A reduction in deep sleep may have adverse consequences for next day performance. Facilitating the highest quality of sleep, especially if the opportunity is restricted, is critical. This means not only protecting sleep from noise but also managing temperature where possible. In addition however, it may also mean that agencies need to take account of sleeping conditions and actual sleep between shifts in assessing operational readiness of personnel for the next shift.

4.2.3 Where to next?

Limited research has focused on the changes to sleep structure in firefighters in the heat. In addition to the shortened sleep opportunities and the increased ambient sleeping temperature, other challenges to sleep in this study included having to sleep in shared quarters. The protocol was designed to simulate the sleeping conditions often experienced by firefighters on deployment [3] but this makes it difficult to determine the specific role of heat in any sleep disruption. In addition, the Hot group was exposed to increased temperatures (33-35°C) during the day as well as during sleep opportunities. There may be residual effects from the high daytime temperature on sleep. Further investigations should examine sleep changes under conditions of:

- High daytime temperatures and low sleeping temperatures
- High sleeping temperatures in the absence of other challenges to sleep (e.g. noise)

The data presented here will comprise part of the peer-review manuscript;

- Jay SM, Smith BP, Aisbett B, Ferguson SA '*Sleeping with your crew: the effects of shared accommodation and increased ambient temperatures on the sleep of rural firefighters on a simulated deployment'.* In preparation

4.3 Cognitive Function

Assessments of cognitive performance were conducted on 85 volunteer and career firefighters across the four-day simulation. Four conditions were studied - Control, Hot, Awake and Awake & Hot. Cognitive test batteries assessed simple cognitive performance such as reaction time and hand-eye co-ordination, as well as higher order cognitive functioning such as processing and memory. All tests were completed in each of five test batteries except for the Go-No Go task, which was completed only in the first and last session of each day. The data were analysed to see if there were differences in performance between conditions, as well as between days and within days. This approach facilitated an understanding of how performance changes with time as well as under certain environmental and occupational stressors.

4.3.1 What was found?

Performance changes varied between the specific tests used. While the higher order processing and memory tasks were unaffected by condition, both Memory and Go-No Go performance declined across the day. This suggests a time on task (or time awake) factor impact performance on these tasks. However, sleep restriction and heat did not compound this influence, or act independently to degrade performance in the higher order tasks.

The simple tasks of reaction time and hand-eye co-ordination were affected by condition. Performance on the OSPAT task, which assesses hand-eye coordination, was poorer in the Awake & Hot condition compared to the Control condition on Days 1 and 3 and poorer in the Awake & Hot condition compared to the Awake condition on Day 1. On Day 1 the groups had not experienced any sleep restriction so the difference in performance is most likely due to the higher ambient temperature. By Day 3, the Awake groups had experienced two consecutive nights of sleep restricted to less than four hours.

Performance on the PVT, a test of vigilance and simple reaction time was mainly impacted in two ways (Figure 4.5). The first was that performance appeared to decline across the days, regardless of condition. This is not the normal pattern seen in cognitive tasks in laboratory studies [52]. Cognitive performance tends to remain relatively steady across the day and peak in the early evening [52]. The addition of physical activity in this simulation may therefore be having an impact on cognitive function.

The other factor that affected PVT performance was sleep restriction. The Awake group performed worse than the Hot group on Day 3. The Awake & Hot group performed also worse than the Hot group on Day 3. Interestingly, there was no difference in performance on the PVT between the Awake group and the Awake & Hot group. This suggests that while sleep restriction affected cognitive performance on the PVT, the addition of heat as an environmental stressor did not further degrade performance. Indeed, there is some indication that heat may have facilitated faster reaction times (Figure 4.5). Having said that, there might be a limit with regards to the degree that heat facilitates performance. For instance, dehydration may offset the benefit of heat on vigilance such that dehydrated workers may perform more poorly [54].

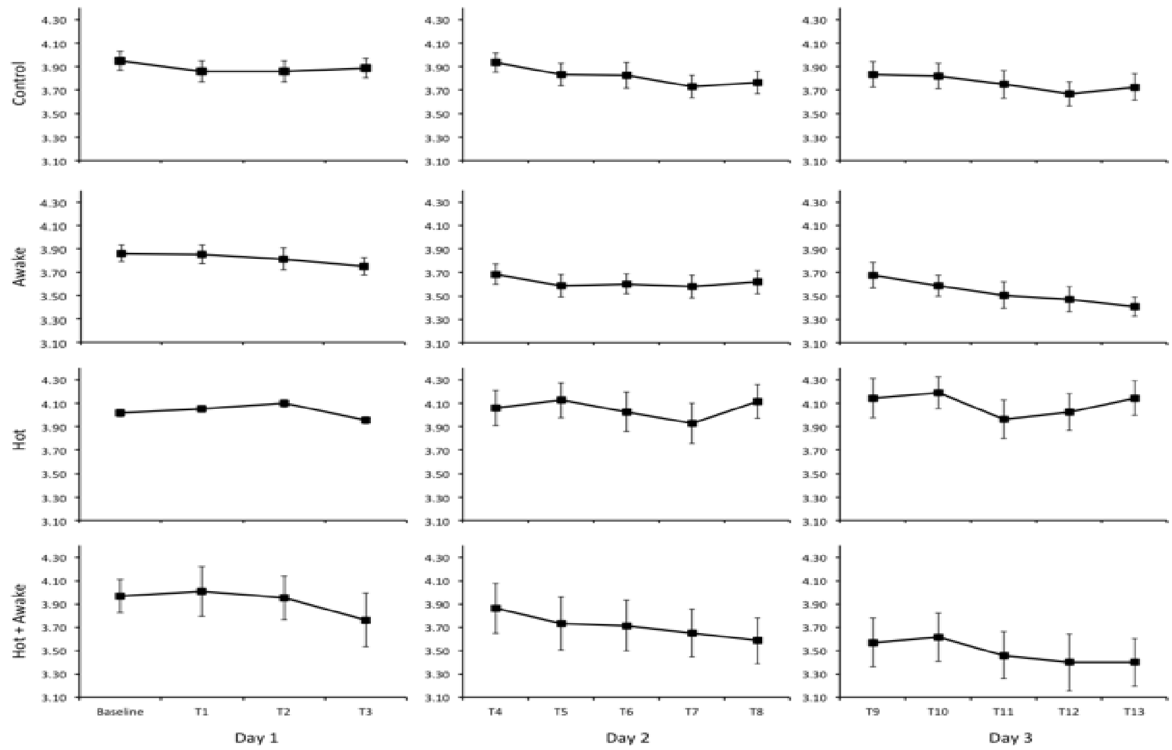


Figure 4.5 Neurocognitive performance (Mean Reciprocal Reaction Time) according to the Psychomotor Vigilance Task across all testing sessions (higher score=better performance).

4.3.2 The Bigger Picture

The test of hand-eye coordination was the only task that was different consistently between conditions. The Awake & Hot group performed consistently worse on the OSPAT task than the Control group. This suggests that the combination of sleep restriction and higher ambient temperatures was worse for hand-eye co-ordination than either stressor alone. These effects emerged after the second night of sleep restriction.

The simple measure of cognitive performance using the PVT was not affected by condition alone. Global performance in the Awake group was not different to global performance in the control group. This finding is counterintuitive but may be related to the intermittent bouts of physical activity in the protocol. Previous work assessing cognitive function during sleep restriction has generally restricted physical activity [35, 52, 53]. The only differences we found were between the Awake and Hot groups and between the Awake & Hot and Hot groups on Day 3. In both comparisons, firefighters with shortened sleep opportunities performed worse. Thus after two nights of sleep opportunities restricted to four hours, performance becomes impaired compared to non-restricted sleep at higher temperatures.

Thus in addition to the physical activity having a potential role in reducing the impact of sleep restriction, heat may also aid performance on some tasks.

The higher order processing functions required by the Stroop task appear unaffected by any conditions, as well as being unchanged across the day. Alternatively, Memory and Go - No Go performance declined across the day. Together these findings suggest that sleep restriction does impact neurobehavioral tasks and that it is more of an issue than ambient temperature (at least at the temperatures the current group of firefighters were exposed to). It is important to note that firefighters in this study had *ad libitum* access to fluids and snacks between testing bouts. In higher temperatures where dehydration is more likely, [54] performance may be adversely affected.

4.3.3 Where to from here?

Given this is one of the few studies to examine cognitive function in the presence of physical activity, there are a number of remaining questions. Two questions that may be of immediate benefit to the emergency services are;

- How much physical activity is needed to offset sleep deprived performance declines?
- If heat is helping to offset sleep restriction declines in cognitive performance, where is the limit?

The data presented here will comprise part of the peer-review manuscript:

- Smith BP, Christoforou T, Cvirn M, Aisbett B, Ferguson SA. '*The effect of multi-stressor environments on the neurocognitive performance of Australian rural fire-fighters'.* <u>In preparation</u>

4.4 Sleep loss and physical work (in mild temperatures)

Thirty-five firefighters were matched and randomly allocated to either a control group (8-hour sleep opportunity, n = 18) or a sleep restricted group (4-hour sleep opportunity, n = 17) and performed simulated firefighting activities across three days. Heart rate, core temperature, and worker activity were measured continuously, while rate of perceived exertion and effort were evaluated at two-hour intervals.

4.4.1 What was found?

Restricting firefighters' sleep by 4 h, on two consecutive nights DID NOT:

- Impair their physical performance (Figure 4.6);
- Significantly elevate their heart rate;
- Alter their perceptions of how hard their physical work was.

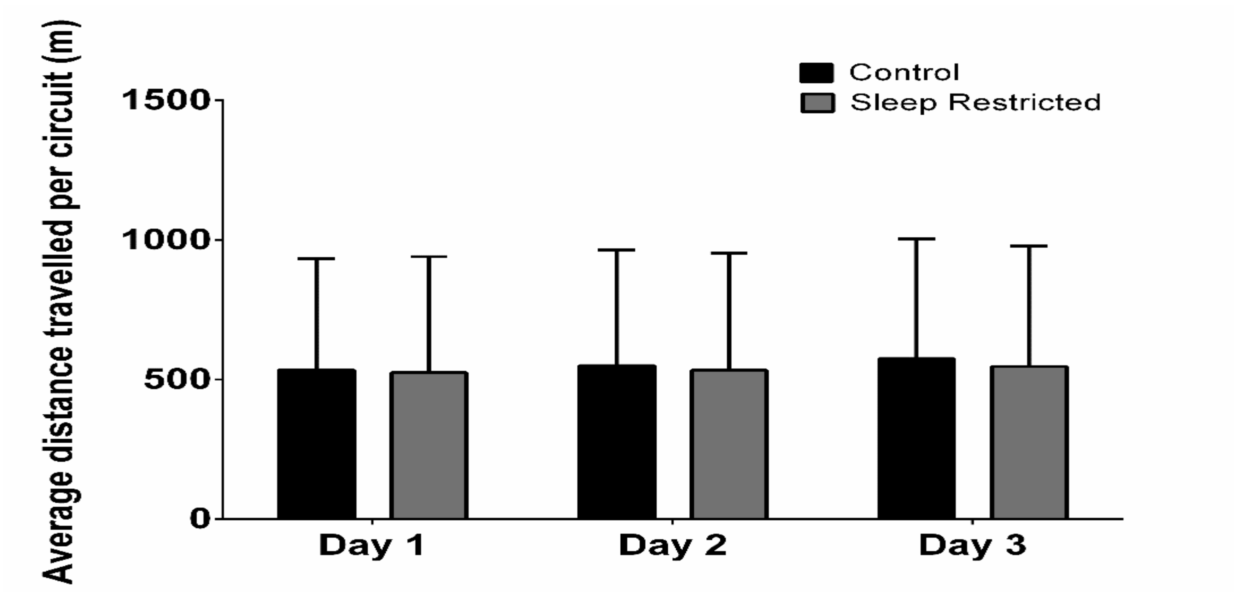


Figure 4.6 Firefighters' physical activity during control (8-h sleep opportunity) and sleep restricted (4-h sleep opportunity) conditions.

4.4.2 The Bigger Picture

This study is the first to objectively measure physical work tasks during consecutive days of partial sleep restriction (~ 4 h). The findings substantiate earlier results that military personnel were able to sustain their work output (as judged by senior officer ratings) despite getting ~ 5 h sleep per night over nine nights [55]. Though limited to two studies, the available evidence suggests that ~ 4 h of sleep restriction, even over consecutive nights will not impair workers' physical output. Not only were workers able to maintain a similar work output (to when receiving ~ 8 h of sleep), their level of exertion was not further increased by restricting their sleep. When combined with previous research it seems that physical work performance only declines when the level of sleep restriction is more severe -

such as no sleep in a 60-h period. Further, it seems only long-duration, lower intensity tasks are susceptible to fatigue [28], whilst short-duration, urgent or maximal effort physical task performance [29] is likely to be preserved.

4.4.3 Where to from here?

Long working hours and shortened sleep can pose significant risks to Australasian emergency services personnel (see section 4.3). Based on the available evidence, these risks do not extend to workers' physical performance or feelings of exertion. Agencies should, instead, invest their fatigue management controls into assisting workers cope with the mental challenges of their work when fatigued (see Section 4.3). It is important to note that should the style of bushfire suppression change (leading to increases or decreases in work intensity, duration and work-to-rest ratios), the relationship between sleep and physical work may also change and need to be re-examined. The data presented here will comprise part of the peer-review manuscript;

- Vincent G, Ferguson SA, Tran J, Aisbett B *'Sleep restriction during simulated wildfire suppression: effect on physical performance and physiological function.'* Submitted to PLOS ONE

4.5 Fluid intake for 'hot' firefighting

Thirty-eight firefighters were matched for age, sex, body mass index and allocated to a control (n = 18) or hot (n = 20) condition. The firefighters arrived at the testing venue the night before their simulated 'shift' (comprising 6 h of intermittent physical tasks, each a proxy for core fireground duties). Before and during their shift, they were simply advised to complete all physical tasks as they would 'on the fireground' and invited to snack (on supplied ration packs) and drink at their own pace. Their fluid intake was measured from 6 pm the night before their shift and throughout the next day's 'firefighting'. Their urine output and specific gravity was measured before, during, and after their shift, to assess hydration. Firefighters' physical work output, core and skin temperatures, and heart rate were also measured throughout their work shift.

4.5.1 What was found?

Firefighters' core (38.24 ± 0.28°C) and skin (37.04 ± 0.50°C) temperature were on average 0.3°C and 3.1°C hotter, respectively, in the hot condition compared to the control trial. During the hot condition, firefighters spent 52.0 ± 51.5 min more time (across the 6 h) with their core temperature above the World Health Organization 'safe work' temperature of 38°C. Despite these differences in temperature;

- Firefighters' physical work performance in the heat (33 °C) was no different to that performed in mild (18 °C) temperatures;
- There was no difference in firefighters' heart rates during self-paced work tasks between conditions; and only minor (~3% of maximum heart rate) elevation when a) holding a hose in a stationary position for 5 min or b) when resting between physical tasks.

It appears that firefighters were able to preserve their physical work output and moderate their exertion in hot conditions. One explanation could be;

- Firefighters fluid intake in the 6 h prior to starting work in the hot condition was 812 ± 815 mL higher than before the control condition (Figure 4.6);
- As a result, they were significantly dehydrated before working in the control condition, whilst hydrated before their work in the hot temperatures;
- During the 6-h work period shift, the firefighters drank 622 ± 673 mL more when working in the hot conditions (1950 ± 970 mL) than the mild environment (Figure 4.6).

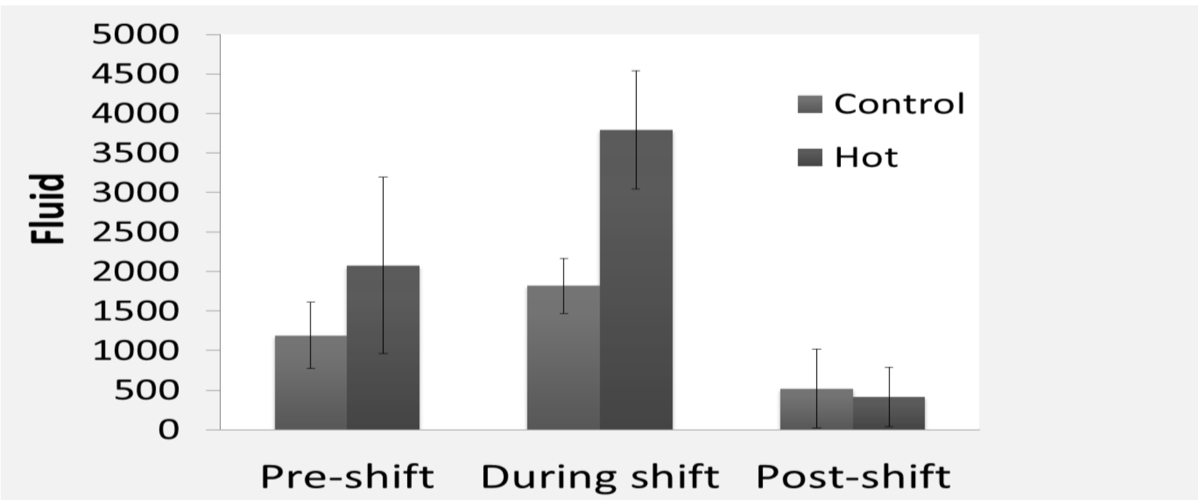


Figure 4.7 Firefighters fluid intake pre-, during and post-shift in control (18-20°C) and hot (33°C) conditions.

4.5.2 The Bigger Picture

This study is the first to show that workers may pre-emptively drink more fluids in preparation for physical work in hot temperatures. These novel findings, do, however, align with recent observations [56] that firefighters may have increased their fluid consumption 'in camp' between bushfire suppression shifts. Research by the current group into two consecutive shifts of bushfire suppression in hot (> 35°C) temperatures identified that workers' hydration 'in camp' between shifts was greater than that reported at home the night before their tour. It is possible, that the pre-emptive fluid intake is a safety behaviour, similar to the fatigue proofing strategies purported by Dawson et al [57] for managing safety critical work during periods of sleep restriction. Higher fluid intakes during the hot working condition confirm previous findings in exercise and sport settings [54]. Hotter ambient conditions are likely to induce greater fluid intake which can increase the body's 'drive' to drink [54].

4.5.3 Where to from here?

If the increase in firefighters' fluid intake 'pre-shift' was a deliberate action, it could be inferred that the efforts made by the Australasian fire community to educate their personnel on the value of appropriate hydration are working. Accordingly, there may be considerable value to investigate whether firefighters do pre-hydrate before working in hot conditions and if so, what information sources motivate their decision making. Understanding how firefighters make their decisions about preserving their hydration may give fire agencies valuable insights into the ways to shape and deliver their messages on a range of key health and safety issues.

From the findings showing higher fluid intakes during hot working conditions, Australasian fire agencies should provide more fluid to brigades and staging areas in hotter temperatures. Based on the available literature it seems that firefighters drink 500 - 600 mL per hour (mixing water and carbohydrate-electrolyte solutions or powders) in temperatures of 33 - 35°C. Firefighters' fluid intake is approximately half this level in more moderate temperatures (e.g., 20°C). These latter values align with field data from Australian firegrounds [47, 48, 56]. To this end, occupational health and safety staff should work with logistics and planning to ensure (wherever practicable) these volumes (e.g., 250 to 600 mL per hour) of fluid are available for deployed firefighters. The data presented here will comprise part of the peer-review manuscript;

- Larsen B, Snow R, Aisbett B *'Effect of heat on firefighters' work performance and physiology'* Submitted to European Journal of Applied Physiology

4.6 The effects of sleep restriction when working in hot conditions

Thirty-two firefighters were matched and randomly allocated to either a hot group (three days work in 33°C, 8-h sleep opportunity between shifts, n = 20) or an Awake & Hot group (three days work in 33°C, 4-hour sleep opportunity on nights two and three, n = 12) and performed simulated firefighting activities. Heart rate, core temperature, and worker activity was measured continuously, while rate of perceived exertion and effort were evaluated at two-hour intervals.

4.6.1 What was found?

Restricting firefighters' sleep across two consecutive nights did not appear to impede their self-paced physical day time work output. Similarly, their objective (e.g., heart rate) and subjective (e.g., RPE) levels did not alter between conditions when performing self-paced work tasks. Firefighters' RPE throughout their third day of work (after two nights of sleep restriction) was higher during a stationary hose holding task. In this task (last five minutes of each physical circuit), firefighters could not pace their efforts, but rather they needed to sustain their effort throughout.

4.6.2 The Bigger Picture

The current study is the first to examine manual handling work performance across consecutive work days. There is only one other study [58], to date, examining physical (45 min of moderate intensity running) performance during hot conditions when partially sleep deprived. In both this recently published work and the current data, the addition of sleep restriction did not impair participants (firefighters or athletes) physical performance, physiological or subjective responses when performing dynamic, whole body movements. Firefighters' perceived exertion was significantly higher across the third day during the only externally paced - static task (hose holding). It is possible, that the repeated exposure to this task (five times across 10 h), its externally paced intensity and/or lack of movement/stimulation contributed to the elevated perceptions of effort. Certainly, longer, more monotonous tasks have been shown to have an exaggerated RPE response when participants are sleep deprived [28].

4.6.3 Where to from here?

Much like the findings from milder (e.g., 18°C) temperatures, firefighters working in hot conditions do not seem to be physically impaired, in the main, by having their sleep partially restricted in the two days before. The available evidence (though limited) does not suggest that Australasian fire agencies need additional resources across an entire shift to aid the physical work of firefighters who are working in hot temperatures without a complete night's sleep between shifts. The reader is referred to Section 4.3 for the fatigue management approach surrounding firefighters' cognitive work in hot conditions during periods of sleep restriction.

The novel findings of an exaggerated perception of exertion during a static hose holding task when sleep restricted warrants further investigation. Future work may be particularly targeted at specific (likely to be supporting or post-incident) roles, reliant on relatively monotonous 'lift and carry' work. Lending further support to this idea, monotonous cognitive tasks have also been shown to be more susceptible to sleep-restriction fatigue than more stimulating or interesting work [28, 59]. Given the paucity of the research in this area, exploring whether the relationships observed in the current study hold in hotter sleeping environments (e.g., over 30°C) or over long consecutive duty cycles (e.g., more than two nights sleep restriction) may yield more insights for researchers and end-users alike. The data presented here will comprise part of the peer-review manuscript;

- Aisbett B, Siegel R, Vincent G, Larsen B, Ferguson SA, *'Effect of sleep restriction on firefighters' physical performance and physiology during work in the heat'* In preparation.

4.7 Subjective assessments

Firefighters must constantly monitor their own levels of fatigue and performance abilities in order to manage safety risks. If a mismatch arises between perceived performance and actual performance, safety may be compromised. If individuals or crews do not detect and respond to a decline in performance, the risks to health and safety cannot be managed. In general, people in laboratory conditions are relatively accurate at judging their neurobehavioral and cognitive performance, even under conditions of sleep restriction or fatigue [60, 61] . Accuracy however, appears to be context specific [60, 61], and no study has examined subjective accuracy during exposure to working conditions similar to those faced by rural firefighters. Accordingly, the aim of this component of the study was to determine how well fire fighters could self-monitor their cognitive performance.

Before and after each cognitive battery, participants completed a number of subjective measures. Subjective assessments of performance were measured using Visual Analogue Scales (VAS). Questions included "how well do you think you will perform" and "how well do you think you performed" respectively. The higher the score on the VAS, the better the fire-fighter believed they would or had performed on the cognitive battery. Fatigue was measured using the Samn-Perelli seven point Fatigue scale [62].

4.7.1 What was found?

Results indicate that firefighters are capable of recognising elevated fatigue levels (i.e., self-reported fatigue increased after successive shifts as performance declined on the PVT task; Figure 4.7) and detecting changes in performance (i.e., perceived performance declined in line with actual performance). Firefighters in the Awake & Hot condition (Figure 4.7), when compared to those in the control, followed a similar pattern of subjective ratings, however they reported higher levels of fatigue, lower levels of alertness, and lower ratings of performance on the tasks. Although firefighters are able to identify performance declines, they are less able to assess the degree to which their performance declines. That is, they were unable to anticipate and evaluate how much their performance was declining, despite being able to identify performance decrements.

4.7.2 Bigger picture

Fatigue management policies in firefighting agencies, where they exist, typically incorporate a broader view of management that allows individuals on the 'frontline' to take control and manage their own mental fatigue (e.g., symptom checklists and self-report behavioural scales). The New South Wales Rural Fire Service (2012) for example, have adapted a model designed by Dawson and McCulloch [63], that places responsibility on their members to report and refrain from working if they believe they are fatigued. Prior to commencement of duty and at any point during their shift, they are required to inform supervisors if they believe they are unfit for duty. In order for such controls to be effective, firefighters must be trained, informed and given the tools to be able to recognise and monitor their own fatigue. Although subjective judgments can be an effective, efficient, and cost effective tool in providing feedback in regard to safety in continuing work, it is important to understand that as fatigue increases, the reliability of self-assessment of fatigue and performance may be compromised.

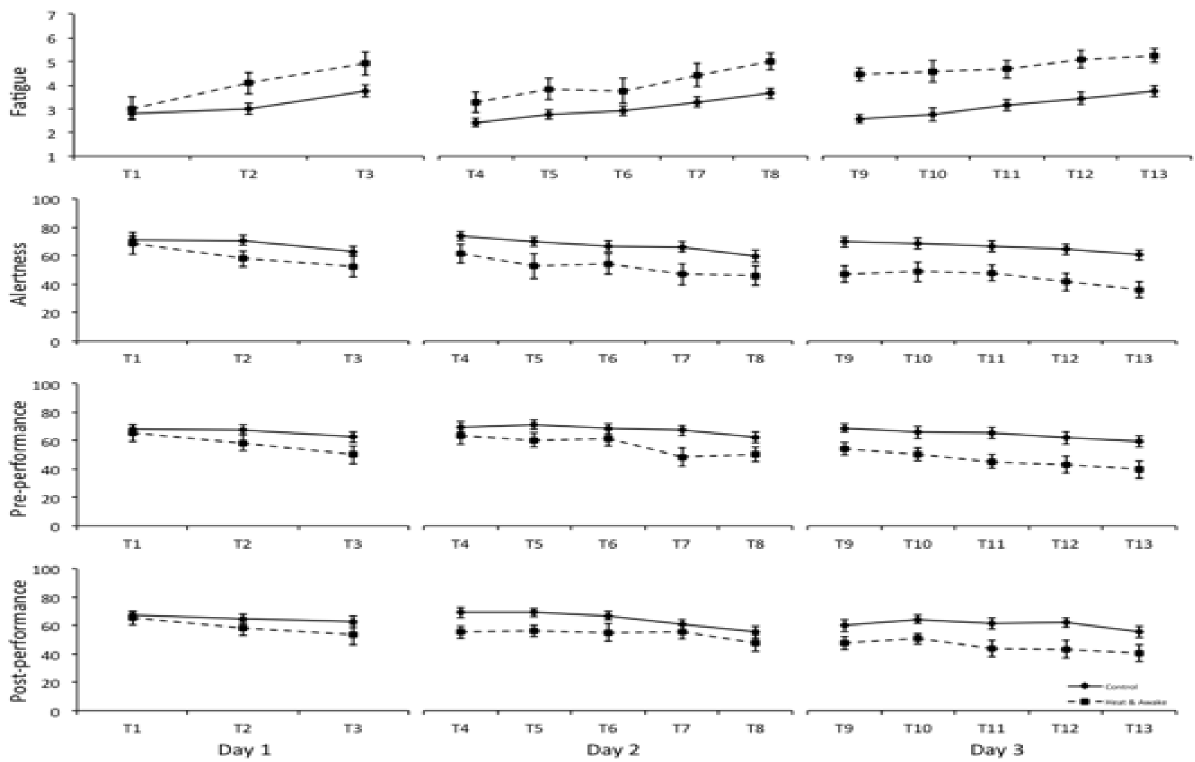


Figure 4.8 Subjective ratings of Fatigue, Alertness, and assessment of Pre-test performance and Post-test performance across all testing sessions for the control group and the Awake & Hot group.

4.7.3 Where to from here?

The presented findings provide an evidence-base for fire and emergency management agencies to manage the risks of fatigue-related performance impairment in the field. In particular, frameworks, tools and guidelines can be developed to manage the risks of fatigue on the health and safety of emergency service workers, and self-assessment tools represent an important component of the system. However, the use of such tools should be evaluated in the field, potentially as part of a fatigue risk management system.

The data presented will here comprise part of the peer-review manuscripts:

- Smith B, Armstrong T, Aisbett B, Ferguson SA. *Are subjective ratings a useful tool for assessing cognitive performance in Australian rural firefighters?* In preparation

- Ferguson S, Smith B, Aisbett B. *Can subjective ratings of fatigue be used to predict physical and mental fatigue in Australian rural firefighters?* In preparation

4.8 Hormonal stress response to sleep restriction and physical work

Though the original scope of the Operational Readiness project focussed on acute performance rather than health, an opportunity arose during the project to examine a critical marker of stress and health - cortisol. To that end, thirty-five firefighters were matched and randomly allocated to either a control group (8-hour sleep opportunity, n = 18) or a sleep restricted group (4-hour sleep opportunity, n = 17) and performed simulated firefighting activities across three days. The ‘stress’ hormone cortisol was analysed from saliva samples collected at 2-hour intervals.

4.8.1 What was found?

Restricting firefighters’ sleep by 4 h, on two consecutive nights leads to (Figure 4.8):

- Higher and flatter diurnal cortisol levels compared with firefighting work alone

- The ‘volume’ of cortisol in firefighters’ saliva during, and the rate with which cortisol levels rose across the simulated work shifts was greater in the sleep restriction condition compared to control conditions.

- Cortisol levels in sleep restriction were outside the normal reference range for adults on days 2 and 3 (Figure 4.8).

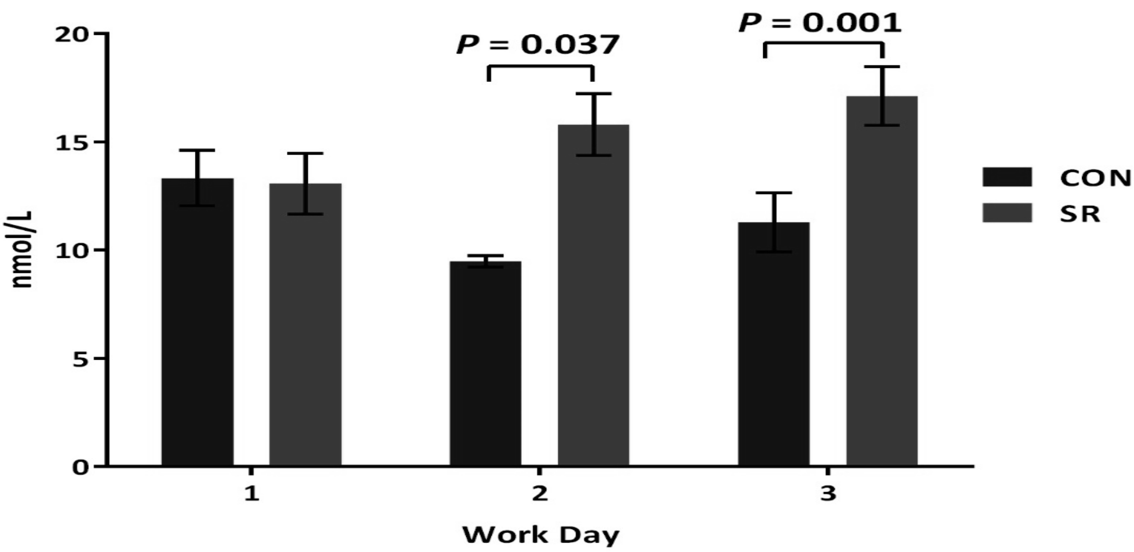


Figure 4.9 Mean daily cortisol levels between workers having an eight-hour sleep opportunity (CON) and a four-hour sleep opportunity (SR) between days one and two, and two and three.

4.8.2 The Bigger Picture

This study was the first to comprehensively assess cortisol levels when participants are completing set work tasks, sleep opportunities are strictly controlled and sleep is objectively measured. Previous research, largely observations during military training [64-66], has not controlled participants' sleep (in terms of time or amount) or precisely measured physical performance. Nevertheless, the current findings confirm earlier observations that restricting sleep disrupts workers' physiological stress responses to hard physical work. In the current study, the physiological disruptions were sufficient to elicit cortisol responses that were outside the referenced 'normal' human range after one and two days of sleep restriction.

4.8.3 Where to from here?

Chronic disturbances to the physiological stress systems have been implicated in the development of cardiovascular disease and depression [67-69] These two illnesses are particularly prevalent in firefighting cohorts worldwide [70], though only limited data is available in Australasia [71]. Researchers and fire agencies should pursue further research to explore;

- Whether the disturbances in cortisol are restored after one night (or more) of unrestricted sleep post deployment;
- Whether the observed disturbances in cortisol are associated with other adverse outcomes such as elevated cardiovascular risk factors or depressed mood scores.

The data presented here will comprise part of the peer-review manuscript;

- Wolkow A, Aisbett B, Ferguson SA, Main LC '*Effects of sleep restriction on cortisol during simulated physical firefighting work'* In preparation

4.9 Engaging end-users in simulation design - II

Physical selection (also known as 'fit for duty') testing can be a controversial topic [72]. Recruit and incumbent workers (and their representatives) can often feel that such testing is discriminatory. Alternatively, management can have genuine concerns about the feasibility of testing, including issues such as the timing, frequency (within and between years) and costs of any testing regimen. Previous research in other sectors has purported that engaging workers in the development of selection testing may lead to greater acceptance of outcomes [49].

The Australasian fire community was engaged in three phases during the design and initial validation process for a physical selection test for rural firefighters suppressing bushfires using fire tankers. The phases were;

1. A panel of seven senior OH&S officers completed a series of survey questions surrounding the parameters of any test prototype (incl. length of test, acceptable costs);
2. Two incumbent firefighters participated in a design workshop (alongside human movement scientists, agency OH&S & training representatives) to determine the test components (e.g., types of tasks, repetitions, etc);

3. Five hundred incumbent firefighters viewed the test prototype through an online survey to assess their acceptance of this prototype.

4.9.1 What was found?

The agency panel unanimously identified that testing should not last longer than 30 min for any worker and include firefighting task specific components.

Firefighters in the workshop panel determined that a manual hose crank task should be added to the published list of physically demanding tasks for Australian rural firefighters [73]. They, in consensus with the training and OH&S officers and human movement specialists, identified three test components

- **Rakehoe Clearance Test:** Participants were instructed to clear a designated area (1.5 m × 1.5 m) box using a Rake hoe, a dual sided metal rake with a six-prong face and flat sharpened edge, at normal operational pace for a total of 150 s;
- **Hose Manoeuvring Test:** Participants walked forwards 20 m carrying a charged 38-mm diameter hose (pressurized filled with water), followed by a repositioning laterally and then back to the starting position;
- **Arm Crank Test:** Participants manually wound two lengths of 38-mm hose onto a spiel mounted on a platform between 0.90-1.2 m on the side of the tanker.

Figure 4.10 Still images of the three test components identified by a mixed panel of experts as the most appropriate tasks to comprise a physical selection test for tanker-based rural firefighters.

The tests were performed and filmed and the footage was added to an online survey where respondents were asked to rate (from 1 - 7; with 1 - no resemblance; 7 - completely identical) their level of agreement that the test components (above) resembled actual firefighting tasks. At present, more than 500 respondents from around Australia have reported the following;

- The rake hoe clearance test bore a strong resemblance to rake hoe work during post fire clean-up (5.4 ± 0.6) and solo rake-hoe work (4.9 ± 1.8);
- The hose manoeuvring was considered to closely resemble advancing (6.1 ± 0.7), laterally repositioning (5.6 ± 1.1) and fully repositioning (5.7 ± 1.3) a charged fire hose;
- The arm crank test was also a close replication (5.9 ± 0.6) of manual retraction of a fire hose.

4.9.2 The Bigger Picture

This study is the first to formally assess worker views about a physical selection test prototype. The approach used here directly addresses the requirement for selection procedures to display high 'content' validity [74]. Previous studies have either a) not formalised their content validity assessment or b) not reported these results.

4.9.3 Where to from here?

The study approach becomes a benchmark for future studies developing physical testing or training tasks before their implementation. Although the decision to implement this prototype lies with individual Australasian fire agencies, it is hoped that the repeated process of end-user engagement through the development phase will facilitate greater acceptance amongst the rural firefighting workforce. In the short-term, future research should explore how the development of cut-off scores (e.g., pass / fail standards) varies between agencies. In the medium-term, agencies and researchers should evaluate whether the implementation of a physical selection test leads to significant differences in key health and safety metrics such as injury, illness and absenteeism.

The data presented here will comprise part of the peer-review manuscript;

- Lord C, Snow R, Robertson S, Aisbett B '*Content-validity assessment for a novel physical selection test for Australian rural firefighters'* In preparation

4.10 Sleeping away from home?

Fighting bushfires often requires emergency services personnel to live in temporary accommodation for several days (and nights). Depending on the agency and the location of the fire, deployed personnel may be housed in hotels/motels or caravan parks, or temporary camps (consisting of tents) set up on an oval or sports facility [3]. Preliminary reports from Australian firefighters indicates that sleeping at the fireground is difficult and disrupted [3]. In parallel to research quantifying firefighters actual sleep on the fireground (see Section 4.11), the research team undertook a narrative review to assess the evidence underpinning (or not) the idea that sleep at home is always best [20].

4.10.1 What was found?

Whilst the team were able to identify and critique 16 published studies where workers sleep at work and home, the vast majority did not allow a clear comparison between sleep at home and or when away with work. The findings from these studies in pilots, miners, train drivers and other industries were confounded by the work performed (or not) [20]. Specifically, the sleep reported at home was often during non-work periods, which did not make for a clear comparison with sleep obtained at work. Only two studies compared workers sleeping between shifts both at home and at work [75, 76]. Importantly, the data shows that there are positives and negatives to both home and away working and sleeping scenarios. One study showed that whilst subjective sleep quality was no different in the work camp versus at home, workers in the camp reported higher fatigue and lower alertness during their day shifts [75]. Alternatively, the other study showed that workers sleeping during the day (e.g., following night shifts) slept better at work than at home [76]. The lack of light in particular and the absence of domestic distracters were thought to have been factors in the discrepancy between the on and offshore workers' daytime sleep.

4.10.2 Where to from here?

Despite the prevailing presumption, there is insufficient evidence to support assertions that sleeping away from home (i.e., near work sites) is always worse than sleeping at home; or indeed that sleeping at home is always better. To this end, Australasian fire agencies should focus their efforts on accommodating their personnel in sleeping quarters (e.g., motels, etc) with optimal sleeping conditions - namely; a cool, dark, quiet environment. For firefighters deployed on successive night shifts, optimising recovery post 'tour' may be challenging. For instance, agencies could consider housing them on their final day to maximise their sleep and recovery, provided the sleeping environment is optimal. However, asking personnel to stay an additional day, away from home, domestic responsibilities and / or salaried employment may reduce their capacity (or willingness) to volunteer. A practical trade-off may be agencies and researchers to explore ways to optimise recovery in transit through formalised recovery practices such napping, food and fluid intake and light physical activity.

The data presented here forms part of the peer-review publication;

- Jay SM, Aisbett B, Sprajcer M, Ferguson SA. (in press) '*Sleeping at work: not all about location, location, location'* Sleep Medicine Reviews (Available May 2nd, 2014), IF: 8.62, http://www.sciencedirect.com/science/article/pii/S1087079214000446

4.11 Sleeping on the fireground

Forty rural firefighters were recruited across Australia's state fire agencies. All measured variables compared two conditions: 1) sleep post-fire suppression duties, and 2) sleep at home (no fire suppression). Sleep was measured objectively using wrist actigraphy for a period of four weeks. 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.

4.11.1 What was found?

Firefighters obtained 4.9 ± 1.1 hours sleep post-fire suppression, compared to 6.8 ± 1.1 hours at home. Sleep efficiency, the time spent asleep during the sleep period, were significantly less during fireground work (82.3%) compared to at home (86.4%). Both pre-sleep fatigue and post-sleep fatigue were significantly greater post-fire suppression (pre: 6.1 ± 1.1 and post: 3.2 ± 1.7) compared to at home (pre: 4.7 ± 1.7 and post: 1.6 ± 1.1). There were no significant differences in sleep latency, quality, and comfort between the two conditions.

4.11.2 The Bigger Picture

This study is the first empirical investigation to provide a detailed characterisation of the sleep quantity and quality of firefighters during bushfire suppression, using both objective and subjective measures. Previous research in North America [51, 77] and Australia [3] relied on firefighters' subjective recall of their sleep during campaign deployments. No comparison was made in these earlier studies to firefighters' normal sleep patterns. However, the reported level of sleep in these earlier studies (3 - 6 h) is similar to that recorded by the current study.

4.11.3 Where to from here?

Sleep restriction of between two and four hours has been shown to lead to significant lapses in several cognitive functions which could increase the risk of injury for deployed firefighters [35, 53]. Future research should explore associations between firefighters' sleep and their work performance both before and after their sleep opportunities. Exploration into the impact of fireground sleep patterns on volunteer firefighters' work and health post-deployment (i.e., back in their salaried employment) would also provide valuable information for agencies and the firefighters themselves. Based on the available data, Australasian fire and emergency services agencies should continue to strive towards optimising the sleep opportunities for their deployed firefighters. These considerations include the timing of consecutive shifts so that workers are afforded 8-h sleep opportunities, not just 8-h break between deployments. Further, wherever possible, providing personnel with cool, dark, and quiet sleeping environments should further optimise the perceived and actual quality of their sleep.

The data presented here will comprise part of the peer-review manuscript;

- Vincent G, Aisbett B, Hall S, Ferguson SA '*Quantifying sleep quality and quantity for Australian rural firefighters during wildfire suppression deployments'* <u>In preparation</u>

4.12 Build it and they will come?

One of the major challenges faced during the Operational Readiness research program was the recruitment of fire and emergency services personnel for a four-day (four-night) simulation. Despite considerable end-user engagement, input and support for the project (see section 4.1), the project known as 'ASH - Awake, Smoky and Hot' was not able to test the forecasted number of participants. The likely reasons are presented in section 4.12.2. As a result, the program could only present research on four of eight conditions. As will be presented later in this document, the available research, together with a rigorous review of the available literature does provide some insights into the interactions between sleep restriction, heat and smoke exposure (see section 4.13). In this section, the research team will briefly outline the approaches to participant recruitment, the underpinning presumptions and lessons learnt.

4.12.1 What was found?

The ASH project has been highly visible since the inception of the Bushfire Co-Operative Research Centre Extension (July 2010). Specifically, the project has been presented to audiences at:

- Three research advisory forums (2010-2012);
- Six AFAC WHSTG meetings (2010-2013);
- Three AFAC / BCRC Annual Conferences (2010-2012);
- Seven state / regional firefighter conferences / symposia (2010-2013); and
- Seven brigade level meetings (2012-2013).

Across these forums the simulation and research generated significant interest and questions. Members of the middle and senior leadership levels within the Australasian fire agencies frequently expressed views such as 'our personnel like to volunteer, you'll get the numbers you need'. Despite the overwhelmingly positive response, participant recruitment was slow from 2011-2012. From late 2012, the recruitment strategy was altered to include the following initiatives;

- Social media notifications at AFAC-, agency-, region-, and brigade levels;
- Attendance at regional firefighter competitions and championships;
- Media coverage through the Fire Australia, 3RRR, state-based ABC radio and TV, and Scope TV (Network Ten);
- Targeted and wide-spread promotion of the research project by the Bushfire CRC communications and research translation staff.

These strategies, together with video postings on social media and YouTube (https://www.youtube.com/watch?v=q-KwY3KFuxE) served to increase firefighters' awareness of the work, which in turned increased participant numbers, but not to levels necessary to address all the research questions originally forecast.

4.12.2 The Bigger Picture

During the same period, the research team was able to successfully recruit salaried and volunteer personnel for 90-minute focus group discussions, fireground research, and short-term (3-h) laboratory studies. Importantly, none of these initiatives had the same level of exposure or attention as the ASH research. When potential participants were not able to participate, they generally cited the four-day (four-night) time commitment for the study as being the major barrier to participation. Current and previous research suggests that volunteer personnel already make considerable sacrifices to family, salaried work, and recreation time to accommodate their voluntary work (please refer to the Bushfire CRC project: Enhancing Volunteerism: http://www.bushfirecrc.com/projects/d3/enhancing-volunteerism). It is reasonable, therefore, to conclude in hindsight, that despite the espoused and recognised benefits of the ASH work, firefighters could not simply give more time (of this magnitude) to data collection.

4.12.3 Where to from here?

Researchers engaging volunteer emergency service workers will need to consider how the time-pressures these workers already face could adversely impact on recruitment. For studies with large time commitments, researchers, agencies and workers' representatives should work in concert to explore additional incentives for participation. In the ASH experience, individual remuneration was rejected as a strategy. Senior agency and association personnel were concerned that remuneration for one activity may shift expectations for future requests for volunteers, potentially impairing future engagement by their personnel when remuneration was not possible. Nevertheless, brigade level incentives, agency-wide recognition of participation, intra- or inter-agency participation competitions should all be explored.

4.13 So what about smoke?

As described above, recruitment challenges for the 'ASH' project precluded formal evaluation of all combinations of shortened sleep, smoke and heat exposure. As such, the current project is unable to update, with certainty, the recommendations made in the published review (see sections 5.1 and 5.3). That said, a review of the literature published since this review, reveals no further studies exploring the cognitive, physiological or physical consequences workers may face when exposed to these combined stressors. With no further advances in the published literature, Australasian fire and emergency services agencies are encouraged to build health and safety guidelines about these interacting stressors in consultation with the aforementioned resources (available through: http://www.bushfirecrc.com/projects/c-11-1/operational-readiness-rural-firefighters-during-bushfire-suppression). Readers should also consult the final report put forth in the parallel project: "Bushfires extending in the rural/ urban interface" (available through: http://www.bushfirecrc.com/publications/citation/bf-4326). In light of the current results around the physical, physiological consequences of shortened sleep and heat exposure (in isolation and combination), the project team make the following (cautious) hypotheses about the additional impacts of smoke;

1. The preservation of self-paced work tasks when working in hot conditions with or without sleep restriction raises the possibility that firefighters may be able to preserve their work efforts when working in typical levels of smoke exposure. Previous research has shown exaggerated sweat responses when smoke (i.e., carbon monoxide) is added to a hot working environment [78]. However, in the current series of results, firefighters increased their fluid intake before their hot shifts and maintained that elevated fluid intake during their work. It is possible, therefore, that any further increase in sweat rate in response to

smoke exposure may also be buffered by pre-emptive and concurrent increases in fluid intake;

2. Previous research indicates that one possible outcome from smoke exposure is an elevated rating of perceived exertion which could a) make tasks with a set work-rate feel more demanding, shortening tolerance time or b) prompt workers to drop their work-rate during self-paced tasks [19]. Based on the available literature, the current team hypothesized that sleep restriction may exert a similar effect. However, shortened sleep, in isolation or in combination with heat exposure did not confer the increase in perceived exertion as expected (see sections 4.4 and 4.6) for the self-paced work tasks. The prospect that firefighters can tolerate these two stressors without undue additional exertion or meaningful drops in work-rate, raises the question, perhaps they can also tolerate moderate smoke exposure during self-paced tasks? Alternatively, there was a noticeable elevation in perceived exertion during the final day of static hose holding in hot conditions with restricted sleep (see section 4.6). It may be reasonable to suggest, therefore, that if the addition of smoke is going to influence physical work exertion and output, it will occur after repeated nights of sleep restriction and in tasks where the work is externally paced. Under these conditions, agencies may need to consider more frequent task rotations. Rotating tasks frequently may limit smoke exposure and allow firefighters' to sustain their work output.

5 Project Outputs

The Operational Readiness Project has produced the following project outputs to date, from 2010 to 2014:

5.1 Journal Articles

Aisbett B, Wolkow A, Sprajcer M, Ferguson SA. (2012) '"Awake, smoky, and hot": providing an evidence-base for managing the risks associated with occupational stressors encountered by wildland firefighters' Applied Ergonomics; 43(5): 916 – 925', Impact Factor (IF): 1.467, http://www.sciencedirect.com/science/article/pii/S000368701200004X

Jay SM, Aisbett B, Sprajcer M, Ferguson SA. (in press) 'Sleeping at work: not all about location, location, location' Sleep Medicine Reviews (Available May 2nd, 2014), IF: 8.62, http://www.sciencedirect.com/science/article/pii/S1087079214000446

5.2 Peer-review conference proceedings

Ferguson SA, Aisbett B, Jay SM, Onus K, Lord C, Sprajcer M, Thomas MJW 'Designing valid and relevant training and testing scenarios for industry' In R.P. Thornton (Ed; 2011), 'Proceedings of Bushfire CRC & AFAC 2011 Conference Science Day' 1 September 2011, Sydney Australia, Bushfire CRC, pg 196 – 204, IF: N / A,

5.3 Non-peer review publications

Ferguson SA & Aisbett B (2013) 'Awake, Smoky, and Hot - fighting fire without fire'. Bushfire Co-Operative Research Centre FireNote Series, Volume 111, June, pg 1 - 4;

Jay SM, Ferguson SA & Aisbett B (2013) 'Sleep and the operational readiness of rural firefighters during bushfire suppression' Bushfire Co-Operative Research Centre Project Resource Fact Sheet, pg 1 - 6;

Maddock N, Aisbett B, Smith B, Ferguson SA (2013) 'Firefighting research needs you!' Fire Australia, Summer Edition;

5.4 Conference Presentations (Oral)

Aisbett B (2010) ‘Awake, Smoky, and Hot’, Australasian Fire Authorities Council / Bushfire Co-Operative Research Centre Annual Conference, Darwin Convention Centre, September 2010;

Ferguson SA (2011) ‘Fatigue management: the recipe and the evidence’. Workshop and Seminar presentation at the Fire and Emergency Services Association of Western Australia inaugural health and safety conference. Perth, WA.

Ferguson SA (2011) ‘Designing valid and relevant training and testing scenarios for industry’ Australasian Fire Authorities Council / Bushfire Co-Operative Research Centre Annual Conference, Sydney Entertainment Centre, August 28 - September 1.

Aisbett B (2012) ‘Awake, Smoky, and Hot’ Fire and Emergency Services Association Health, Safety, and Welfare Summit, Mercure Hotel, Perth, July 16-18;

Ferguson S (2012) ‘Fatigue Management’ Fire and Emergency Services Association Health, Safety, and Welfare Summit, Mercure Hotel, Perth, July 16-18;

Aisbett B (2012) ‘Awake, Smoky, and Hot’ Tasmania Fire Service State Association Conference, Tram Sheds, Launceston, July 21;

Ferguson SA (2012) ‘Awake, Smoky, and Hot’ Rural Fire Research Workshop, Scion, Rotorua, New Zealand, June 14-16;

Ferguson, SA (2013) ‘Ensuring performance in the field: Techniques for faster recovery’ Plenary speaker, Department of Fire and Emergency Services of Western Australia conference. Perth, WA

Lord C (2013) ‘A task-based physical selection test prototype for Australian tanker-based firefighters’ Australasian Fire Authorities Council / Bushfire Co-Operative Research Centre Annual Conference, Melbourne Exhibition Centre, September 2 - 4;

Wolkow A (2014) ‘Effect of Sleep Restriction on Cortisol’ Health and Wellness Conference, Vancouver, Canada, March 14 - 15;

Vincent G (2014) ‘Fighting fires and fatigue: sleep, shift work, physiology, and physical performance’ SLEEP 2014, the 28th Annual Meeting of the Associated Professional Sleep Societies, Minneapolis Convention Center in Minneapolis, Minnesota, May 31 – June 4.

Vincent G (2014) ‘Sleep on the fireground’ XX World Congress on Safety and Health at Work 2014, Frankfurt, Germany, 24–27 August 2014.

Larsen B (2014) ‘The effect of heat on firefighters’ work behaviour and physiology during simulated firefighting shifts’ XX World Congress on Safety and Health at Work 2014, Frankfurt, Germany, 24–27 August 2014.

5.5 Conference Presentations (Poster)

Lord C, Snow R, Aisbett B (2013) A task-based physical selection test prototype for tanker-baed firefighters, Australasian Fire Authorities Council / Bushfire Co-Operative Research Centre Annual Conference, Melbourne Exhibition Centre, September 2 - 4;

Onus K, Reisen F, Main LC, Ferguson SA, Aisbett B (2012) ‘Awake, Smoky and Hot - the Effect of Carbon Monoxide on Firefighter Health and Performance’ Australasian Fire Authorities Council / Bushfire Co-Operative Research Centre Annual Conference, Perth Convention Centre, August 28 - September 1;

Smith B, Barry E, Cvirn M, Jay SM, Aisbett B, Ferguson SA (2013) ‘Can volunteer rural firefighters accurately self-monitor their cognitive performance?’ Australasian Fire Authorities Council / Bushfire Co-Operative Research Centre Annual Conference, Melbourne Exhibition Centre, September 2 - 4;

Vincent G, Aisbett B, Ferguson SA (2012) ‘Extended wakefulness and work physiology of wildland firefighters’ Australasian Fire Authorities Council / Bushfire Co-Operative Research Centre Annual Conference, Perth Convention Centre, August 28 - September 1;

Vincent G, Aisbett B, Ferguson SA (2013) ‘Fighting fires while fighting fatigue - how do firefighters sleep during wildfire suppression’ Australasian Fire Authorities Council / Bushfire Co-Operative Research Centre Annual Conference, Melbourne Exhibition Centre, September 2 - 4;

Lord C, Snow R, Aisbett B (2013) Physical selection test development and validation for Australian rural firefighters', Australasian Fire Authorities Council / Bushfire Co-Operative Research Centre Annual Conference, Perth Convention Centre, August 28 - September 1;

Wolkow A, Aisbett B, Ferguson SA, Main LC (2013) 'SLEEP DEPRIVATION & STRESS RESPONSES - Could emergency work have a negative impact on your health? Australasian Fire Authorities Council / Bushfire Co-Operative Research Centre Annual Conference, Melbourne Exhibition Centre, September 2 - 4;

Jay SM, Aisbett B, Smith B, Sprajcer M, Ferguson SA (2013) 'Sleeping on the fireground' Australasian Fire Authorities Council / Bushfire Co-Operative Research Centre Annual Conference, Melbourne Exhibition Centre, September 2 - 4;

Larsen B, Snow R, Aisbett B (2012) 'The effects of heat on firefighters' work behaviour and physiology during simulated firefighting shifts'. Australasian Fire Authorities Council / Bushfire Co-Operative Research Centre Annual Conference, Perth Convention Centre, August 28 - September 1;

Larsen B, Snow R, Aisbett B (2013). 'The effect of extreme heat on the performance of a simulated firefighting task' Australasian Fire Authorities Council / Bushfire Co-Operative Research Centre Annual Conference, Melbourne Exhibition Centre, September 2 - 4;

Wolkow A, Aisbett B, Ferguson SA, Main LC (2012) 'Interactions of physical work, sleep deprivation and stress responses' Australasian Fire Authorities Council / Bushfire Co-Operative Research Centre Annual Conference, Perth Converntion Centre, August 28 - September 1;

Larsen B, Snow R, Aisbett B (2013) 'Effect of heat on firefighters' work performance and physiology' Exercise and Sports Science Australia Conference, Adelaide Convention Centre, April 9 - 11;

Vincent G, Ferguson S, Tran J, Aisbett B (2013) ' Fighting fires and fatigue: sleep deprivation during simulated bushfire suppression' Exercise and Sports Science Australia Conference, Adelaide Convention Centre, April 9 - 11;

5.6 Invited Seminars

Aisbett B (2012) 'Awake, Smoky and Hot' Country Fire Authority, Region 12 Meeting, Seymour, November, 2012;

Aisbett B (2012) 'Awake, Smoky and Hot' Country Fire Authority, Region 7 Meeting, Corio, October, 2012;

Aisbett B (2012) 'Awake, Smoky and Hot' Forests NSW, Research Meeting, Sydney, October 2012;

Aisbett B (2010) 'Awake, Smoky and Hot - Update' Australasian Fire Authorities Council Worker Health and Safety Training Group, East Melbourne, June 2010;

Ferguson SA (2011) 'Awake, Smoky and Hot - Update' Australasian Fire Authorities Council Worker Health and Safety Training Group, East Melbourne, June 2011;

Aisbett B (2011) 'Awake, Smoky and Hot - Update' Australasian Fire Authorities Council Worker Health and Safety Training Group, East Melbourne, November 2011;

Aisbett B (2012) 'Awake, Smoky and Hot - Update' Australasian Fire Authorities Council Worker Health and Safety Training Group, East Melbourne, April 2012;

Aisbett B (2012) 'Awake, Smoky and Hot - Update' Australasian Fire Authorities Council Worker Health and Safety Training Group, East Melbourne, September 2012;

Aisbett B (2013) 'Awake, Smoky and Hot - Update' Australasian Fire Authorities Council Worker Health and Safety Training Group, East Melbourne, April 2013;

6 State of Knowledge - Now

Collectively, the work of the Operational Readiness project has made significant, original contributions in simulation design, sleep and work physiology. The research findings, be they novel or confirmatory for the local (i.e., Australian and New Zealand) context, have the potential to directly inform or underwrite policy and practice for the Australasian Fire and Emergency Services sector. This section will synthesize the research findings (see Section 4) to address the project aim and objectives (see Section 1); demonstrate how the novel findings (and/or methods) have advanced the state of knowledge (see Section 2); and present new research questions for the areas of simulation design, physical and cognitive performance, and sleep. The section will conclude with the positive legacies left by the Operational Readiness project that fall outside the array of project outputs presented in section 5.

6.1 Addressing Aim and Objectives

The aim of the Operational Readiness project was to conduct industry-specific research to assist the fire industry to develop comprehensive policy, best practice guidelines, and training and educational materials to preserve the health and safety of their firefighters during multi-day bushfire suppression deployments. The findings presented in section 4 were primarily applicable to firefighters' physical and cognitive performance on multi-day deployments. From the presented results, the project team believe the following novel findings should be taken under consideration by the fire and emergency services sector for incorporation into policy, practice and training materials;

- In hot conditions, where firefighters are also sleep deprived, fire and emergency services agencies should consider implementing additional safety measures for workers performing tasks requiring **hand-eye co-ordination and externally paced, but monotonous physical work**. Existing research in high-risk work places suggests that <u>some</u> of these safety practices may be already in place. The sector should work with experienced incumbent workers to identify, document, and where appropriate, adopt these practices. As previously, having workers develop and then evaluate procedures may improve their uptake across the workforce.

- Firefighters are receiving significantly less (and lower quality) sleep during deployments than when at home. The ensuing **sleep restriction not only leads to acute impairments in firefighters' cognitive performance** (despite the presence of physical work), and **self-assessment of their fatigue, but also their acute physiological stress** (cortisol) **responses.** In the case of the latter, repeated impairments in cortisol response are implicated in negative long-term outcomes (e.g., increased risk of cardiovascular disease and/or depression). Thus the current findings strongly support the sector's efforts to protect workers' sleep between shifts on tour.

- **Firefighters drank significantly more fluid in the hot temperatures than in mild conditions.** Though not entirely novel, the consistency of these laboratory findings with published field work [47, 48, 56] will enable the sector to more accurately predict the volumes of fluid they should provide to firefighters during deployments. The presented work should also underpin the development of more uniform fluid provision guidelines across the sector. Fluid prescription guidelines vary considerably agency to agency [79], increasing the risk of confusion between workers, particularly working in multi-jurisdictional events. The prevailing research indicates that **provided workers have access to fluid, they will be able to self-pace their drinking to maintain their hydration levels across a work shift.**

The Operational Readiness project set three objectives to support the overarching aim, namely;

1. Work with key fire industry informants to validate a three-day bushfire suppression tour simulation;
2. Investigate the impact of, and interaction between, multiple fireground stressors (i.e., sleep disruption, heat and smoke) on firefighters' physiological responses, physical and cognitive work performance across a simulated three-day bushfire suppression tour;
3. Present the research findings (from 2, above) to key fire industry stakeholders to inform comprehensive policy, best practice guidelines, and training and educational materials for the preservation of firefighters' health and safety.

The evidence for objective three has been documented in sections 5.2 to 5.6 (to date) and includes industry-focussed reports, presentations and posters. Instead, the remainder of this section will focus on how the current findings advance understanding in the areas of simulation design (objective one) and physical and cognitive performance (objective two). Though not explicitly identified in the original objectives, the advances in knowledge around applied sleep issues will also be presented (section 6.1.4).

6.1.1 Simulation Design

It has been previously purported that protocols with high face validity [72], and those derived through close engagement with end-users [49], improve uptake of job selection procedures. Through the development, refinement, and evaluation of the 'ASH' simulator (see section 4.1) and physical section test prototype (see section 4.9), the current findings provide significant support for these earlier proposals. In the case of the ASH simulation, endorsement for the simulated tasks determined as the most frequent and intense fireground tasks, was anecdotal collected from multiple audiences at brigade, group, region and inter-agency level. More robust feedback was, however, sought during the development of a physical selection test prototype for tanker-based bushfire suppression. Over 500 incumbent workers identified that the tests chosen by their peers (together with other subject matter experts) closely resembled critical fireground tasks. From these data (and process), the authors strongly recommend that the researchers and end-users charged with developing training and testing materials take the time to a) formally engage incumbents in the development phase and b) quantify the level of acceptance across the sector <u>before</u> implementation. Documenting 'high fidelity' before implementation and/or refining designs following initial feedback of 'low fidelity' should continue to promote more end-user engagement. However, the degree of participation could, ultimately, hinge on the commitments (particularly time) asked of the workforce. The transfer from engagement to participation may be particularly limited for volunteer workers, where salaried work, volunteerism, and family all compete for the same 'waking' hours.

6.1.2 Physical work performance

Prior to the Operational Readiness project, the prevailing research could not confidently identify whether work performance on simulated firefighting tasks changes under conditions of high ambient heat and sleep restriction. The novel findings presented here now show that two consecutive nights of moderate sleep restriction DO NOT impair self-paced physical work, physiology or augment perceived exertion under temperate or hot working conditions. There is some evidence that workers' perceived exertion may escalate when they are partially sleep deprived and performing externally-paced, monotonous work in hot conditions. However, hot temperatures alone DO NOT impair self-paced physical work or exertion within a single work shift. Firefighters' ability to tolerate sleep restriction or hot working temperatures may relate to the nature of their work and the simulated environment. For instance, none of the self-paced tasks performed within the ASH environment were sustained for longer than two minutes (without a break), though in some instances multiple repetitions of each task were performed consecutively. Though the two-minute duration is representative of a number of fireground tasks, workers performing longer duration work (such as line building for land management crews) may be more challenged by sleep restriction or hot temperatures. The frequent task rotation employed during ASH - a function of the testing environment, may have also created sufficient rest and/or cognitive stimulation (see section 6.1.3) to preserve function when hot or fatigued. Rather than just a limitation of the ASH design, the authors contend that this hypothesis warrants further investigation. Specifically, a mixed methods design where a) workers are surveyed to identify whether task rotation is an existing (and presumed effective) practice on the fireground and b) a quantitative study to evaluate what effect (if any) high versus low task rotation has on physical work performance when hot and/or fatigued. Further research in relation to physical performance could also include;

- Dedicated investigation into the physical (and physiological) responses of workers performing bushfire suppression duties during 'night' or 'afternoon' shifts;

- Verifying whether the observed relationships between work, sleep and work observed during the current simulation also persist on the fireground during emergency deployments;

- Exploring whether firefighters' ability to tolerate hot temperatures and sustain their work output extends to extreme temperatures (e.g., 45°C);

6.1.3 Cognitive Performance

Before the Operational Readiness Project the available evidence-base was insufficient for researchers and end-users to confidently identify how subjective and objective cognitive performance between bouts of physical activity affected by conditions of high ambient temperature and restricted sleep. The current findings now indicate that two consecutive nights of sleep restriction DOES NOT impair more complex and memory-based tasks of short duration. Both types of task performance fell across the shift. Therefore, the issue may not be the sleep restriction *per se*, but rather the long working hours encountered on deployment. There may be an interaction between long working hours and sleep-restriction, but isolating these potential drivers is not possible with the current data set. Agencies may need to consider additional risk management strategies late in shifts and particularly during post-shift travel. Engaging researchers with expertise in fatigue risk management and experience working with sectors who also employ long shifts may be a valuable starting point to identify potential strategies for firefighters. Further, engaging incumbent workers on their own experiences (and strategies) will also be worthwhile [57]. The potential need for specific fatigue management strategies late in fireground shifts is further underlined through the unanticipated degradation of reaction time across a shift. The inclusion of intermittent physical work (novel for research in sleep restriction and cognitive performance) may have, unexpectedly, altered reaction time. It is not clear how repeated physical task performance is implicated in this finding as the normal pathways, such as dehydration and physical exhaustion (which degrades motivation) were not present in the current study. Inclusion of physical activity may provide <u>some</u> buffer to the decrements usually observed with sleep restriction. Whilst there is some evidence for this possibility, previous findings have suggested that physical activity is more beneficial to the subjective feelings of sleepiness and fatigue rather than objectively measured performance [39]. The implications for personnel working on incident management teams (IMT), with limited exposure to physical activity during a shift are two-fold – (1) work is not broken up with changes in physical location or type of task and (2) subjective feelings of fatigue and sleepiness increase under conditions of high cognitive workload, long shifts and no active breaks. IMTs therefore need to be aware of the impacts of both changes in performance due to elevated fatigue, but also changes in subjective feelings of fatigue that may influence mood, communication, morale and team-work. As purported earlier, it is possible that the frequent task rotation (between various physical tasks, physiological measurements and cognitive tasks) may play a role in the current findings and should be further explored. The results (see section 4.3) and discussion above, also prompt the question;

- What are the threshold levels of physical work (or activity) and ambient temperatures at which the expected declines in cognitive performance (due to sleep restriction) stop being offset, and start being exaggerated?

6.1.4 Sleep

The existing evidence-base nominates noise, heat and light as the natural 'enemies' of sleep [20]. By necessity, Australasia's fire and emergency service workers may encounter all three 'enemies' when trying to sleep between consecutive shifts on deployment. The current findings suggest that for temperatures 23 - 25°C, firefighters' sleep was largely preserved if 'unrestricted' compared to control (18-20°C) conditions. However, if the sleep opportunity was shortened to 4 h (as occurs on Australian firegrounds), then sleeping in these only slightly hotter temperatures was potentially not as restorative, with less 'deep' sleep than in more temperate (18-20°C) conditions. The pure impact of temperature on sleep cannot be definitely answered by the current results. In pursuit of a number of research questions (see sections 4.2 to 4.8), the research team could not isolate the impact of night time temperature. Sleeping in 23-25°C was preceded by work in hot (33°C) temperatures whilst sleeping in temperate conditions (18-20°C) was preceded by work at 18-20°C. Future research directions should strive to 'unpack' these confounding variables of day time, night time temperature and physical work to examine;

- Sleep during hot (>28°C) and temperate (18-20°C) conditions when preceded by work in hot (~ 35°C) conditions;

- Sleep during high night-time (>28°C) temperatures when preceded by predominantly physical or cognitive work in hot (~ 35°C) conditions;

6.2 Project Legacy

The financial and in-kind investment made by the Australasian Fire and Emergency Services Authorities Council (via the Bushfire Co-Operative Research Centre) has left a profound positive legacy for the future of health and safety research. Namely;

- Scholarship support for five doctoral students who will confer across 2014-2015;
    - **Cara Lord 'Physical selection test development and validation for Australia Rural fire** fighters', Deakin University Postgraduate Research Scholarship and Bushfire CRC Scholarship 2011-2013;
    - **Brianna Larsen** 'The effect of heat on firefighters' work behaviour and physiology during simulated firefighting shifts', Bushfire CRC Scholarship 2012-2014;
    - **Grace Vincent** 'Extended wakefulness and work physiology of wildland firefighters', Deakin University Postgraduate Research Scholarship and Bushfire CRC Scholarship 2012-2014;
    - **Alexander Wolkow** 'The Interactions of Physical Work, Sleep Deprivation and Stress Responses', Deakin University Postgraduate Research Scholarship and Bushfire CRC Scholarship 2012-2014;
    - **Michael Cvirn** 'The effects of regular intermittent concurrent physical activity, heat, and partial sleep deprivation on cognitive performance', Appleton Institute / Bushfire CRC Scholarship 2012-2013.
- Graduation of five honours level research students;
    - **Madeline Sprajcer** 'The Effects of Sleep Restriction on Mood, Snacking and Food Cravings During Three Days of Concurrent Physical Work' Flinders University [First Class Honours];
    - **Emma Barry** 'The Effect of Sleep Restriction on the Perception of Cognitive and Physical Performance in Bushland Fire-Fighters' Central Queensland University [Second Class Honours];

- **Sarah Jefferies** 'The inflammatory response to repeated bouts of intermittent physical work, on a single and across three consecutive days during simulated bushfire suppression' Deakin University [First Class Honours];
- **Tess Armstrong** 'Can Australian Bush Fire Fighters Accurately Self-monitor Their Cognitive Performance during a 3-day Simulated Fire-ground Campaign? CQUniversity (First class Honours).
- **Tamika Christoforou** The Effect of Sleep Restriction and Exposure to Physical Activity on the Cognitive Ability of Volunteer Firefighters across a 3-day Simulated Fire-ground Tour. (Second class Honours).

- Collectively, the development of these young scientists, in concert with early career researchers Dr Sarah Jay, Dr Bradley Smith, Dr Luana Main, and Dr Jessica Paterson provide tangible evidence of the sustainable emergency service worker health and safety research hubs at Deakin and Central Queensland Universities;
- Facilitation of an ongoing nexus between the AFAC WHTSG and these research teams, establishing a culture of knowledge sharing and co-operation between key industry stake holders and researchers in health and safety (http://www.afac.com.au/research/news-details/2014/04/29/work-health-safety-technical-group).

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8 Appendix 1

Abbreviations for Figure 4.1

PSY – Psychological fidelity

PHY – Physical fidelity

EQP – Equipment

ENV - Environment

PSY REAL – Realism;

PSY COG – Cognitive skills

PSY EXP – Expertise

PSY WORK – Cognitive workload

PSY TEAM – Team performance

PSY STRS – Stressor

PHY BIO – Biomechanical

PHY DYN – Dynamic load

PSY STAT – Static load

PHY END – Physical endurance

PHY MOT – Motion cues

EQP FNCT – Functional

EQP HAPT – Haptic

EQP VIS – Visual

EQP AUD – Auditory

ENV LOC – Location

ENV PRES – Performance pressure

ENV DIST – Distances

ENV TIME – Time of day

ENV NOISE – Noise

ENV TEMP – Temperatures

ENV VIS - Visibility