Simulated Self-Paced Wildfire Suppression Work in Different Thermal Conditions

by

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Submitted in fulfilment of the requirements for the degree of Doctor of Philosophy

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Overview

There is a substantial body of research investigating the influence of ambient temperature on sport and exercise performance. However, research investigating the effect of heat on the performance of manual-handling work, as performed by personnel across many physically demanding occupations, is relatively scarce. Wildland firefighters are commonly tasked with performing manual-handling work under conditions of high ambient heat, and will likely do so more frequently under a continually warming climate. Heat-related illness also currently represents a substantial threat to the safety and wellbeing of wildland firefighters when on duty. Understanding the role of ambient heat in moderating firefighter performance may be important for wildland fire agencies in forecasting the effectiveness of their workforce. Further, quantifying the physiological response of firefighters working in such conditions may assist in preventing heat-related incidents on the fireground. Therefore, assessing the influence of hot ambient conditions on the work output of wildland firefighters, as well as the magnitude of their thermoregulatory and cardiovascular response, was the primary focus of this thesis.

Due to the inherent variability of wildfire behaviour, and the subsequent difficulty in measuring work performance in an operational setting, the current program of research utilised high-fidelity work simulations to assess changes in work output in response to ambient heat. Study 1 investigated the self-selected work output of wildland firefighters in both temperate (18°C) and hot (32°C) ambient conditions over a six-hour simulated shift, and indices of thermal stress (e.g., core temperature) and exertion (e.g., heart rate) were measured. Study 2 reported the cumulative effect of ambient heat on the work performance and physiological response of wildland firefighters performing three consecutive days of simulated wildfire suppression. Finally, Study 3 measured the self-selected work output and thermoregulatory responses of wildland firefighters performing a raking task in both 45°C

and 18°C conditions. The adaptive behaviours of firefighters (e.g., in ad-libitum fluid intake) were also documented during all studies. Collectively, the results from these studies provides novel insight into the operational effectiveness of wildland firefighters under a range of ambient conditions, and their concurrent physiological and behavioural responses.

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Journal articles

Larsen, B., Snow, R., Aisbett, B. (2015). Effect of heat on firefighters' work performance and physiology. *Journal of Thermal Biology*, 53, 1-8.

Larsen, B., Snow, R., Vincent, G., Tran, J., Wolkow, A., Aisbett, B. (2015). Multiple days of heat exposure on firefighters' work performance and physiology. *PLOS ONE*, 10(9).

Larsen, B., Snow, R., Williams-Bell, M., Aisbett, B. (2015). Simulated firefighting task performance and physiology under very hot conditions. *Frontiers in Physiology* (in press).

Conference presentations

Larsen, B., Snow, R., Aisbett, B. *Heat and hydration: Firefighters know what to do*. Poster presented at the Australasian Fire Authorities Council Conference, 2-5 September 2014, Wellington, New Zealand.

Larsen, B., Snow, R., Aisbett, B. *The effect of heat on firefighters' work performance and physiology*. Oral presentation at the XX World Congress on Safety and Health at Work (Forum for Prevention), 24-27 August 2014, Frankfurt, Germany.

Larsen, B., Snow, R., Aisbett, B. *Effect of heat on firefighters' work performance and physiology*. Poster presented at the 6th Exercise & Sports Science Australia Conference and Sports Dieticians Australia Update: Research to Practice, 10-12 April 2014, Adelaide, Australia.

Larsen, B., Snow, R., Aisbett, B. *The effect of extreme heat on the performance of a simulated firefighting task*. Poster presented at the Australasian Fire Authorities

Council/Bushfire Cooperative Research Centre Conference, 2-5 September 2013, Melbourne, Australia.

Larsen, B., Snow, R., Aisbett, B. *The effect of heat on firefighters' work behaviour and physiology during simulated firefighting shifts – an overview*. Poster presented at the Australasian Fire Authorities Council/Bushfire Cooperative Research Centre Conference, 28-31 August 2012, Perth, Australia.

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List of Abbreviations

%	Percent
=	Equals
<	Less than
>	Greater than
±	Plus or minus
≤	Less than or equal to
≥	More than or equal to
°	Degrees
~	Approximately
$	Dollars
β	Beta
ANOVA	Analysis of variance
BA	Breathing apparatus
beats·min^{-1}	Beats per minute
BMI	Body mass index
C	Celsius
CFA	Country Fire Authority
cm	Centimetre(s)
CO_2	Carbon dioxide
CON	Control
ET	Effective temperature
GLMM	General linear mixed models
GPS	Global positioning system

HOT	Hot
HR	Heart rate
HR_{max}	Maximal heart rate
h	Hour(s)
IQR	Inter quartile range
kg	Kilogram(s)
$kg.m^{2}$	Kilograms per metres squared
kJ	Kilojoule(s)
km	Kilometre(s)
$km.h^{-1}$	Kilometres per hour
$kW.m^{-2}$	Kilowatts per metres squared
L	Litre(s)
$l.min^{-1}$	Litres per minute
MET	Metabolic equivalent
m	Metre(s)
m^{2}	Metres squared
mg	Milligram(s)
$mg.kg^{-1}$	Milligrams per kilogram
$m.s^{-1}$	Metres per second
$m^{2}.min^{-1}$	Metres squared per minute
min	Minute(s)
$min.2h^{-1}$	Minutes per two hours
mL	Millilitre(s)
$mL.kg^{-1}$	Millilitres per kilogram
mm	Millimetre(s)
n	Sample size
η^{2}_{p}	Partial eta squared

O_2	Oxygen
P	Probability
PPC	Personal protective clothing
PSI	Physiological strain index
RH	Relative humidity
RPE	Rating of perceived exertion
s	Second(s)
SCBA	Self-contained breathing apparatus
SD	Standard deviation
SE	Standard error
SPSS	Statistical Package for the Social Sciences
$steps.min^{-1}$	Steps per minute
T_{arm}	Arm temperature
T_c	Core temperature
T_{chest}	Chest temperature
T_{leg}	Leg temperature
T_{sk}	Skin temperature
T_{thigh}	Thigh temperature
TWL	Thermal work limit
USG	Urine specific gravity
VH	Very hot
VO_2	Volume of oxygen consumption
VO_{2max}	Maximal volume of oxygen consumption
VO_{2peak}	Peak oxygen consumption
W	Watt(s)
WBGT	Wet bulb globe temperature
WTT	Work tolerance time

A note for readers

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

Chapter 1: General Introduction

1.1 BACKGROUND

Wildfires (also known as wildland fires, or bushfires) can be defined as uncontrolled fires that occur in vegetation using natural fuels, in areas without substantial human development (e.g., farmland, rural communities, national parks) (NWCG 2014). Wildfires cause significant damage on a global scale (Bowman et al. 2009; Schmuck et al. 2014), thus, wildland firefighters play a vital role in protecting communities worldwide against loss of land, property, and most importantly, human life. Annually, wildfires cause billions of dollars in damages in spite of the significant resources and manpower dedicated to fire suppression globally (Bowman et al. 2009; Hyde et al. 2008; Teague et al. 2010). For instance, it is estimated that there are 220,000 volunteer firefighters in Australia, which make up the vast majority of the country's defence against wildfire (McLennan and Birch 2005). In the United States, there are approximately 34,000 federal workers employed to perform wildfire-related activities (Campbell and Dalsey 2012), along with close to 800,000 volunteers who assist with fire suppression (NFPA 2014). Unfortunately, wildfires are predicted to rapidly become more frequent and severe as a result of a continually warming climate (Hennessy et al. 2006; Liu et al. 2010; Moritz et al. 2012; Pechony and Shindell 2010).

While wildfires are often synonymous with hot weather (Aisbett et al. 2012; Cheney 1976), and will likely become more so as global temperatures increase (Luber and McGeehin 2008), wildland firefighters perform their duties under an array of ambient conditions. For example, during the 2009 Black Saturday bushfires in Victoria (and subsequent 'clean-up' work), firefighters performed their duties in ambient temperatures as high as 46.4°C (Teague et al. 2010), and as low as 15.8°C (Raines et al. 2012). Thus, fire agencies would benefit from understanding the effect of environmental temperature on their crews' ability to work, as well as on firefighter health and safety. Wildland firefighting is typically of low-moderate intensity, interspersed with brief periods of arduous physical work (Aisbett and Nichols 2007; Cuddy et al. 2007; Cuddy et al. 2015; Phillips et al. 2011; Raines et al. 2013; Rodríguez-Marroyo et al. 2012). Furthermore, firefighters often perform long work shifts over multiple days (Aisbett and Nichols 2007; Aisbett et al. 2007), with little rest in between

(Cater et al. 2007). The small body of existing field research suggests that, for the most part, wildland firefighters are able to perform their duties in a way that avoids excessive thermal strain or exertion (Cuddy et al. 2015; Raines et al. 2013; Rodríguez-Marroyo et al. 2012). However, there have also been several wildland firefighter deaths attributed to working in the heat (Baldwin and Hales 2010, 2012, 2014; Fahy 2011; Jackson 2006; Shults et al. 1992), and a number of injury reports that list heat illness as a major hazard for wildland firefighting personnel (Karter 2012; Smith 2008). Data investigating the interplay between ambient temperature, work output, physiological responses, and adaptive behaviours (e.g., fluid intake) in this population is currently limited. Given the potentially devastating consequences of heat-related illness, and the critical role wildland firefighters play in public safety, investigating work performance and thermal physiology in this population should be an ongoing research priority.

1.2 THE RESEARCH PROBLEM

To date, the available literature is insufficient to determine the effect of ambient temperature on wildland firefighter performance. For the purpose of this thesis, wildland firefighter performance refers to the productivity of firefighters performing physical work tasks (e.g., as opposed to cognitive task performance). The existing laboratory studies that measure the effect of heat on manual-handling tasks (relevant to wildland firefighting) suggest that work performance will be impaired under hot ambient conditions (McLellan et al. 1993; Snook and Ciriello 1974). However, these studies are yet to capture the work to rest ratios and breadth of movements exhibited during wildland fire suppression (Phillips et al. 2011; Phillips et al. 2012). Further, the available field research contains confounding variables (e.g., no 'control' group, inherent variability of fire conditions across work days) that may limit the interpretation of work performance outcomes. Thus, quantifying the precise effect of heat on worker performance is currently problematic. Furthermore, there is a distinct lack of research (both in the field and laboratory-based) investigating the cumulative effect of long-duration, repeated heat exposures on work performance, as is a common feature of wildland fire suppression spanning multiple days (Aisbett and Nichols 2007; Aisbett et al. 2007). Firefighting agencies would benefit from understanding how personnel regulate their work efforts during different ambient conditions (both during a single shift and over multiple shifts), as this will directly influence the fire suppression effort as a whole. Fire suppression efficiency may also become increasingly important as wildfires globally become more frequent, and burn for extended periods (Hennessy et al. 2006; Liu et al. 2010). Therefore, research that measures the work output of firefighters performing self-paced, manual-handling work over prolonged periods under hot ambient conditions is required.

While the thermoregulatory response of individuals performing walking or running exercise in the heat has been granted considerable research focus (e.g., Costello et al. 2014; McLellan and Selkirk 2006; Morris et al. 1998; Sköldström 1987; Wilson et al. 1975), there is a paucity of research which examines the thermal stress and exertion placed on personnel performing long-duration, manual-handling work in different ambient environments. Those that have investigated the relationship between ambient heat and physiology during manual-handling tasks (in a controlled environment) have observed higher heart rates (Smith et al. 1997; Snook and Ciriello 1974), rectal (Snook and Ciriello 1974), tympanic (Smith et al. 1997), and skin (Payne et al. 1994) temperature values, and perception of exertion and thermal sensation (Smith et al. 1997). However, these select studies have investigated the relationship between ambient temperature and thermal physiology over only short durations (e.g., 15 – 45 minutes) (Payne et al. 1994; Smith et al. 1997; Snook and Ciriello 1974), and/or have utilised generic (e.g., box-lifting) rather than occupation-specific exercise protocols (McLellan et al. 1993; Snook and Ciriello 1974). Therefore, the magnitude of the physiological response to performing long-duration, manual-handling work tasks in the heat (when compared to more temperate conditions) remains unknown, and warrants further investigation. Further, the relationship between firefighters' thermal physiology and adaptive behaviours (e.g., self-selected fluid intake, changes in work behaviour) has not been thoroughly examined under controlled conditions. An individuals' hydration status is known to influence measures of thermal stress, exertion, and work tolerance (Cheung et al. 2000; Sawka et al. 2011). Therefore, a greater understanding of the way firefighters manage their drinking behaviour under hot conditions may assist the fire industry in developing strategies to reduce heat-related injuries, and maintain firefighter productivity on the fireground.

1.3 THESIS OBJECTIVES

The primary aim of this thesis was to investigate the effect of ambient heat on the work performance and physiological response of wildland firefighters. Specifically, the three studies that make up this thesis aimed to:

1. Quantify the effect of ambient heat (32°C) on firefighters' manual-handling work performance, thermal physiology (e.g., heart rate, core and skin temperature), perceptual responses (e.g., perceived exertion and thermal sensation), and adaptive behaviours (e.g., self-selected fluid intake) during simulated, prolonged wildfire suppression work when compared to the same work in a more temperate environment (19°C; Study 1).

2. Assess the cumulative effect of heat exposure (33°C) on firefighters' work performance, physiological, perceptual, and behavioural responses (as above) during prolonged, simulated wildfire suppression over three consecutive work days when compared to the same work under temperate ambient conditions (19°C; Study 2).

3. Measure wildland firefighters' work performance, thermal physiology, perception, and behaviour when performing a single simulated fireground task (rakehoe work) for three hours under very hot (45°C) ambient conditions, when compared to a temperate control condition (18°C; Study 3).

While applicable to the broader wildland firefighting community, the scope of this research focuses on firefighters from Southern Australia, and draws upon field research quantifying the physical and physiological demands of Australian wildfire suppression (Phillips et al. 2011; Phillips et al. 2012) to inform study design.

1.4 SIGNIFICANCE OF THE RESEARCH

This thesis will contribute valuable knowledge to the existing research investigating ambient heat as an occupational stressor. Previous research has, typically, fallen into one of two broad categories: field research that measures the physiological response of incumbents as they work, and laboratory studies utilising generic exercise protocols (e.g., treadmill walking) while manipulating ambient temperature. Whilst both approaches provide insight into the expected responses of individuals working (or exercising) in hot ambient temperatures, they are not without limitation. The former is descriptive with respect to temperature, and any results may be influenced by factors outside the scope of the study design (e.g., changes in fire behaviour). The latter typically does not reflect the work to rest ratios, durations, and movement patterns encountered during 'real' fire suppression work, and thus, application of the results may be limited. The current thesis aims to bridge the gap in the current body of knowledge by capturing the work demands of wildland firefighters, but in controlled, high-fidelity simulations. This type of design will allow for the quantification of changes in work output according to ambient temperature, as well the scale of the thermoregulatory response (e.g., core body temperature, heart rate), and the concurrent adaptive responses in behaviour (e.g., ad libitum fluid intake). In addition, the duration of the study designs and the range of ambient temperatures utilised reflect a novel contribution to the science in this area.

From a practical standpoint, this research will help inform the fire industry of the physical and physiological responses of their workforce under various ambient conditions. Understanding the implications of hot ambient temperatures with respect to firefighters' work output may be important for fire agencies in predicting the efficiency of their crews. For example, if the results demonstrate that firefighters selectively reduce their work output in hot (or very hot) conditions, fire agencies may choose to modify work practices (e.g., increase rest periods, reduce shift lengths) in the heat in order to maximise the effectiveness of wildfire suppression operations. Further, by better understanding the physiological stress placed on personnel working under hot ambient conditions, and the behavioural responses (if any) that accompany these responses, fire agencies may be better able to target strategies to minimise heat-related illness on the fireground.

1.5 REFERENCES

Aisbett, B and Nichols, D (2007), 'Fighting fatigue whilst fighting bushfire: an overview of factors contributing to firefighter fatigue during bushfire suppression', *The Australian Journal of Emergency Management,* 22 (3), 31-39.

Aisbett, B, Wolkow, A, Sprajcer, M, and 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), 916-25.

Aisbett, B, Phillips, M, Sargeant, M, Gilbert, B, and Nichols, D (2007), 'Fighting with fire: How bushfire suppression can impact on fire fighters' health', *Australian Family Physician,* 36 (12), 994-97.

Baldwin, T and Hales, T (2010), 'Fire fighter trainee suffers fatal exertional heat stroke during physical fitness training – Texas', (NIOSH Fire Fighter Fatality Investigation and Prevention Program).

Baldwin, T and Hales, T (2012), 'Wildland fire fighter dies from hyperthermia and exertional heatstroke while conducting mop-up operations - Texas', (NIOSH Fire Fighter Fatality Investigation Team,).

Baldwin, T and Hales, T (2014), 'Captain dies from hyperthermia and exertional heatstroke while performing advanced survival training - Texas', (NIOSH Fire Fighter Fatality Investigation and Prevention Program).

Bowman, DMJS, Balch, JK, Artaxo, P, Bond, WJ, Carlson, JM, Cochrane, MA, D'Antonio, CM, DeFries, RS, Doyle, JC, Harrison, SP, Johnston, FH, Keeley, JE, Krawchuk, MA, Kull, CA, Marston, JB, Moritz, MA, Prentice, IC, Roos, CI, Scott, AC, Swetnam, TW, van der Werf, GR, and Pyne, SJ (2009), 'Fire in the earth system', *Science,* 324 (5926), 481-84.

Campbell, C and Dalsey, L (2012), 'Wildland Fire Fighting Safety and Health', (NIOSH Science Blog: Centers for Disease Control and Prevention).

Cater, H, Clancy, D, Duffy, K, Holgate, A, Wilison, B, and Wood, J (2007), 'Fatigue on the fireground: The DPI Experience', *Australasian Fire Authorities Council/Bushfire Co-Operative Research Centre Annual Conference* (Hobart, Australia).

Cheney, NP (1976), 'Bushfire disasters in Australia, 1945–1975', *Australian Forestry,* 39 (4), 245-68.

Cheung, SS, McLellan, TM, and Tenaglia, S (2000), 'The thermophysiology of uncompensable heat stress: physiological manipulations and individual characteristics', *Sports Medicine,* 29 (5), 329-59.

Costello, JT, Stewart, KL, and Stewart, IB (2014), 'The effects of metabolic work rate and ambient environment on physiological tolerance times while wearing explosive and chemical personal protective equipment', *BioMed Research International*.

Cuddy, JS, Sol, JA, Hailes, WS, and Ruby, BC (2015), 'Work patterns dictate energy demands and thermal strain during wildland firefighting', *Wilderness & Environmental Medicine*.

Cuddy, JS, Gaskill, SE, Sharkey, BJ, Harger, SG, and Ruby, BC (2007), 'Supplemental feedings increase self-selected work output during wildfire suppression', *Medicine & Science in Sports & Exercise,* 39 (6), 1004-12.

Fahy, RF (2011), 'US firefighter deaths related to training, 2001-2010', (Fire Analysis and Research Division, National Fire Protection Association).

Hennessy, K, Lucas, C, Nicholls, N, Bathols, J, Suppiah, R, and Ricketts, J (2006), 'Climate change impacts on fire-weather in south-east Australia', in Bureau of Meteorology (ed.), (Canberra: Australian Government).

Hyde, AC, Blazer, A, Caudle, S, Clevette, RE, Shelly, JR, and Szayna, T (2008), '2007 US Forest Service & Department of Interior large wildfire cost review: assessing progress toward an integrated risk and cost fire management strategy', *Brookings Institution, US Secretary of Agriculture*.

Jackson, JS (2006), 'Fatality assessment and control evaluation report: Recruit fire fighter suffers heat stroke during physical fitness training and dies nine days later in Florida', (NIOSH Fire Fighter Fatality Investigation and Prevention Program).

Karter, MJ (2012), 'Patterns of firefighter fireground injuries', (Quincy, MA: National Fire Protection Association Fire - Analysis and Research Division).

Liu, Y, Stanturf, J, and Goodrick, S (2010), 'Trends in global wildfire potential in a changing climate', *Forest Ecology & Management,* 259 (4), 685-97.

Luber, G and McGeehin, M (2008), 'Climate change and extreme heat events', *American Journal of Preventive Medicine,* 35 (5), 429-35.

McLellan, TM and Selkirk, GA (2006), 'The management of heat stress for the firefighter: A review of work conducted on behalf of the Toronto fire service', *Industrial Health,* 44 (3), 414-26.

McLellan, TM, Jacobs, I, and Bain, JB (1993), 'Influence of temperature and metabolic rate on work performance with Canadian Forces NBC clothing', *Aviation, Space, And Environmental Medicine,* 64 (7), 587-94.

McLennan, J and Birch, A (2005), 'A potential crisis in wildfire emergency response capability? Australia's volunteer firefighters', *Environmental Hazards,* 6, 101-07.

Moritz, MA, Parisien, MA, Batllori, E, Krawchuk, MA, Van Dorn, J, Ganz, DJ, and Hayhoe, K (2012), 'Climate change and disruptions to global fire activity', *Ecosphere,* 3 (6), art49.

Morris, GJ, Nevill, ME, Lakomy, HKA, Nicholas, C, and Williams, C (1998), 'Effect of a hot environment on performance of prolonged, intermittent, high-intensity shuttle running', *Journal of Sports Sciences,* 16 (7), 677-86.

NFPA (2014), 'The United States Fire Service Fact Sheet', (2015; Massachusetts: Fire Analysis & Research Division).

NWCG (2014), 'Glossary of wildfire terminology', (Boise, ID: National Wildfire Coordinating Group, Program Management Unit).

Payne, WR, Portier, B, Fairweather, I, Zhou, S, and Snow, R (1994), 'Thermoregulatory response to wearing encapsulated protective clothing during simulated work in various thermal environments', *American Industrial Hygiene Association Journal,* 55 (6), 529-36.

Pechony, O and Shindell, DT (2010), 'Driving forces of global wildfires over the past millennium and the forthcoming century', *Proceedings of the National Academy of Sciences of the United States of America* (107), 19167-70.

Phillips, M, Payne, W, Lord, C, Netto, K, Nichols, D, and Aisbett, B (2012), 'Identification of physically demanding tasks performed during bushfire suppression by Australian rural firefighters', *Applied Ergonomics,* 43 (2), 435-41.

Phillips, M, Netto, K, Payne, W, Nichols, D, Lord, C, Brooksbank, N, Onus, K, Jefferies, S, and Aisbett, B (2011), 'Frequency, intensity and duration of physical tasks performed by Australian rural firefighters during bushfire suppression', in Thornton RP (ed.), *Bushfire CRC & AFAC Conference* (Sydney, Australia), 205-13.

Raines, J, Snow, R, Petersen, A, Harvey, J, Nichols, D, and Aisbett, B (2012), 'Pre-shift fluid intake: effect on physiology, work and drinking during emergency wildfire fighting', *Applied Ergonomics,* 43 (3), 532-40.

Raines, J, Snow, R, Petersen, A, Harvey, J, Nichols, D, and Aisbett, B (2013), 'The effect of prescribed fluid consumption on physiology and work behavior of wildfire fighters', *Applied Ergonomics,* 44 (3), 404-13.

Rodríguez-Marroyo, J, López-Satue, J, Pernía, R, Carballo, B, García-López, J, Foster, C, and Villa, J (2012), 'Physiological work demands of Spanish wildland firefighters during wildfire suppression', *International Archives of Occupational & Environmental Health,* 85 (2), 221-28.

Sawka, MN, Wenger, CB, and Pandolf, KB (2011), 'Thermoregulatory responses to acute exercise - heat stress and heat acclimation', *Comprehensive Physiology*.

Schmuck, G, San-Miguel-Ayanz, J, Camia, A, Durrant, T, Boca, R, Liberta, G, Petroliagkis, T, Di Leo, M, Rodrigues, D, and Boccacci, F (2014), 'Forest fires in Europe, Middle East and North Africa 2013', (Italy: Joint Research Centre, Institute for Environment and Sustainability.).

Shults, RA, Noonan, GP, and Turner, NL (1992), 'Investigation of a heat stress-related death of a fire fighter', *Fire Technology,* 28, 317-31.

Sköldström, B (1987), 'Physiological responses of fire fighters to workload and thermal stress', *Ergonomics,* 30 (11), 1589-97.

Smith, DL (2008), 'Firefighter fatalities and injuries: the role of heat stress and PPE', (Illinois: Firefighter Life Safety Research Center, Illinois Fire Service Institute).

Smith, DL, Petruzzello, SJ, Kramer, JM, and Misner, JE (1997), 'The effects of different thermal environments on the physiological and psychological responses of firefighters to a training drill', *Ergonomics,* 40 (4), 500-10.

Snook, SH and Ciriello, VM (1974), 'The effects of heat stress on manual handling tasks', *American Industrial Hygiene Association Journal,* 35 (11), 681-85.

Teague, B, McLeoud, R, and Pascoe, S (2010), '2009 Victorian Bushfires Royal Commission', (Parliament of Victoria).

Wilson, BD, Gisolfi, CV, and Smith, TF (1975), 'Thermal responses to intermittent work in selected environments', *American Industrial Hygiene Association Journal*, 648-52.

Chapter 2: Literature Review

2.1 INTRODUCTION

This review of the literature focuses on ambient heat and how it influences the performance, physiology, and behaviour of those performing manual-handling work, with an emphasis on wildland firefighting. The review begins by explaining the catastrophic effects of wildfire on a global scale, and then summarises future climate predictions and the projected impact on wildfire frequency and severity. The thermal stressors intrinsic to firefighting work are then outlined, and an overview of thermal physiology (i.e., how the body regulates temperature) under hot conditions is then presented. The physical and physiological demands of wildfire suppression are then described (with a focus on Australian wildland firefighting), and the potential negative health outcomes that may arise when performing fire suppression under hot ambient conditions are briefly examined. The review then discusses, in detail, the physiological, perceptual, and work performance responses of individuals performing work (or exercise) in the heat. The ways in which firefighters may attempt to regulate their thermal response (e.g., pacing their work efforts, increasing fluid intake) are also considered. Finally, the review will conclude by briefly highlighting the gaps in the current body of research knowledge.

2.2 WILDFIRE: A GLOBAL ISSUE

Wildfire is a global concern, causing widespread destruction in Europe, the Americas, Asia, and Australia (Aisbett et al. 2012; Bowman et al. 2009; Hyde et al. 2008; Schmuck et al. 2014). In fact, more than 30% of the earth's surface experiences significant wildfire frequency, across a vast range of climates and geographical latitudes (Chuvieco et al. 2008). Wildfires not only destroy millions of acres of land and cost billions in damages (Hyde et al. 2008; Teague et al. 2010), but annually threaten human life (Bushfire CRC 2009; Teague et al. 2010). For example, the South-East Asia and Latin America wildfires of the late 1990's cost an estimated $9 billion and $15 billion US dollars, respectively, with the latter burning over 20 million hectares of land (Bowman et al. 2009). In the summer of 2010, Russia experienced more than 500 wildfires, resulting in the loss of 30% of the country's grain harvest (Coumou and Rahmstorf 2012). In the US, the number, severity, and length of wildfires has increased markedly since the 1980's, now costing in excess of $1 billion dollars annually (Westerling et al. 2006). Finally, wildfires cause annual devastation in Australia, which is one of the most fire prone regions in the world (Aisbett et al. 2007; Bowman et al. 2009; Buxton et al. 2011). Most notably, the Victorian 'Black Saturday' bushfires in 2009 claimed 173 lives, which far exceeded the loss of life from any previous wildfire in Australia (Teague et al. 2010). More than 300 wildfires burned that day, destroying more than 2000 homes, and causing an estimated $4 billion in damages (Teague et al. 2010). Wildfires, accordingly, present a significant global threat to land and property, the economy, and most importantly, human life.

2.2.1 Future climate and wildfire predictions

The world is getting warmer, and the number of monthly heat records set globally is currently more than three times what would be expected in a stable climate (Coumou and Rahmstorf 2012). In recent times, the United States and Australia have been experiencing twice as many record hot days as record cold days (Coumou and Rahmstorf 2012; Dunlop and Brown 2008). Such an occurrence preceded the 'Black Saturday' fire disaster, where temperatures on the three days prior to the event exceeded 43°C (Coumou and Rahmstorf 2012; Teague et al. 2010), and temperature on the day peaked at 46.4°C (Teague et al. 2010). Indeed, heat events in Australia kill more people than any other natural hazard (PWC 2011). In 2010, central Russia experienced its hottest summer since 1500, and in July 2011 the US Southern plains suffered a record-breaking heatwave (Coumou and Rahmstorf 2012). Finally, the devastating European heatwave of 2003 represented the hottest summer in at least 500 years, and claimed 70,000 lives (Coumou and Rahmstorf 2012). While these events may be rare, their severity and the rate at which they occur is increasing (Coumou and Rahmstorf 2012; Hanna et al. 2011). Climate change research predicts that global warming will continue, at a quicker rate, in the coming century (Hanna et al. 2011; Liu et al. 2010; Luber and McGeehin 2008), which will almost certainly be accompanied by an increase in global wildfire activity (Bowman et al. 2009; Hennessy et al. 2006; Liu et al. 2010; Moritz et al. 2012; Pechony and Shindell 2010).

Over the past decade there has been a rise in the number of serious, uncontrolled wildfires on all vegetated continents, regardless of firefighting capacity and resources (Bowman et al. 2009). Globally, wildfires are projected to become more frequent, severe, and last for longer periods (Liu et al. 2010). For example, a two-fold increase in carbon dioxide (CO_2; as a result of climate change) in Northern California is predicted to double the frequency of uncontrolled wildfires and land area burnt (Fried et al. 2004). Worryingly, this represents a minimum expected change, and is in spite of the projected concurrent enhancement of fire suppression efforts (Fried et al. 2004). Depending on the model used, this increased fire activity is also predicted to result in an increased property loss of 12 – 75% (Westerling and Bryant 2008). A doubling of atmospheric CO_2 is also expected to cause an earlier start to the annual fire season in Canada and Russia, and significantly increase the number of 'extreme' fire danger days experienced in both countries (Stocks et al. 1998). More recently, ambient temperature has been shown to be the most important predictor of area burned by wildfire in Canada, and it is estimated that a continually warming climate will render Canadian fire agencies ineffective in suppressing wildfire within the next two decades (Flannigan et al. 2009).

In Australia, predicted increases in ambient temperature and evaporation of water resources, coupled with decreases in annual rainfall, will compound the risk of catastrophic wildfire events (Buxton et al. 2011; Dunlop and Brown 2008; Hennessy et al. 2006). It is predicted that, by 2020, the number of 'extreme' fire risk days in Australia will increase by 4 – 25%, and 15 – 70% by 2050 (Hennessy et al. 2006; Lucas et al. 2007). These environmental changes, alongside the ever-increasing population in high fire-risk areas (e.g., Victoria's urban fringe), will almost certainly coincide with greater losses of life and property as a result of wildfire (Buxton et al. 2011). It is clear, then, that wildland firefighters (both in Australia and internationally) will face significant challenges in the years ahead. A warming climate and the ensuing increases in fire frequency and severity will likely mean wildfire fighters will be charged with performing arduous fire suppression in the heat, more often. Thus, robust research into the effects of ambient heat on firefighter safety, work performance, physiology, and behaviour should be a priority.

2.3 THERMAL STRESSORS FACED DURING WILDFIRE SUPPRESSION

Performing physically demanding work in hot environments is an intrinsic part of many occupations (e.g., the military, mining), including firefighting (Aisbett and Nichols 2007; Cheung et al. 2010; Khogali 1997). Thermal stressors are abundant during wildfire suppression; not only are firefighters producing metabolic heat while performing the work (Budd et al. 1997d), but they do so under high ambient temperatures (Aisbett et al. 2012; Cheney 1976; Teague et al. 2010) and while sometimes exposed to radiant heat from the sun, or the fire itself (Budd 2001). Further, whilst the personal protective clothing (PPC) firefighters wear on shift is designed to protect personnel from heat exposure, in some cases it may exacerbate heat stress by impairing heat dissipation mechanisms (Cheung et al. 2000; Davis and Dotson 1987; Eglin 2007; Guidotti and Clough 1992).

2.3.1 Metabolic heat

While the metabolic heat generated through firefighting activities has been reviewed in some detail (Cheung et al. 2010; Eglin 2007; Rossi 2003), the focus of this work has been on structural rather than wildland firefighting. Structural firefighters are trained to attack fires threatening individual buildings in urban areas, and to protect adjoining (and nearby) structures (NFPA 2011). Wildland firefighters typically respond to forest fires, with a mission to protect natural resources (National Fire Protection Association 2011). Whilst wildland firefighters may sometimes be charged with the protection of homes and properties, the methods used to suppress fires, the PPC worn, and the tasks performed are inherently different between the two occupations (see Sections 2.3.3, 2.3.4, and 2.5.1, respectively, for more details). To the current author's knowledge, the only research to compare the relative contribution of metabolic heat storage with other thermal stressors during wildfire suppression is the Project Aquarius series (Budd et al. 1997b). One paper from this series specifically focused on the heat load elicited from physical exertion, weather, and fire during Australian wildfire suppression (Budd et al. 1997d). Metabolic heat (or exertion) accounted for 71% of the total heat load experienced by firefighters in the study, with fire and weather accounting for the remaining 29% (Budd et al. 1997d). Thus, metabolic heat as a result of the physical workload represents the major thermal stressor faced by wildland firefighters in the field. Further detail on the physical and physiological demands of wildfire fighting is presented in Section 2.5.2.

2.3.2 Ambient temperature/humidity

Typically, wildfires occur in hot, dry, and windy weather conditions (Aisbett et al. 2012). For example, fire events in Australia have been associated with ambient temperatures of 35 – 45°C, less than 20% humidity, and wind speeds of up to 75 $km.h^{-1}$ (Cheney 1976). In extreme cases, ambient temperatures in excess of 45°C have been recorded, such as during the devastating 'Black Saturday' fires (Teague et al. 2010). Despite hot weather being synonymous with wildland firefighting, there have been recorded instances where firefighters have performed their duties under mild to cool environmental conditions (Raines et al. 2012). Raines et al (2012) found that in the days following 'Black Saturday', firefighters were performing recovery operations in average ambient temperatures as low as 15.8°C. Given the range of environmental conditions under which wildland firefighters' work, fire agencies would benefit from understanding the effect of various environmental temperatures on firefighters' wellbeing and productivity.

2.3.3 Personal Protective Clothing

Firefighters encounter a range of hazards (e.g., heat, flames) that necessitate the use of protective clothing and equipment (Barr et al. 2010). Wildland firefighter PPC consists of a coverall, two-piece suit, helmet, gloves, and boots, and must be able to retain thermal stability up to 260°C (ISO 2011). Unfortunately, when the radiant heat load is relatively low, such protection may be granted at the expense of the body-heat balance. The increased metabolic cost of wearing PPC, coupled with the decreased ability to dissipate heat, often results in accelerated body heat storage (Barr et al. 2010; Cheung et al. 2000; Cheung et al. 2010; Havenith 1999; Taylor 2006). Metabolic rate has been shown to increase by 15.7% when wearing structural firefighting PPC during an obstacle course of simple physical tasks (e.g., walking, stepping, box-lifting), when compared to the same work in exercise attire (Dorman and Havenith 2009). Research investigating the effect of structural firefighting PPC has also observed increases in heart rate (Baker et al. 2000; Duncan et al. 1979; Eglin 2007; Faff and Tutak 1989), oxygen consumption (Baker et al. 2000; Duncan et al. 1979; Eglin 2007), skin temperature (Duncan et al. 1979), rectal temperature (Duncan et al. 1979; Eglin 2007), and body mass loss (Duncan et al. 1979; Faff and Tutak 1989) when compared to the same exercise in sports clothes. Further, cycling exercise duration was significantly reduced when firefighters wore structural PPC compared with exercise clothes (Faff and Tutak 1989). Although structural firefighting gear is typically heavier and differs somewhat to wildfire suppression PPC (e.g., structural firefighters utilise breathing apparatus, Australian wildland firefighters do not), it is possible that wildfire PPC would also induce some (or all) of these impairments on firefighter physiology and performance. Indeed, one study investigating wildland firefighting PPC (albeit ~18 years ago) showed that wildfire PPC hindered sweat evaporation, thereby increasing heat storage, cardiovascular strain, discomfort, and fatigue when compared to the same work in lighter clothing (i.e., coveralls only) (Budd et al. 1997f). Although there is a large body of work investigating the effects of various PPC ensembles on thermal stress, PPC use in wildfire fighting is mandatory, thus the consequences of wearing PPC (compared to other attire) will not be the focus of this review of the literature. However, research that includes the use of PPC when investigating the effect of heat will be preferentially drawn upon throughout the remainder of the review, as these findings may be more easily extrapolated to the wildland firefighting population.

2.3.4 Radiant heat

Exposure to radiant heat from the fire is an additional thermal stressor faced by wildland firefighters (Barr et al. 2010; Guidotti and Clough 1992; Rossi 2003), but one that has again garnered greater interest in the structural firefighting research community. Nevertheless, wildland firefighters may be exposed to radiant heat, either from the sun, the fire, or a combination of the two (Budd 2001). It is important to note, however, that wildland fire suppression typically falls into one of three categories: parallel, direct, or indirect attack

(Budd et al. 1997e; Rodríguez-Marroyo et al. 2011). During parallel attacks, firefighters build firebreaks close to the edge of the fire, but drop back to avoid intense heat or smoke (Budd et al. 1997e). Direct attacks require firefighters to work directly at the fire edge (e.g., to contain a spot fire), whereas indirect attacks refer to the tasks performed away (> 100 metres) from the fire-front (Budd et al. 1997e). In many cases, direct attacks may be difficult or even impossible during wildfire suppression (depending on the terrain, weather, fuel loading etc.), and thus, indirect attacks (i.e., building a firebreak some distance from the fire perimeter) are often preferred (FEMA 2002). Although some very brief periods of high radiant heat have been recorded at the fireline (the highest being 8.6 $kW.m^{-2}$), Budd et al (1997d) observed that wildland firefighters performing all types of wildfire suppression attacks (parallel, direct, and indirect) typically worked far enough away from the flames to avoid high radiant heat flux. In fact, the authors' suggested that the average radiant heat experienced by firefighters across all attack types in the study was little more than the intensity of sunlight (1.6 $kW.m^{-2}$ on average compared to 1.0 $kW.m^{-2}$ from the sun) (Budd et al. 1997a). These findings suggest that radiant heat (from the fire) may play a smaller role in the heat stress of wildland firefighters than it does for their structural firefighting counterparts (Budd et al. 1997d).

2.4 THERMAL PHYSIOLOGY IN HOT ENVIRONMENTS: A BRIEF OVERVIEW

Typically, when heat is generated through increased metabolic activity, such as during exercise (or work), the human body is able to maintain a thermal steady state by activating heat dissipation mechanisms (Cheung et al. 2000). However, hot and/or humid work environments impose additional thermal stress to the heat generated through the performance of physical tasks, thereby further challenging the ability of individuals to maintain thermal homeostasis (Cheung et al. 2000; Cheuvront et al. 2010). Further, the limited permeability of PPC (including firefighting PPC) creates a humid microclimate between the skin and the garment (Eglin 2007), and as a result, the evaporative heat loss required to maintain a thermal steady state can often exceed the evaporative capacity of the environment (Cheung et al. 2000; Cheuvront et al. 2010). Therefore, working in hot ambient conditions and wearing PPC are well-recognised risk factors for the development of heat illness (Cheung et al. 2000; Havenith 1999).

Exercising (or working) in hot conditions increases physiological strain, which can impair an individual's exercise capacity, and lead to exhaustion, heat illness, and ultimately death (Cheung and Sleivert 2004). Exercise heat stress can impede performance via impaired central nervous system, metabolic, and cardiovascular function (Cheuvront et al. 2010). During exercise in the heat, brain wave, motor-neural output, and sensory responses are impaired (Cheuvront et al. 2010; Nielsen and Nybo 2003), and substrate depletion in the muscle is accelerated (Cheuvront et al. 2010). For instance, muscle glycogen depletion is accelerated by heat stress, and oxidation rates of ingested carbohydrates are reduced (Cheuvront et al. 2010). Thus, limited fuel availability can contribute to impaired performance during prolonged, sub-maximal work in the heat (Cheuvront et al. 2010). Further, when core and skin temperature become elevated during exercise heat stress, heart rate increases (as cardiac filling and stroke volume decline), and muscle blood flow and blood pressure control are compromised (Cheuvront et al. 2010; Crandall and González-Alonso 2010; Hargreaves 2008). Cardiovascular impairments may be exacerbated by dehydration, which can reduce plasma volume, and further decrease cardiac filling and stroke volume (Armstrong et al. 2007; Cheuvront et al. 2010; Crandall and González-Alonso 2010). Finally, maximal oxygen uptake is also impaired during exercise in hot conditions, which limits maximal exercise performance (Cheuvront et al. 2010; Hargreaves 2008).

In order to avoid the many adverse consequences that may arise under conditions of exercise heat stress, the human body has an array of heat dissipation mechanisms. Elevations in skin blood flow and sweat rate are the key heat exchange mechanisms that defend against heat related illness (Crandall and González-Alonso 2010; Hargreaves 2008; Nybo et al. 2014; Wendt and van Loon 2007). Skin blood flow carries heat (via convection) from the skeletal muscles to the body surface for heat exchange with the external environment (Cheung et al. 2000; Nybo et al. 2014). However, when the ambient temperature exceeds body temperature, the body will gain rather than lose heat via radiation and convection (Wendt and van Loon 2007). Under these circumstances, evaporative heat loss via sweating becomes the primary means of heat dissipation (Wendt and van Loon 2007). Increased sweating will assist in cooling the skin via evaporative heat losses (Cheung et al. 2000; Nybo et al. 2014). However the rate of evaporation is dependent on the water pressure gradient between the skin and the external environment (Sawka and Wenger 1988), which will be minimised during exercise in a hot-humid environment, or via the use of PPC (Havenith 1999). In addition to heat loss via the skin, a small amount of heat will be dissipated through the lungs via respiration (Havenith 1999; Sawka and Wenger 1988).

Alongside the various physiological thermoregulation processes, behavioural thermoregulation can play an important role in managing heat strain (Nybo et al. 2014). Selectively decreasing work output (during self-paced exercise) in hot conditions has been shown to modulate body temperature regulation, relative to fixed pace exercise, under uncompensable heat stress conditions (Schlader et al. 2011). Another effective countermeasure in reducing heat storage during exercise in the heat is adequate hydration, both before and during exercise (Cheung et al. 2000; Wendt and van Loon 2007). Even minor levels of hypohydration will increase physiological strain and decrease exercise tolerance, whereas fluid replacement during exercise will decrease physiological strain and improve exercise tolerance (Cheung et al. 2000). For example, a body water deficit as small as 1% increases core body temperature during exercise in hot conditions, and this increase will be exacerbated as the body water deficit grows (Cheung et al. 2000; Sawka et al. 2011). Dehydration also increases heart rate, and decreases stroke volume and cardiac output, during exercise-heat stress, and causes exhaustion to occur at a lower core temperature (Cheung et al. 2000; Sawka et al. 2011). Finally, pre-cooling, clothing removal, and changing environment (e.g., moving to an air-conditioned space) are three other strategies which can mitigate exercise heat stress (Hargreaves 2008; Nybo et al. 2014; Sawka and Wenger 1988; Wendt and van Loon 2007), but may not always be practical, or even possible, in an occupational setting.

It is also important to note that individual characteristics play a role in how an individual will respond to exercise heat stress. Since the 1950's, heat acclimation has been recognised as an extremely important adaptation for workers performing physically demanding occupations (Peter and Wyndham 1966; Wyndham et al. 1954; Wyndham 1967). If a person is heat-acclimatised, their metabolic rate, oxygen uptake, heart rate, core body temperature, and blood lactate accumulation will be decreased during exercise in the heat relative to those who are not acclimatised (Cheung et al. 2000; Hargreaves 2008; Sawka et al. 2011). These changes occur in parallel with increases in stroke volume, sweating adaptations (e.g., increased sweat rate, earlier onset of sweating, and decreased sodium volume in sweat), and improvements in exercise tolerance time (Cheung et al. 2000; Hargreaves 2008; Sawka et al. 2011). People who are endurance trained exhibit many of the same characteristics of those who are heat-acclimatised, provided that their training is of a high enough intensity to increase core temperature and invoke the sweat response (Cheung et al. 2000; Sawka et al. 2011). Unfortunately, the thermoregulatory advancements gained through acclimatisation and/or aerobic fitness will be negated by dehydration (Sawka et al. 2011). The physiological heat strain of older adults is also generally greater than that of younger adults when exercising in the heat, however this difference may be somewhat attenuated if aerobic fitness and a healthy percentage of body fat is maintained into older adulthood (Sawka et al. 2011). Body composition, circadian patterns, sleep loss, race, certain medications, injuries, and illnesses will also play a role in how an individual responds to exercise heat stress (Sawka et al. 2011). Finally, the thermoregulatory response of women to exercise heat stress is dictated, at least in part, by the phase of their menstrual cycle (Cheung et al. 2000; Sawka et al. 2011).

2.5 WILDLAND FIREFIGHTING

2.5.1 Wildland firefighting in Australia

Given the size of the land mass, large distances between major cities, and relatively sparse human settlement, trained volunteer firefighters represent the primary response capacity to wildfire events in Australia (McLennan and Birch 2005). Rural fire services employ a small number of salaried or retained firefighters, however the bulk of the work-force is comprised of unpaid volunteers (McLennan and Birch 2005). It is estimated that the ratio of salaried to volunteer wildfire fighters is between 1:130 and 1:150, and that the total national volunteer population exceeds 220,000 (McLennan and Birch 2005). In concert with an ageing population at a national level, the Australian volunteer firefighting population is also getting older (McLennan 2008). For example, in 2006 the median age of volunteer firefighters in Victoria had increased to 46 years, compared to 41 years in 2001 (McLennan 2008).

During their shifts, Australian wildfire fighters primarily use fire-tanker hoses to deliver water and fire suppressants to the fireground, and use hand-tools such as rakehoes and axes to create firebreaks (i.e., clearing low-lying vegetation to manage fire spread) and perform 'blacking out' activities (i.e., inspecting burnt debris for embers post-fire) (Phillips et al. 2011; Phillips et al. 2012). Wildfire fighting is comprised of manual-handling actions such as carry, drag, dig, and rake (Phillips et al. 2012). In a study that used video footage, heart rate monitors, and GPS units to quantify the frequency, duration, and intensity of tasks performed by Australian tanker-based wildfire crews, five tasks (out of 34) were found to rank highly for at least two of the three task domains (Phillips et al. 2011). These tasks included operating a charged fire hose, building firebreaks with hand tools, using a charged hose during post-fire clean up (or 'blacking out'), laterally positioning a charged fire hose, and tightly coiling fire hoses (e.g., during pack up) (Phillips et al. 2011). While the tasks themselves were found to be relatively short in duration (averaging 17 seconds – 7.6 minutes, depending on the task) (Phillips et al. 2011), fire personnel regularly perform such tasks in shifts lasting 8 – 14 hours, over multiple days (Aisbett and Nichols 2007; Aisbett et al. 2007; Cater et al. 2007).

2.5.2 Physical and physiological demands of wildland firefighting

Researchers have attempted to characterise the physical demand of firefighting work through monitoring the physiological responses (e.g., heart rate, core body temperature) of firefighters during firefighting drills (Bilzon et al. 2001; Holmér and Gavhed 2007; Ilmarinen and Mlikinen 1992; Ilmarinen and Koivistoinen 1999; Perroni et al. 2010; Romet and Frim 1987; Rossi 2003; Smith and Petruzzello 1998; Smith et al. 2001) or actual fire events (Aisbett et al. 2007; Bos et al. 2004; Cuddy et al. 2007; Cuddy et al. 2015; Raines et al. 2012, 2013; Rodríguez-Marroyo et al. 2011; Rodríguez-Marroyo et al. 2012; Ruby et al. 2002). An important distinction to make is that some of this research reflects the physical demands of structural firefighting (Barr et al. 2010; Holmér and Gavhed 2007; Ilmarinen and Mlikinen 1992; Ilmarinen and Koivistoinen 1999; Perroni et al. 2010; Romet and Frim 1987; Rossi 2003; Smith and Petruzzello 1998; Smith et al. 2001), whilst others refer to the demands imposed on firefighters during wildland fire suppression (Aisbett and Nichols 2007; Cuddy et al. 2007; Cuddy et al. 2015; Raines et al. 2012, 2013; Raines et al. 2015; Rodríguez-Marroyo et al. 2011; Rodríguez-Marroyo et al. 2012; Ruby et al. 2002). Though structural firefighting is undoubtedly important, wildfire fighting is the focus of this thesis. Thus, this review of the literature will henceforth focus primarily on personnel performing wildfire suppression, drawing on the structural firefighting literature where appropriate.

The physical and physiological demands of wildfire fighting in the field have been measured during only a handful of studies, perhaps due to the impracticality of accessing firefighters prior to their shifts in a way that is safe for researchers and does not interfere with fire suppression efforts (Aisbett and Nichols 2007). Activity data quantifying wildland firefighter activity over the course of a shift (or over multiple shifts) has demonstrated a 'typical' energy expenditure in excess of 2.5 × basal metabolic rate (Cuddy et al. 2015; Ruby et al. 2002). However, wildfire suppression is characterised by predominantly low- to moderate-intensity work, interspersed with brief periods of strenuous physical activity (Aisbett and Nichols 2007; Cuddy et al. 2007; Cuddy et al. 2015; Phillips et al. 2011; Raines et al. 2013; Rodríguez-Marroyo et al. 2011).

Rodriguez-Marroyo and colleagues (2011; 2012) measured the heart rate of Spanish firefighters as they suppressed wildland fires. Depending on the length of fire suppression, and whether the fire suppression was direct (i.e., at the fire-front), indirect (i.e., away from the fire), or mixed (i.e., a combination of both), they observed mean heart rates ranging from 111 – 133 beats.min^{-1} and maximal heart rates of 165 – 175 beats.min^{-1} (Rodríguez-Marroyo et al. 2011; Rodríguez-Marroyo et al. 2012). Direct and mixed attacks elicited a greater heart rate response than indirect (Rodríguez-Marroyo et al. 2011). Similar results have been observed when investigating the physical demands of bushfire suppression in Australia, with firefighters eliciting average heart rates of 101 ± 13 beats.min^{-1} and peak heart rates of 169 ± 18 beats.min^{-1} (Aisbett and Nichols 2007). A very recent study by Cuddy et al (2015) examined the energy demands of firefighters performing three days of wildland firefighting in the US. Firefighters in this study elicited heart rates of < 100 beats.min^{-1} during 37 ± 19% of each shift, with only 5% of each shift being spent at > 160 beats.min^{-1} (Cuddy et al. 2015). Budd et al (1997a) observed higher average heart rates (152 ± 14 beats.min^{-1}) when firefighters exclusively performed simulated fireline raking tasks, and more recently, peak heart rates of 86% HR_{max} have been observed as wildfire fighters in the field built firebreaks using hand tools (Phillips et al. 2011). Finally, Australian wildfire fighters have been shown to cover 9.3 – 15.6 kilometres on foot during a standard fireground shift (Aisbett and Nichols 2007; Raines et al. 2013).

Researchers have also attempted to characterise the thermal stress and subjective experience of wildland firefighters when on duty. Raines et al (2012, 2013) measured core body temperature as firefighters performed a 'regular' shift of fire suppression duties in average daily temperatures ranging from 15.8 – 26.4°C (with peak temperatures as high as 33.9°C). The average core temperature for firefighters in the control groups during these studies (e.g., without prescribed fluids) was 37.4 ± 0.2°C, and peak core temperature was 38.1 ± 0.1°C. Spanish wildland firefighters have been observed to elicit mean core body temperatures ranging from 37.6 – 38.3°C during wildfire suppression (mean air temperatures ranging from 26.1 – 28.4°C, maximal air temperatures as high as 41.9°C), with peak core temperatures ranging from 37.8 – 39.2°C (again depending on the length and type of fire suppression performed) (Rodríguez-Marroyo et al. 2011; Rodríguez-Marroyo et al. 2012). During wildfire suppression in hot ambient conditions (peak ambient temperatures ranging from 31.8 – 36.1°C), US wildland firefighters have been observed to spend the majority of their shifts with core temperatures in the 37.5 – 38.0°C range, and only 1 ± 3% of the shift with core temperatures between 38.5 – 39.0°C (never exceeding 39°C) (Cuddy et al. 2015). However, skin temperatures were quite high during the same period, with firefighters spending more than half their shift with a chest skin temperature > 34°C (Cuddy et al. 2015). Budd et al (1997a) found that firefighters building a fireline in air temperatures ranging from 17 – 35°C under simulated fire conditions obtained average rectal temperature values of 38.2 ± 0.2°C, peaking at 38.6 ± 0.4°C. Further, firefighters performing this task reported that the work was 'somewhat hard' (14 on the RPE scale), felt 'just too warm' (6 on a 7-point Thermal Comfort scale), and that they were 'wet' with sweat (3 on a 4-point Perceived Sweatiness scale) (Budd et al. 1997a).

It is evident that, although highly variable, wildfire suppression can be physically strenuous. Perhaps surprisingly though, several of the field studies that have measured the physiological response of wildland firefighters suggest that the levels of exertion are, for the most part, manageable, and the heat load compensable (Cuddy et al. 2015; Raines et al. 2012, 2013; Rodríguez-Marroyo et al. 2011; Rodríguez-Marroyo et al. 2012). Nonetheless, there have been several documented cases of heat-related illness or even death among firefighters (see Section 2.6), which highlights the need for continued focus on the health and wellbeing of fire personnel working in hot environments, particularly under a warming climate.

2.6 POTENTIAL HEALTH OUTCOMES WHEN WORKING IN THE HEAT

For the purpose of this review, firefighter injury or illness will refer to any incident that requires medical attention or withdrawal from the fireground. Heat stroke is a severe illness characterised by core temperatures exceeding 40°C accompanied by central nervous system abnormalities (e.g., convulsions), whereas heat exhaustion refers to a more moderate illness resulting from body water or salt depletion during exposures to high ambient heat and/or strenuous physical activity (Bouchama and Knochel 2002). Heat exhaustion typically elicits symptoms such as dizziness, headache, and intense thirst (Bouchama and Knochel 2002).

Research into wildland firefighter illness and injury (including heat illness) is scarce in the Australian fire industry. However, there have been several documented cases in the US that highlight the possible devastating effects of performing wildland firefighting work in the heat (Baldwin and Hales 2010, 2012, 2014; Cuddy and Ruby 2011; Jackson 2006; Shults et al. 1992). Shults and colleagues (1992) investigated the heat-related death of a 25-year old US male firefighter that occurred during the clean-up phase of a wildfire. The deceased was considered to have good health and fitness and no previous history of heat illness, yet died after being exposed to a combination of high ambient temperatures (36.7°C), high predicted radiant heat loads (not reported), and moderate-heavy physical work (Shults et al. 1992). Additionally, two young trainee firefighters died due to exertional heat stroke during physical fitness training in Texas (Baldwin and Hales 2010) and Florida (Jackson 2006), in ambient conditions of just 23°C and 26°C, respectively. A 23-year old male wildland firefighter from Texas also died after performing standard fireground mop-up activities in 40.6°C heat (Baldwin and Hales 2012), and most recently, a 46-year old volunteer firefighter died from hyperthermia after performing advanced survival training in ~33°C (Baldwin and Hales 2014). Cuddy and Ruby (2011) also investigated a case of serious heat illness in a young (24 years) male wildland firefighter. This case was non-fatal but extremely severe; the subject recorded a core temperature of 40.1°C and presented with symptoms of heat stroke that required helicopter evacuation from the fireground. Whilst high ambient temperatures (mean of 44.6°C in the 2.5 hours leading up the heat exhaustion) coupled with arduous physical activity were the obvious catalysts behind the heat illness, this case was noteworthy as the firefighter consumed large amounts of water across the day (840 mL per hour in the seven hours leading up to the incident). This demonstrates, then, that heat-related incidents can occur during wildland fire suppression even with aggressive and sustained water intake.

In a large-scale analysis of US fire injury data from 2005 - 2009, Karter (2012) found that, annually, exhaustion or fatigue 'including heat exhaustion' accounted for 2150 out of 38,660 firefighter injury cases. Given the information provided, it is impossible to quantify the exact number of heat illness cases that make up this statistic. However, as 'overexertion during fireground tasks' and 'exposure to heat or flame' were identified as two of the primary causes of injury (Karter 2012), it is not unreasonable to assume that heat illness represented a significant proportion of the 2150 cases identified. Smith et al (2008), however, reported as many as 3550 US firefighters (both wildland and structural) injured due to thermal stress in 2005 alone. The authors also suggest that this number is probably underestimated, as heat stress could reasonably be one of the primary catalysts for the vast number of injuries attributed to sudden cardiac events and slips/trips/falls (Smith 2008). Lastly, 5% of firefighter fatalities that occurred during training in the 2001 – 2010 period in the US were attributed to heat stroke (Fahy 2011), and 2 – 6% of all injuries reported by leading wildfire agencies in Southern Australia over the 2003 – 2006 period were heat-related (Aisbett et al. 2007).

Despite the scarcity of robust injury research in the Australian wildland firefighting community, it is clear that heat-related illness is a concern for this sector, particularly when personnel are faced with working in a hot environment. Notwithstanding the physical and emotional toll on those affected, heat illness places a significant financial burden on industry in the form of both compensation (Bonauto et al. 2010) and lost work days (Bonauto et al. 2010; Donoghue et al. 2000). Given the potential for these negative consequences, it is extremely important to understand the relationship between various ambient temperatures and their effects on the work performance and physiology of personnel. If fire agencies (and other physically demanding industries) can quantify the effect of ambient temperature on work behaviour and physiology, they will be able to; a) reduce the likelihood of personnel developing heat-related illness on-shift, and b) maximise the performance capabilities of personnel, which in turn will optimise the effectiveness of the workforce. The review will now provide a brief outline of the current strategies various fire agencies (and other organisations) use to modify worker behaviour when faced with high ambient heat.

2.7 CURRENT HEAT POLICIES

As heat events become increasingly common, greater focus is being placed on heat-illness prevention programs at a national (PWC 2011) and international (Parsons 1999) level. Certain occupations associated with increased heat exposure have developed their own specific guidelines around working in the heat, in particular the military (Budd 2008; Bureau of Medicine and Surgery 2009), construction (Morioka et al. 2006; Rowlinson et al. 2014), and mining industries (Brake et al. 1998; Kalkowsky and Kampmann 2006; Leveritt 1998). For example, in the German coal mining industry, air temperature and Effective Temperature (ET; uses dry bulb temperature, wet bulb temperature, and air velocity to provide an indication of thermal comfort) are directly used to determine the shift length of mining personnel (Kalkowsky and Kampmann 2006). Working time is reduced to six hours for personnel working for > 3 hours at 25°C, five hours for miners spending > 2.5 hours at 29°C, and working above a ET of 30°C is prohibited entirely (Kalkowsky and Kampmann 2006). In some Australian mines, limits have been set for work at an ET of 29.4°C and a minimum air movement of 15.2 $m.min^{-1}$ (Leveritt 1998).

Several governing bodies (e.g., International Organization for Standardization, World Health Organization, National Institute for Occupational Safety and Health, the American Conference of Governmental Occupational Hygienists) have developed or recommended heat stress indices for occupational heat exposure (Maté and Oosthuizen 2012). There are currently a multitude of available heat stress indices in use. The most common and widely recognised of these is the Wet Bulb Globe Temperature (WBGT) index, a composite measure which estimates the effect of temperature, humidity, wind speed, and radiation on humans (ISO 2004; Taylor 2006). While setting threshold limit values based on the ambient environment may be feasible in some industries, heat exposure is an inherent feature of firefighting, and thus, removing firefighters from duty at a set ambient temperature limit is not practicable. An alternative to setting an environmental threshold is to monitor the workers themselves, and set physiological limits by which personnel are deemed safe or unsafe to continue work (Cotter and Tipton 2014; Khogali 1997; Maté and Oosthuizen 2012; Miller and Bates 2007b; Moran et al. 1998; Taylor 2006). Common heat indices based on an individual's physiological response are the Thermal Work Limit (TWL) and the Physiological Strain Index (PSI), which are assessed using metabolic rate (TWL), and heart rate and rectal temperature (PSI), respectively (Khogali 1997; Maté and Oosthuizen 2012).

While some US firefighting agencies have implemented physiological (e.g., heart rate) thresholds by which to monitor their personnel (California Department of Forestry and Fire Protection 2003; IAFF 2006), fire agencies more typically provide incumbents with only generalised recommendations on working in the heat (Country Fire Authority 2012; NSW Rural Fire Service 2011; Sharkey 2001; USFA 2008). Indeed, upon searching for heat stress policies for wildland firefighters in Australia, only general advice (e.g., in the form of websites, operations bulletins) could be found (Country Fire Authority 2012; Country Fire Service 2011; Dawson and Woods 2006; NSW Rural Fire Service 2011). For example, the Country Fire Authority in Victoria released an Operations Bulletin in 2012 (entitled 'Management of Heat Stress'; Appendix A). This bulletin provides firefighters with recommendations such as "ensure extra supplies of water and electrolyte drinks are available", "where possible task rotation should be used", and "implement cooling techniques" (Country Fire Authority 2012). While useful in a general sense, such advice reflects generic guidelines rather than evidence-based policy specific to wildland firefighters. In the absence of robust heat exposure policies, it is possible that firefighters in the field are being subjected to levels of thermal stress that are hazardous to human health. While field data suggests that wildland firefighters are generally able to maintain their levels of thermal stress within acceptable limits (Cuddy et al. 2015; Raines et al. 2012, 2013; Rodríguez-Marroyo et al. 2011; Rodríguez-Marroyo et al. 2012), firefighter injury data (albeit from the US) suggests that heat-related illness is still a very real threat to firefighter safety (Baldwin and Hales 2010, 2012, 2014; Cuddy and Ruby 2011; Karter 2012; Shults et al. 1992; Smith 2008). Therefore, this review of the literature will now turn its focus to research that specifically explores the effect of hot environmental temperatures on firefighters' physiological and perceptual responses.

2.8 PHYSIOLOGICAL AND PERCEPTUAL RESPONSES TO HEAT EXPOSURE

Quantifying the physiological and subjective responses to working in various ambient temperatures is important in preserving the safety and wellbeing of fire personnel. For example, knowledge of the expected thermal responses to firefighting work in the heat may allow fire agencies to intervene with hydration or cooling strategies to prevent heat-related illness on the fireground. As previously discussed, several field studies have measured the physiological and subjective responses of wildfire fighters while on duty (Aisbett and Nichols 2007; Budd et al. 1997a; Cuddy et al. 2015; Raines et al. 2012; Raines et al. 2015; Rodríguez-Marroyo et al. 2011; Rodríguez-Marroyo et al. 2012). Heart rate (Aisbett and Nichols 2007; Budd et al. 1997a; Cuddy et al. 2015; Raines et al. 2012; Raines et al. 2015; Rodríguez-Marroyo et al. 2012) and core body temperature (Budd et al. 1997a; Cuddy et al. 2015; Raines et al. 2012; Raines et al. 2015; Rodríguez-Marroyo et al. 2012) have been the most commonly measured indices of physiological strain in the wildland firefighting population to date, along with measures (either direct or proxy) of hydration status (Budd et al. 1997a; Cuddy et al. 2015; Raines et al. 2012; Raines et al. 2015). However, these field studies were designed to be descriptive with respect to temperature, rather than to explicitly assess the difference in physiological response across various ambient conditions. As such, this section of the review will focus on laboratory and simulation studies that have specifically manipulated the ambient environment in order to monitor the change in similar physiological variables. Attention will also be afforded to perceptual indices of thermal stress and exertion. An individual's subjective experience is an important moderator of self-paced work or exercise (Hampson et al. 2001; Seiler and Sjursen 2004; Tucker et al. 2006), which is a common feature of wildland firefighting (Budd 2001).

A small number of existing studies have investigated the physiological response to performing manual-handling work in the heat. Payne and colleagues (1994) assessed the thermoregulatory impact of performing simulated chemical accident clean-up work in ambient temperatures of 15, 22, and 30°C. Ten male participants wearing PPC completed the 30-minute work circuit, which comprised tasks such as walking while pulling a charged hose, moving 200-litre chemical drums, and moving 20-litre car buoys and stacks (Payne et al. 1994). Rectal temperatures (ranging from 37.40 – 37.44°C) and body mass change (ranging from 0.207 to 0.265 kg) were not different between the various ambient temperatures investigated in the study (Payne et al. 1994). Mean skin temperature, however, was significantly influenced by chamber temperature; an increase in ambient temperature from 15 to 30°C resulted in a rise of 2.15°C (Payne et al. 1994). Mean heart rate also increased with chamber temperature (101, 108, and 109 beats.min^{-1} at 15, 22, and 30°C, respectively), although the difference between the latter two ambient conditions was not statistically significant (Payne et al. 1994). Conversely, no differences were observed between conditions for participants' ratings of perceived exertion (mean RPE was 11 for each trial). Snook and Ciriello (1974) tested 16 male industrial workers in self-selected lifting, pushing, and carrying tasks at ambient temperatures of 22 and 30°C. They observed higher heart rates and rectal temperatures in the hotter condition (30°C) compared to the control trial (22°C) during the 40-minute work bouts (Snook and Ciriello 1974). For each task (lifting, pushing, and carrying), heart rate was 9 – 10 beats.min^{-1} higher in the hot condition, and rectal temperature was elevated by 0.2 – 0.3°C compared to the same task in the control trial (Snook and Ciriello 1974). Smith et al (1997) examined the physiological responses of firefighters performing a 16-minute simulated ceiling overhaul task in either a cool (13.7°C) or very hot (89.6°C) environment, while wearing structural PPC. When compared to the cool trial, firefighters in the heat experienced increases in heart rate (139 ± 11 vs. 176 ± 8 beats.min^{-1}), tympanic temperature (36.91 ± 0.61 vs. 39.82 ± 0.48°C), RPE and thermal sensation (~14 vs. ~16.5 and ~5.5 vs. ~7, respectively; these data presented in graph form only) (Smith et al. 1997). Finally, McLellan et al (1993) investigated soldiers performing an intermittent walking and lifting task in cool (18°C) and warm (30°C) environments at various intensities (e.g., differences in walking speed and weight lifted), wearing three different combinations of PPC. Irrespective of exercise intensity or PPC configuration, increases in rectal temperature, skin temperature, and body fluid loss were all exacerbated in the 30°C compared to the 18°C trial (McLellan et al. 1993).

These studies (McLellan et al. 1993; Payne et al. 1994; Smith et al. 1997; Snook and Ciriello 1974) are important as they represent the only readily available research that investigates the physiological and subjective responses to performing manual-handling work in the heat, compared to the same work in temperate conditions (in a controlled environment). However, it is probable that the protocols employed in these studies do not specifically reflect the work to rest ratios or the breadth of movement patterns encountered during wildfire suppression. It is also likely that the relatively short work protocols did not reflect the sustained thermal loads experienced by firefighters performing longer-duration work shifts (~12 hours). Thus, more research utilising wildfire-specific movement patterns, and work to rest ratios, over longer durations is required to better understand the physiological and subjective responses when performing wildland firefighting work in the heat. In the absence of such work, the review will now discuss the effect of ambient temperature on thermal stress and exertion during more commonly used exercise protocols. Numerous researchers have investigated the effect of ambient temperature on physiological mechanisms during cycling (Almudehki et al. 2012; Caldwell et al. 2012; Faff and Tutak 1989; Fink et al. 1975; Galloway and Maughan 1997; Gonzalez-Alonso et al. 1999; Hartley et al. 2012; Mohr et al. 2006; Nybo and Nielsen 2001; Parkin et al. 1999; Périard et al. 2011; Tucker et al. 2004). However, cycle ergometer protocols poorly reflect the movements and actions performed during wildfire suppression, and thus, will not be discussed further in this review. There is, however, a considerable body of work that utilises walking (or running) protocols to assess the physiological impact of ambient heat (Costello et al. 2014; Duncan et al. 1979; McLellan and Selkirk 2006; Morris et al. 1998; Sköldström 1987; Wilson et al. 1975), which may be of more relevance to certain aspects of wildland firefighting (e.g., patrolling).

Duncan et al (1979) had firefighters wearing structural PPC walk on a treadmill for 15 minutes at 4km.h^{-1} (10% gradient), in 16.3 and 41.8°C. Heart rates were significantly increased during the hot trial (173 ± 3 beats.min^{-1}) when compared to the cooler condition (136 ± 4 beats.min^{-1}). The heat also negatively impacted all measures of thermal stress; core and mean skin temperature increased by 0.56 ± 0.10°C and 5.69 ± 0.20°C in the hot condition, compared to only 0.23 ± 0.04°C and 1.30 ± 0.10°C in the control trial, respectively (Duncan et al. 1979). Additionally, body mass change (to reflect sweat loss) was higher in the 41.8°C environment (0.48 ± 0.05 kg) when compared to the 16.3°C environment (0.19 ± 0.03 kg) (Duncan et al. 1979). Sköldström (1987) had eight firefighters in structural PPC walk at 3.5km.h^{-1} on a treadmill, at 15 and 45°C, for one hour. Again, heart rate was significantly higher in the 45°C trial (169 ± 18 beats.min^{-1}) when compared to the cooler condition (100 ± 10 beats.min^{-1}) (Sköldström 1987). Ratings of perceived exertion coincided with heart rate, with firefighters rating the hot condition as 18 ± 1 compared to only 13 ± 2 in the cool condition (Sköldström 1987). Furthermore, thermal responses were also significantly elevated as a result of the heat exposure, with core and skin temperature values reaching 1.2 and 3.2°C higher, respectively, than in the cooler environment (Sköldström 1987). Wilson (1975) had four heat-acclimated participants walk intermittently on a treadmill for eight hours (40 minutes walking in the test environment: 40 minutes rest in 22°C, repeatedly) at 30% VO_{2max}, in 25, 35, 40, 45, and 50°C. Pooled rectal temperature data for the 25, 35, and 40°C conditions was 37.7°C on average over the course of the protocol, compared to 37.9 and 38.5°C for the 45 and 50°C conditions, respectively (Wilson et al. 1975). Similarly, heart rate was significantly increased in the latter two conditions (relative to the first three conditions, pooled) by 30 and 45 beats.min^{-1}, and there was a two-fold increase in sweating rate (Wilson et al. 1975). However, fluid intake also increased significantly with ambient temperature (e.g., fluids consumed at 50°C were double that at 40°C), and thus, participants in all conditions were able to maintain their body weight over the course of the trials (Wilson et al. 1975). Morris et al (1998) had 12 male university students perform prolonged, intermittent shuttle running until fatigue, in both 20 and 30°C. Despite decreasing the total distance covered in the hot trial, participants elicited significantly higher heart rate (186 ± 2 vs. 179 ± 2 beats.min^{-1}) and rectal temperature (39.4 ± 0.1 vs. 38.0 ± 0.1°C) values when compared to the more temperate condition (Morris et al. 1998). However, through doubling their fluid intake in the hot trial, there was no difference in participants' level of dehydration between trials, and comparable ratings of perceived exertion were reported (Morris et al. 1998). More recently, McLellan and Selkirk (2006) and Costello et al (2014) assessed the effect of environmental temperature on individuals performing treadmill walking whilst wearing PPC. However, the significant discrepancies in work tolerance time between conditions preclude direct comparisons of thermal physiology at individual time points, and thus, these studies will be discussed in more detail in Section 2.9.

All of the research discussed provides compelling evidence that exercising in the heat exacerbates the physiological and perceptual responses elicited through exercise in more temperate environmental conditions. However, there are various limitations that prohibit these findings being directly applied to the wildland firefighting population. Firstly, much of the research is too short in duration to reflect the thermal stress and exertion placed on wildland firefighters over the course of a work shift (or multiple shifts). Further, whether the work to rest ratios and movement patterns employed in the various studies serve as an appropriate proxy for the breadth of tasks performed by wildland firefighters is unknown. It is also possible that the individual characteristics of participants did not always reflect that of the wildland firefighting population (e.g., the mean age of participants across the five walking/running protocols was 26 years; Costello et al. 2014; Duncan et al. 1979; Morris et al. 1998; Sköldström 1987; Wilson et al. 1975). The existing manual-handling studies utilised slightly older participants (e.g., mean of 30 years; McLellan et al. 1993; Payne et al. 1994; Smith et al. 1997; Snook and Ciriello 1974), which may somewhat better reflect the ageing Australian wildfire fighting population (McLennan 2008). It is evident, then, that research directly simulating the movement patterns, work to rest ratios, and possible shift lengths of wildland firefighting, using a cohort that reflects the wildland firefighting population, is necessary to more accurately determine the effect of high ambient heat on firefighters' physiological and subjective responses. This research could, in turn, allow for the development of evidence-based work practices (e.g., cooling interventions) that protect the safety and wellbeing of the wildland firefighting cohort.

2.9 HEAT AND WORK PERFORMANCE

Whilst working in the heat is a well-documented risk factor for negative health outcomes (see Section 2.6), little research has investigated how ambient heat immediately impacts manual-handling work performance. Characterising the effect of heat exposure on the performance of wildfire suppression duties could allow for the implementation of workplace practices (e.g., flexible shift lengths) that best optimise the effectiveness of fire personnel. Thus, this review will now critique the available literature to provide some insight into the effects of heat on work (or exercise) performance.

Several field researchers have attempted to quantify differences in the work output of wildland firefighters according to environmental temperature. Rodriguez-Marroyo et al (2012) conducted a descriptive study of the work demands of Spanish wildland firefighters during wildfire suppression in warm-hot ambient conditions (average air temperature of ~27°C and maximal air temperature of 41.9°C), across different work durations (< 1h, 1 – 3h, 3 – 5h, > 5h). Despite the relatively low average work intensity observed in this study, work intensity (calculated using the TRIMP method) decreased as work duration increased, beginning after the first hour (Rodríguez-Marroyo et al. 2012). It is highly possible that ambient temperature played a role in the observed decrease in work intensity. However, the TRIMP score does not explicitly describe the work behaviour or productivity of personnel in relation to their wildfire suppression duties, but merely provides a 'score' integrating exercise intensity and duration using physiological markers of exertion (i.e., heart rate, respiratory gas exchange). Therefore, these findings reflect physiological responses (as a proxy for work) rather than actual work output. Relying on heart rate as an index of work output may be problematic, as heart rate can increase independently of changes in ambient temperature (e.g., as a result of dehydration) (Cheung et al. 2000; Sawka et al. 2011). Additionally, without a control condition from which to draw comparisons, it is not possible to make firm conclusions as to the effect of heat on the performance of fireground duties. Apud and Meyer (2011) investigated the various factors that influence the workload of Chilean wildland firefighters performing wildfire suppression. Specifically, the rate at which firefighters were able to construct a fireline ($m^2.min^{-1}$) during different environmental conditions (e.g., different ambient temperatures) was evaluated (Apud and Meyer 2011). It was observed that, when ambient temperatures reached 90°C (due to extremely high radiant heat loads), firefighters were working at a rate of 1.7 $m^2.min^{-1}$, which was equivalent to only 12% of the highest value (8.7$m^2.min^{-1}$) recorded during the work shift (Apud and Meyer 2011). However, reviewing this study is problematic, as only very select data are reported. Further, the performance findings are at times counter-intuitive. The highest workload was reported in ambient temperatures of close to 60°C; the rate of fireline construction at this temperature was higher than at all temperatures ranging from 15 - 55°C, at times by almost 80% (Apud and Meyer 2011). This strongly suggests that factors other than ambient temperature (e.g., fire behaviour) were dictating the work output of firefighters, which makes it difficult to tease out the precise influence of heat on work performance. It is also possible that firefighters performed different work tasks at different times (e.g., in a different order) across a given work shift. If this is the case, fireline construction on its own may poorly reflect work productivity as a whole in this study, particularly given that direct attacks (and the ensuing exposure to such radiant heat loads) make up only a portion of the work performed by wildland firefighters in the field (Budd et al. 1997e; FEMA 2002; Rodríguez-Marroyo et al. 2011). Thus, without further information provided by the authors, it is difficult to quantify the effect of ambient temperature on the overall performance of fire suppression duties. Budd et al (1997c) also studied environmental factors (i.e., ambient temperature) and their influence on work productivity in men constructing firebreaks (using hand tools). Air temperature across all trials in this study ranged from 17.4 – 35.4°C. Contrary to previous findings (Apud and Meyer 2011; Rodríguez-Marroyo et al. 2012), regression analyses indicated that the total energy expenditure of firefighters decreased only a small, insignificant percentage as air temperature increased (Budd et al. 1997c). These findings should, however, be extrapolated to all wildland fire settings with caution. The 'Project Aquarius' series that encompassed this research focused only on the hand tool work performed by firefighters during fire suppression (Budd et al. 1997b). Hand tool work (e.g., building a firebreak using a rakehoe) is often repetitive and continuous, as opposed to the intermittent, varied-intensity nature of other tasks commonly performed during wildfire suppression (Phillips et al. 2011). Therefore, this study provides only partial insight into the work tasks performed by wildland firefighters on duty (Phillips et al. 2012).

Field research inherently contains confounding variables that may limit the interpretation of performance findings. For instance, the external environment cannot be controlled, and therefore it is possible that factors outside the scope of the study design could play a role in the results obtained. As an example, firefighters in the field may be given directions by a supervisor that dictates their work choices, which may be incorrectly attributed to an effect of the ambient environment. Alternatively, dehydration may have played a role in impeding fire suppression performance in the field beyond that of the ambient environment alone. However, with the exception of the Project Aquarius work (which measured body mass change) (Budd et al. 1997c), neither of the other field studies measured firefighters' hydration status (Apud and Meyer 2011; Rodríguez-Marroyo et al. 2012). While field research is undeniably important in order to understand how research findings can be implemented in an applied setting, the results may not truly reflect the influence of ambient temperature on work behaviour if factors that may sway the findings of the research are not reported. Thus, this review of the literature will now move towards studies that have utilised a more rigorously controlled laboratory setting to assess the effect of heat on work/exercise performance. As in previous sections, cycling protocols will be excluded from review, as the movements performed are too different from wildland firefighting to be extrapolated to firefighting task performance.

Despite the number of personnel (across various occupations) that perform manual-handling work, there is a paucity of research that investigates the effect of ambient temperature on manual-handling work performance. As discussed in Section 2.8 of this review, Snook and Ciriello (1974) tested male industrial workers performing generalised manual-handling tasks in both 22 and 30°C. Participants were asked to lift and carry a 33 × 48 x 14-cm box, and push against a stationary bar on a manually powered treadmill, for 40 minutes. Nine participants were able to self-select the frequency at which they performed the tasks, and were asked at the end of the 40-minute work period whether they could maintain the selected task frequency for an eight-hour day without unreasonable fatigue. The remaining seven participants had the opportunity to adjust the load being lifted, carried, or pushed during the 40 minutes of work. The combined responses from both sets of participants (i.e., those that self-selected frequency and those that manipulated load) showed that, when working in the heat, lifting and carrying performance were reduced by 20% and 11%, respectively, and the force exerted during the pushing task was reduced by 16% (Snook and Ciriello 1974). However, the fact that performance responses across both types of work were combined (rather than reported separately) makes it difficult quantify the extent to which participants adjusted their workload across the course of the protocol (i.e., as they were being exposed to the hot environment). Further, there was no measure of hydration reported in this study (either pre-, during-, or post-protocol), and thus, it is possible that participants' hydration status may have played a role in the performance results observed. McLellan et al (1993) assessed soldiers' work tolerance time (WTT) as they performed intermittent 'light' exercise (walking 1.11m.s^{-1} at 0% grade, alternating with lifting 10kg) and 'heavy' exercise (walking 1.33 m.s^{-1} at 7.5% grade, alternating with lifting 20kg) in three different PPC configurations, at 18 and 30°C. Although the focus of this study was the difference in performance and physiological responses according to PPC load, it is also possible (by looking at the WTT graphs) to assess the effect of the ambient environment on performance. With the exception of the 'low' PPC garments during 'light' exercise, WTT was reduced in the heat for all other combinations of PPC and exercise type (McLellan et al. 1993). For example, during the 'heavy' exercise trials, WTT in the 'low' PPC was 300 minutes in the cool and ~170 minutes in the heat (McLellan et al. 1993). Similarly, in the 'medium' and 'high' PPC trials, WTT was ~240 and ~60 minutes in the cool compared to only ~70 and ~40 minutes in the 30°C condition (McLellan et al. 1993). Although their application to wildland firefighting may not be perfect, these studies suggest that decrements in performance will be observed in individuals performing manual-handling tasks under hot ambient conditions.

In the absence of further studies investigating the effect of ambient heat on manual-handling work performance, this review will now discuss the effect of heat on WTT during walking/running exercise protocols. McLellan and Selkirk (2006) examined the effects of various ambient temperatures (25, 30, and 35°C) on the performance of very light-, light-, moderate-, and heavy-intensity treadmill walking. The participants (structural firefighters) wore PPC and carried self-contained breathing apparatus while performing 20-minute bouts of walking followed by 10 minutes rest, repeated until exhaustion (McLellan and Selkirk 2006). At all work intensities, participants' time to exhaustion was reduced as ambient temperature increased (McLellan and Selkirk 2006). For instance, during light exercise, time to exhaustion was 134 ± 9.3 minutes in 25°C compared to only 67.3 ± 3.0 minutes in 35°C. In fact, time to exhaustion was reduced by 28 – 56% in the 35°C condition (relative to the 25°C trial), depending on the exercise intensity (McLellan and Selkirk 2006). Similarly, Costello et al (2014) observed significant decreases in the WTT of healthy males wearing chemical and explosion-resistant PPC (> 35kg) as both work intensity and WBGT increased, despite equivalent body mass loss across ambient conditions. In this study, participants performed treadmill walking at three different speeds (2.5, 4, and 5.5 $km.h^{-1}$) at a WBGT of 21, 30, and 37°C (Costello et al. 2014). Even at the slowest walking speed, tolerance time was reduced in the hottest condition (to 33.5 minutes) when compared to the 21°C trial

(52.1 minutes) (Costello et al. 2014). Finally, Morris et al (1998) found that the total distance covered by students performing intermittent, high-intensity shuttle running in the heat was reduced (to 8842 ± 790 m) compared to the same task in a moderate environment (11,280 ± 214 m), again in spite of comparable body mass loss between the two ambient conditions.

The research discussed throughout this section of the review provides compelling evidence that ambient heat negatively affects work and exercise performance. However, there are limitations that prevent this research from being directly extrapolated to predict the impact of heat on the performance of wildfire suppression duties. As previously discussed, field research fundamentally contains confounding factors that may skew findings or mask the actual mechanisms behind the results. The more rigorously controlled laboratory experiments go some way towards correcting this problem, but do not currently reflect the breadth of movements, fitness components, and work to rest ratios that make up wildland firefighting. To date, the tasks performed have been general rather than specialised, and do not reflect the work to rest ratios of firefighting work. Furthermore, the duration of the work protocols have, for the most part, been relatively short compared to a firefighting shift (~12 hours), and changes in hydration status have not always been measured (or reported). Thus, the inherent interaction between heat, dehydration, and work performance during manual-handling work performance warrants further research attention. Finally, while the ambient temperatures tested may reflect the temperatures encountered during some fire conditions, they give little insight into the 'extremes' encountered on the fireground; for example, the range of ambient temperatures (15.8 to 45°C) firefighters were exposed to during and following the Black Saturday fire disaster (Raines et al. 2012; Teague et al. 2010).

2.9.1 Multiple days of work in the heat

As previously discussed (see Section 2.5.1), wildland firefighters often perform consecutive work shifts under hot ambient conditions. However, few research studies have attempted to measure occupational work performance over multiple days. There are, however, three wildland firefighting studies that have measured the activity level of wildfire fighters over consecutive work shifts (Cuddy et al. 2015; Raines et al. 2015; Ruby et al. 2002). Cuddy et al (2015) observed that US firefighters performing wildfire suppression over three days decreased their activity from day one to day two, and again between days two and three (Cuddy et al. 2015). Conversely, Raines et al (2015) found that Australian firefighters performing two consecutive days of planned-burn operations maintained comparable activity levels between days one and two, and Ruby (2002) found that firefighters total energy expenditure was stable across a five-day bout of wildfire suppression. The contrary findings observed in these studies are not altogether surprising given the likely differences between planned burns and actual wildfire suppression (e.g., in preparedness, severity of the fire etc.), and the inherent variability in wildfire behaviour (and subsequent suppression duties). Ambient temperature during these studies was considered hot (peak daily ambient temperatures ranging between 31.8 – 39°C; Cuddy et al. 2015; Raines et al. 2015; Ruby et al. 2002), and thus, it is not unreasonable to assume that heat could have played a fatiguing role both within and between shifts. However, there are no comparable studies conducted during more temperate (or indeed, very hot) ambient conditions from which to draw comparisons. Likewise, while physical activity data provides some insight into the work output of fire personnel, it is not a direct measure of work performance. For example, an increase in activity could reflect firefighters increasing their work output to more efficiently build a firebreak, or an increase in the distance walked by a wildland firefighter as they await instructions from supervisors. Finally, the inherently variable nature of wildfire suppression in the field prohibits the direct measurement of the effect of ambient heat on performance outcomes, irrespective of other factors (e.g., severity of the fire, supervisor instructions, competency of other fire crew members, terrain etc.).

A study in construction workers performing three consecutive work shifts in hot-very hot conditions (32.5 to 49°C) has suggested that these workers self-paced their work efforts in order to avoid adverse physiological consequences (Bates and Schneider 2008). However, no measure of work performance is measured in this study; rather, the authors have drawn this conclusion based on the fact that thermoregulatory responses (e.g., aural temperature) were relatively stable across the three-day period. While this is perhaps not an unreasonable conclusion, the absence of any measure of work precludes thorough understanding of the workers' productivity during this period.

The difficulty in using the existing multi-day field literature to predict performance outcomes in the heat over consecutive days is evident. There is, however, a considerable body of heat acclimation research that involves exposing participants to heat over multiple days (Castle et al. 2011; Garrett et al. 2009; Garrett et al. 2012). Unfortunately, the heat exposure periods are too short (< 90 minutes), and the modes of exercise too far removed from fire suppression (e.g., cycling, rowing), to be of direct use. These studies are explicitly designed so that participants gain the benefits of repeated exercise heat exposure (see Section 2.4), and thus, are not likely to induce an equivalent level of fatigue as an 8 – 14 hour firefighting work shift comprised of intermittently performed manual-handling tasks. Given that firefighters are commonly exposed to consecutive days of high ambient temperatures whilst performing long shifts of arduous physical work (Aisbett and Nichols 2007; Aisbett et al. 2007), research investigating the accumulative effect of heat exposure over multiple days on firefighters' work performance is warranted. In order to improve, or even just measure, the capacity of fire crews performing wildfire suppression in different ambient environments, controlled research that reflects the work demands of firefighting is essential. To date, no such research fulfils these requirements. This fundamental work will serve as a platform for researchers and the wildland firefighting sector to better understand the operational capacities of personnel deployed to campaign fires.

2.10 HEAT AND ADAPTIVE BEHAVIOURS

The final topic that will be discussed in this review of the literature is that of adaptive behaviours. Given that working in the heat is an inherent characteristic of wildland firefighting (Aisbett and Nichols 2007; Aisbett et al. 2012), it is possible that firefighters have developed work practices (e.g., self-pacing) or other behaviours (e.g., increased fluid consumption) that allow them to complete their duties in a safe manner. Indeed, Snook and Ciriello (1974) observed that participants self-selected lighter loads when performing manual-handling work tasks in the heat. However, the same study also observed that these decreases in workload were not substantial enough to moderate physiological responses; heart rate and core temperature were still significantly elevated compared to those reported in the control condition (Snook and Ciriello 1974). It is possible, then, that individuals do not have a firm understanding of their physiological limits when performing manual-handling work in the heat. Unfortunately, it is difficult to assess this hypothesis, as the remaining research investigating manual-handling or walking performance under hot conditions has done so using a sustained exercise modality. However, firefighting work is largely self-paced (albeit with some external pressures; e.g., instructions from superiors, the fire itself) (Budd et al. 1997b; Budd 2001), and thus, set-paced exercise protocols may not best reflect the influence of heat on the performance of wildland firefighting duties.

Results from sporting literature suggests that people performing self-paced exercise in the heat anticipate early fatigue and, thus, decrease their level of exertion in an attempt to sustain the exercise and maintain thermal homeostasis (Cheung and Sleivert 2004; Cheuvront et al. 2010; Tucker et al. 2004; Tucker 2009; Tucker and Noakes 2009). This is in contrast to set-paced exercise, in which thermal fatigue (e.g., substantial elevations in core temperature) usually occurs, and ultimately results in cessation of the activity (Cheung and Sleivert 2004; Cheuvront et al. 2010). However, cycling has been the major focus of research investigating set vs. self-paced exercise in the heat to date (Hartley et al. 2012; Schlader et al. 2011; Tucker et al. 2004), and so the direct applicability of such research to the carry, drag, dig, and rake actions performed during wildland firefighting (Phillips et al. 2012) may be limited. If indeed firefighters selectively reduce their work output under hot ambient conditions, this would have significant implications for the fire industry. If fire agencies were able to predict the level of drop-off in the performance of wildfire suppression tasks according to ambient temperature, they would then be able to make informed decisions in order to maximise the wildfire suppression effort (e.g., by allocating more personnel to a task to ensure that it is completed in a timely manner). Therefore, further research that allows firefighters to pace themselves as they would on the fireground, while measuring the concurrent effects on fire suppression productivity, would be a valuable addition to the current body of knowledge.

Working in PPC in hot ambient conditions results in profuse sweating, and thus, without adequate fluid replacement individuals can quickly dehydrate (Barr et al. 2010; Kenefick and Sawka 2007). It has been observed that structural firefighters performing live firefighting activities in a hypohydrated state elicit greater cardiovascular strain than those performing the same work while euhydrated (Brown et al. 2007). Inadequate water intake is known to exacerbate the cardiovascular and thermoregulatory strain placed on an individual performing exercise in the heat, and reduce heat tolerance (Cheung et al. 2000; Cheuvront et al. 2010; Hargreaves 2008; Montain and Coyle 1992). Nevertheless, personnel across a number of physically demanding industries (e.g., forestry workers, miners, industrial workers) have been observed to arrive on shift in a hypohydrated state (Bates et al. 2001; Bates et al. 2009; Biggs et al. 2011; Brake and Bates 2003; Miller and Bates 2007a; Miller and Bates 2010), including Australian wildland firefighters (Raines et al. 2012; Raines et al. 2015). However, when conditions were cool – moderately hot, the latter cohort have been observed to consume enough fluids across their workday to complete their shifts in a euhydrated state (Raines et al. 2012). Unfortunately, the same may not be true in hot conditions (peak of 37°C), where Australian wildland fire personnel have been observed to remain equally (though not more) hypohydrated at the end of their work shift (Raines et al. 2015). Internationally, there is evidence to suggest that wildland firefighters in the US have increased their water intake during fire suppression (relative to 15 years ago), perhaps due to a strong emphasis being placed on fluid consumption during safety briefings (Cuddy et al. 2015). While these descriptive field studies show some promise that firefighters are able to self-regulate drinking behaviour in a way that moderates their physiological response (at least under temperate – moderately hot conditions), the regularity in which heat illness occurs on the fireground (see Section 2.6) suggests that this may not be the case under all circumstances. Further, these studies are not designed to compare differences between ambient conditions, and thus, it is not possible to determine if workers preferentially adapt their drinking behaviour in hotter temperatures. There is currently a paucity of manual-handling research investigating the inherent interaction between work performance and hydration status. Thus, future research should aim to explore the relationship between different ambient temperatures, fluid intake, physiology, and work performance in a controlled environment.

2.11 CONCLUSION

The world is getting warmer, and future increases in global temperature will almost certainly correspond with a significant escalation in wildfire activity worldwide. Therefore, wildland firefighters will more frequently be tasked with performing their duties under conditions of high ambient heat. While the existing field research shows that the heat load placed on wildland firefighters is often compensable, the number of fireground injuries, and even fatalities, attributed to hot weather suggests that heat illness is still a very real threat to firefighter health and safety. A more thorough understanding of the physiological response to performing such work under an array of ambient conditions may allow fire agencies to target specific areas for intervention. Even more scarce, however, is research investigating the performance outcomes associated with suppressing wildland fires in the heat. With fires predicted to rapidly become more frequent and severe, maximising firefighter productivity will likely become a top priority for fire agencies in the coming years. To date, little is known about the way firefighters pace their work efforts in different ambient temperatures. Therefore, future research should aim to quantify the physiological and work performance outcomes of performing wildfire suppression in the heat, with the aim of preserving firefighter health and safety whilst also optimising the effectiveness of the workforce.

2.12 REFERENCES

Aisbett, B and Nichols, D (2007), 'Fighting fatigue whilst fighting bushfire: an overview of factors contributing to firefighter fatigue during bushfire suppression', *The Australian Journal of Emergency Management,* 22 (3), 31-39.

Aisbett, B, Wolkow, A, Sprajcer, M, and 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), 916-25.

Aisbett, B, Phillips, M, Sargeant, M, Gilbert, B, and Nichols, D (2007), 'Fighting with fire: How bushfire suppression can impact on fire fighters' health', *Australian Family Physician,* 36 (12), 994-97.

Almudehki, F, Girard, O, Grantham, J, and Racinais, S (2012), 'Hot ambient conditions do not alter intermittent cycling sprint performance', *Journal of Science and Medicine in Sport,* 15 (2), 148-52.

Apud, E and Meyer, F (2011), 'Factors influencing the workload of forest fire-fighters in Chile', *Work: A Journal of Prevention, Assessment and Rehabilitation,* 38 (3), 203-09.

Armstrong, LE, Casa, DJ, Millard-Stafford, M, Moran, DS, Pyne, SW, and Roberts, WO (2007), 'American College of Sports Medicine position stand: Exertional heat illness during training and competition', *Medicine & Science in Sports & Exercise,* 39 (3), 556-72.

Baker, SJ, Grice, J, Roby, L, and Matthews, C (2000), 'Cardiorespiratory and thermoregulatory response of working in fire-fighter protective clothing in a temperate environment', *Ergonomics,* 43 (9), 1350-58.

Baldwin, T and Hales, T (2010), 'Fire fighter trainee suffers fatal exertional heat stroke during physical fitness training – Texas', (NIOSH Fire Fighter Fatality Investigation and Prevention Program).

Baldwin, T and Hales, T (2012), 'Wildland fire fighter dies from hyperthermia and exertional heatstroke while conducting mop-up operations - Texas', (NIOSH Fire Fighter Fatality Investigation Team,).

Baldwin, T and Hales, T (2014), 'Captain dies from hyperthermia and exertional heatstroke while performing advanced survival training - Texas', (NIOSH Fire Fighter Fatality Investigation and Prevention Program).

Barr, D, Gregson, W, and Reilly, T (2010), 'The thermal ergonomics of firefighting reviewed', *Applied Ergonomics,* 41 (1), 161-72.

Bates, G, Parker, R, Ashby, L, and Bentley, T (2001), 'Fluid intake and hydration status of forest workers - A preliminary investigation', *International Journal of Forest Engineering,* 12 (2), 27-32.

Bates, GP and Schneider, J (2008), 'Hydration status and physiological workload of UAE construction workers: A prospective longitudinal observational study', *Journal of Occupational Medicine & Toxicology,* 3, 1-10.

Bates, GP, Miller, VS, and Joubert, DM (2009), 'Hydration status of expatriate manual workers during summer in the Middle East', *Annals of Occupational Hygiene*, 1-7.

Biggs, C, Paterson, M, and Maunder, E (2011), 'Hydration status of South African forestry workers harvesting trees in autumn and winter', *Annals of Occupational Hygiene,* 55 (1), 6-15.

Bilzon, JLJ, Scarpello, EG, Smith, CV, Ravenhill, NA, and Rayson, MP (2001), 'Characterization of the metabolic demands of simulated shipboard Royal Navy fire-fighting tasks', *Ergonomics,* 44 (8), 766-80.

Bonauto, D, Rauser, E, and Lim, L (2010), 'Occupational Heat Illness in Washington State, 2000 – 2009', (Safety & Health Assement & Research for Prevention, Washington State Department of Labor & Industries).

Bos, J, Mol, E, Visser, B, and Frings-Dresen, MHW (2004), 'The physical demands upon (Dutch) fire-fighters in relation to the maximum acceptable energetic workload', *Ergonomics,* 47 (4), 446-60.

Bouchama, A and Knochel, J (2002), 'Heat stroke', *New England Journal of Medicine,* 346 (25), 1978-88.

Bowman, DMJS, Balch, JK, Artaxo, P, Bond, WJ, Carlson, JM, Cochrane, MA, D'Antonio, CM, DeFries, RS, Doyle, JC, Harrison, SP, Johnston, FH, Keeley, JE, Krawchuk, MA, Kull, CA, Marston, JB, Moritz, MA, Prentice, IC, Roos, CI, Scott, AC, Swetnam, TW, van der Werf, GR, and Pyne, SJ (2009), 'Fire in the earth system', *Science,* 324 (5926), 481-84.

Brake, DJ and Bates, GP (2003), 'Fluid losses and hydration status of industrial workers under thermal stress working extended shifts', *Occupational and Environmental Medicine,* 60 (2), 90-96.

Brake, R, Donoghue, M, and Bates, G (1998), 'A new generation of health and safety protocols for working in heat', *1998 Queensland Mining Industry Health and Safety Conference*.

Brown, J, Derchak, A, Bennett, A, LePore, M, and Edwards, S (2007), 'Impact of pre-participation hydration status on structural firefighter cardio-respiratory response to standard training activities', Medicine & Science in Sports & Exercise, 39 (5), 139.

Budd, GM (2001), 'How do wildland firefighters cope? Physiological and behavioural temperature regulation in men suppressing Australian summer bushfires with hand tools', *Journal of Thermal Biology,* 26, 381-86.

Budd, GM (2008), 'Wet-bulb globe temperature (WBGT)—its history and its limitations', *Journal of Science and Medicine in Sport,* 11 (1), 20-32.

Budd, GM, Brotherhood, JR, Hendrie, AL, Jeffery, SE, Beasley, FA, Costin, BP, Zhien, W, Baker, MM, Cheney, NP, and Dawson, MP (1997a), 'Project Aquarius 7. Physiological and subjective responses of men suppressing wildland fires', *International Journal of Wildland Fire,* 7 (2), 133-44.

Budd, GM, Brotherhood, JR, Hendrie, AL, Jeffery, SE, Beasley, FA, Costin, BP, Zhien, W, Baker, MM, Cheney, NP, and Dawson, MP (1997b), 'Project Aquarius 1. Stress, strain, and productivity in men suppressing Australian summer bushfires with hand tools: background, objectives, and methods', *International Journal of Wildland Fire,* 7 (2), 69-76.

Budd, GM, Brotherhood, JR, Hendrie, AL, Jeffery, SE, Beasley, FA, Costin, BP, Zhien, W, Baker, MM, Cheney, NP, and Dawson, MP (1997c), 'Project Aquarius 10. Effects of work, weather, and fire on the energy expenditure, strain, and productivity of men suppressing wildland fires', *International Journal of Wildland Fire,* 7 (2), 167-80.

Budd, GM, Brotherhood, JR, Hendrie, AL, Jeffery, SE, Beasley, FA, Costin, BP, Zhien, W, Baker, MM, Cheney, NP, and Dawson, MP (1997d), 'Project Aquarius 6. Heat load from exertion, weather, and fire in men suppressing wildland fires', *International Journal of Wildland Fire,* 7 (2), 119-31.

Budd, GM, Brotherhood, JR, Hendrie, AL, Jeffery, SE, Beasley, FA, Costin, BP, Zhien, W, Baker, MM, Cheney, NP, and Dawson, MP (1997e), 'Project Aquarius 4. Experimental bushfires, suppression procedures, and measurements', *International Journal of Wildland Fire,* 7 (2), 99-104.

Budd, GM, Brotherhood, JR, Hendrie, AL, Jeffery, SE, Beasley, FA, Costin, BP, Zhien, W, Baker, MM, Hoschke, BN, Holcombe, BV, Cheney, NP, and Dawson, MP (1997f), 'Project Aquarius 13. The thermal burden of high insulation and encapsulation in wildland firefighters' clothing', *International Journal of Wildland Fire,* 7 (2), 207-18.

Bureau of Medicine and Surgery (2009), 'Heat and cold stress injuries (ashore, afloat, and ground forces)', (Washington DC: Manual of Naval Preventative Medicine).

Bushfire CRC (2009), 'Victorian 2009 bushfire research response: Final report', (East Melbourne: Bushfire Co-Operative Research Centre).

Buxton, M, Haynes, R, Mercer, D, and Butt, A (2011), 'Vulnerability to bushfire risk at melbourne's urban fringe: The failure of regulatory land use planning', *Geographical Research,* 49 (1), 1-12.

Caldwell, JN, Patterson, MJ, and Taylor, NAS (2012), 'Exertional thermal strain, protective clothing and auxiliary cooling in dry heat: evidence for physiological but not cognitive impairment', *European Journal of Applied Physiology,* 112 (10), 3597-606.

California Department of Forestry and Fire Protection (2003), 'Preventing heat illness', (California Department of Forestry and Fire Protection).

Castle, P, Mackenzie, RW, Maxwell, N, Webborn, ADJ, and Watt, PW (2011), 'Heat acclimation improves intermittent sprinting in the heat but additional pre-cooling offers no further ergogenic effect', *Journal of Sports Sciences,* 29 (11), 1125-34.

Cater, H, Clancy, D, Duffy, K, Holgate, A, Wilison, B, and Wood, J (2007), 'Fatigue on the fireground: The DPI Experience', *Australasian Fire Authorities Council/Bushfire Co-Operative Research Centre Annual Conference* (Hobart, Australia).

Cheney, NP (1976), 'Bushfire disasters in Australia, 1945–1975', *Australian Forestry,* 39 (4), 245-68.

Cheung, SS and Sleivert, GG (2004), 'Multiple triggers for hyperthermic fatigue and exhaustion', *Exercise & Sport Sciences Reviews,* 32 (3), 100-06.

Cheung, SS, McLellan, TM, and Tenaglia, S (2000), 'The thermophysiology of uncompensable heat stress: physiological manipulations and individual characteristics', *Sports Medicine,* 29 (5), 329-59.

Cheung, SS, Petersen, SR, and McLellan, TM (2010), 'Physiological strain and countermeasures with firefighting', *Scandinavian Journal of Medicine & Science in Sports,* 20, 103-16.

Cheuvront, SN, Kenefick, RW, Montain, SJ, and Sawka, MN (2010), 'Mechanisms of aerobic performance impairment with heat stress and dehydration', *Journal Of Applied Physiology,* 109 (6), 1989-95.

Chuvieco, E, Giglio, L, and Justice, C (2008), 'Global characterization of fire activity: Toward defining fire regimes from Earth observation data', *Global Change Biology,* 14 (7), 1488-502.

Costello, JT, Stewart, KL, and Stewart, IB (2014), 'The effects of metabolic work rate and ambient environment on physiological tolerance times while wearing explosive and chemical personal protective equipment', *BioMed Research International.*

Cotter, JD and Tipton, MJ (2014), 'Moving in extreme environments: What's extreme and who decides?', *Extreme Physiology & Medicine,* 3 (1), 11.

Coumou, D and Rahmstorf, S (2012), 'A decade of weather extremes', *Nature,* 2, 491-96.

Country Fire Authority (2012), 'Management of Heat Stress', *Operations Bulletin* (Fire and Emergency Management), 1-5.

Country Fire Service (2011), 'CFS Fact Sheet: How people die in bushfires and how they survive', (Government of South Australia).

Crandall, CG and González-Alonso, J (2010), 'Cardiovascular function in the heat-stressed human', *Acta Physiologica,* 199 (4), 407-23.

Cuddy, JS and Ruby, BC (2011), 'High work output combined with high ambient temperatures caused heat exhaustion in a wildland firefighter despite high fluid intake', *Wilderness & Environmental Medicine,* 22 (2), 122-25.

Cuddy, JS, Sol, JA, Hailes, WS, and Ruby, BC (2015), 'Work patterns dictate energy demands and thermal strain during wildland firefighting', *Wilderness & Environmental Medicine*, 26 (2), 221-26.

Cuddy, JS, Gaskill, SE, Sharkey, BJ, Harger, SG, and Ruby, BC (2007), 'Supplemental feedings increase self-selected work output during wildfire suppression', *Medicine & Science in Sports & Exercise,* 39 (6), 1004-12.

Davis, PO and Dotson, CO (1987), 'Physiological aspects of fire fighting', *Fire Technology,* 23, 280-91.

Dawson, M and Woods, B (2006), 'Medical guidelines for firefighters: Summary document', (Australasian Fire Authorities Council Health and Fitness Working Group).

Donoghue, AM, Sinclair, MJ, and Bates, GP (2000), 'Heat exhaustion in a deep underground metalliferous mine', *Occupational And Environmental Medicine,* 57 (3), 165-74.

Dorman, LE and Havenith, G (2009), 'The effects of protective clothing on energy consumption during different activities', *European Journal of Applied Physiology,* 105 (3), 463-70.

Duncan, HW, Gardner, GW, and Barnard, RJ (1979), 'Physiological responses of men working in fire fighting equipment in the heat', *Ergonomics,* 22 (5), 521-27.

Dunlop, M and Brown, PR (2008), 'Implications of climate change for Australia's national reserve system: A preliminary assessment', (Canberra, Australia: Department of Climate Change, Department of the Environment, Water, Heritage and the Arts).

Eglin, CM (2007), 'Physiological responses to fire-fighting: Thermal and metabolic considerations', *Journal of the Human-Environmental System,* 10 (1), 7-18.

Faff, J and Tutak, T (1989), 'Physiological responses to working with fire fighting equipment in the heat in relation to subjective fatigue', *Ergonomics,* 32 (6), 629-38.

Fahy, RF (2011), 'US firefighter deaths related to training, 2001-2010', (Fire Analysis and Research Division, National Fire Protection Association).

FEMA (2002), 'Introduction to wildland/urban interface firefighting for the structural company officer', (Federal Emergency Management Agency, U.S. Department of Homeland Security).

Fink, WJ, Costill, DL, and Van Handel, PJ (1975), 'Leg muscle metabolism during exercise in the heat and cold', *European Journal of Applied Physiology & Occupational Physiology,* 34 (3), 183-90.

Flannigan, M, Stocks, B, Turetsky, M, and Wotton, M (2009), 'Impacts of climate change on fire activity and fire management in the circumboreal forest', *Global Change Biology,* 15 (3), 549-60.

Fried, JS, Torn, MS, and Mills, E (2004), 'The impact of climate change on wildfire severity: A regional forecast for Northern California', *Climatic Change,* 64 (1-2), 169-91.

Galloway, SD and Maughan, RJ (1997), 'Effects of ambient temperature on the capacity to perform prolonged cycle exercise in man', *Medicine & Science in Sports & Exercise,* 29 (9), 1240-49.

Garrett, A, Creasy, R, Rehrer, N, Patterson, M, and Cotter, J (2012), 'Effectiveness of short-term heat acclimation for highly trained athletes', *European Journal of Applied Physiology,* 112 (5), 1827-37.

Garrett, AT, Goosens, NG, Rehrer, NG, Patterson, MJ, and Cotter, JD (2009), 'Induction and decay of short-term heat acclimation', *European Journal of Applied Physiology,* 107 (6), 659-70.

Gonzalez-Alonso, J., Teller, C., Andersen, S. L., Jensen, F. B., Hyldig, T., and Nielsen, B. (1999), 'Influence of body temperature on the development of fatigue during prolonged exercise in the heat', *Journal of Applied Physiology,* 86 (3), 1032-39.

Guidotti, TL and Clough, VM (1992), 'Occupational health concerns of firefighting', *Annual Review Of Public Health,* 13, 151-71.

Hampson, DB, Gibson, A, Lambert, MI, and Noakes, TD (2001), 'The influence of sensory cues on the perception of exertion during exercise and central regulation of exercise performance', *Sports Medicine,* 31 (13), 935-52.

Hanna, EG, Kjellstrom, T, Bennett, C, and Dear, K (2011), 'Climate change and rising heat: population health implications for working people in Australia', *Asia-Pacific Journal of Public Health,* 23 (2 Suppl.), 14-26.

Hargreaves, M (2008), 'Physiological limits to exercise performance in the heat', *Journal of Science and Medicine in Sport,* 11 (1), 66-71.

Hartley, GL, Flouris, AD, Plyley, MJ, and Cheung, SS (2012), 'The effect of a covert manipulation of ambient temperature on heat storage and voluntary exercise intensity', *Physiology & Behavior,* 105 (5), 1194-201.

Havenith, G (1999), 'Heat balance when wearing protective clothing', *Annals of Occupational Hygiene,* 43 (5), 289-96.

Hennessy, K, Lucas, C, Nicholls, N, Bathols, J, Suppiah, R, and Ricketts, J (2006), 'Climate change impacts on fire-weather in south-east Australia', in Bureau of Meteorology (ed.), (Canberra: Australian Government).

Holmér, I and Gavhed, D (2007), 'Classification of metabolic and respiratory demands in fire fighting activity with extreme workloads', *Applied Ergonomics,* 38 (1), 45-52.

Hyde, AC, Blazer, A, Caudle, S, Clevette, RE, Shelly, JR, and Szayna, T (2008), '2007 US Forest Service & Department of Interior large wildfire cost review: assessing progress toward an integrated risk and cost fire management strategy', *Brookings Institution, US Secretary of Agriculture*.

IAFF (2006), 'Thermal heat stress protocol for fire fighters and hazmat responders', (International Association of Fire Fighters).

Ilmarinen, R and Mlikinen, H (1992), 'Heat strain in fire-fighting drills', *The Fifth International Conference on Environmental Ergonomics* (Manstricht, The Netherlands), 90-91.

Ilmarinen, R and Koivistoinen, K (1999), 'Heart rate and thermal responses in prolonged job-related fire-fighting drills', *International Ergonomics VIII. International Series on Environmental Ergonomics* (San Diego, CA), 99-102.

ISO (2004), 'ISO 9886: Ergonomics - Evaluation of thermal strain by physiological measurements', (Geneva: International Organization for Standardization).

ISO (2011), 'ISO 16073: Wildland firefighting personal protective equipment — Requirements and test methods', (Geneva: International Organization for Standardization).

Jackson, JS (2006), 'Fatality assessment and control evaluation report: Recruit fire fighter suffers heat stroke during physical fitness training and dies nine days later in Florida', (NIOSH Fire Fighter Fatality Investigation and Prevention Program).

Kalkowsky, B and Kampmann, B (2006), 'Physiological strain of miners at hot working places in German coal mines', *Industrial Health,* 44 (3), 465-73.

Karter, MJ (2012), 'Patterns of firefighter fireground injuries', (Quincy, MA: National Fire Protection Association Fire - Analysis and Research Division).

Kenefick, RW and Sawka, MN (2007), 'Hydration at the work site', *Journal of the American College of Nutrition,* 26 (5), 597-603.

Khogali, M (1997), 'Heat illness alert program. Practical implications for management and prevention', *Annals Of The New York Academy Of Sciences,* 813, 526-33.

Leveritt, S (1998), 'Heat stress in mining', *Work-Safe Australia Ergonomics Review*.

Liu, Y, Stanturf, J, and Goodrick, S (2010), 'Trends in global wildfire potential in a changing climate', *Forest Ecology & Management,* 259 (4), 685-97.

Luber, G and McGeehin, M (2008), 'Climate change and extreme heat events', *American Journal of Preventive Medicine,* 35 (5), 429-35.

Lucas, C, Hennessy, K, Mills, G, and Bathols, J (2007), 'Bushfire weather in southeast Australia: Recent trends and projected climate change impacts', in Bushfire CRC & CSIRO (ed.), (Melbourne, Australia: The Climate Institute of Australia).

Maté, J and Oosthuizen, J (2012), 'Global warming and heat stress among Western Australian mine, oil and gas workers', *Environmental Health – Emerging Issues and Practice*, 289-307.

McLellan, TM and Selkirk, GA (2006), 'The management of heat stress for the firefighter: A review of work conducted on behalf of the Toronto fire service', *Industrial Health,* 44 (3), 414-26.

McLellan, TM, Jacobs, I, and Bain, JB (1993), 'Influence of temperature and metabolic rate on work performance with Canadian Forces NBC clothing', *Aviation, Space, And Environmental Medicine,* 64 (7), 587-94.

McLennan, J (2008), 'Issues facing Australian volunteer-based emergency services organisations: 2008 – 2010 ', (Melbourne, Australia: Research Group (CDRG), La Trobe University).

McLennan, J and Birch, A (2005), 'A potential crisis in wildfire emergency response capability? Australia's volunteer firefighters', *Environmental Hazards,* 6, 101-07.

Miller, V and Bates, G (2007a), 'Hydration of outdoor workers in north-west Australia', *Journal of Occupational Health and Safety Australia and New Zealand,* 23 (1), 79.

Miller, VS and Bates, GP (2007b), 'The Thermal Work Limit is a simple reliable heat index for the protection of workers in thermally stressful environments', *Annals of Occupational Hygiene,* 51 (6), 553-61.

Miller, VS and Bates, GP (2010), 'Hydration, hydration, hydration', *Annals of Occupational Hygiene,* 54 (2), 134-36.

Mohr, M, Rasmussen, P, Drust, B, Nielsen, B, and Nybo, L (2006), 'Environmental heat stress, hyperammonemia and nucleotide metabolism during intermittent exercise', *European Journal of Applied Physiology,* 97 (1), 89-95.

Montain, SJ and Coyle, EF (1992), 'Influence of graded dehydration on hyperthermia and cardiovascular drift during exercise', *Journal of Applied Physiology,* 73 (4), 1340-50.

Moran, DS, Shitzer, A, and Pandolf, KB (1998), 'A physiological strain index to evaluate heat stress', *American Journal of Physiology: Regulatory, Integrative & Comparative Physiology,* 44 (1), 129.

Morioka, I, Miyai, N, and Miyashita, K (2006), 'Hot environment and health problems of outdoor workers at a construction site', *Industrial Health,* 44 (3), 474-80.

Moritz, MA, Parisien, MA, Batllori, E, Krawchuk, MA, Van Dorn, J, Ganz, DJ, and Hayhoe, K (2012), 'Climate change and disruptions to global fire activity', *Ecosphere,* 3 (6), art49.

Morris, GJ, Nevill, ME, Lakomy, HKA, Nicholas, C, and Williams, C (1998), 'Effect of a hot environment on performance of prolonged, intermittent, high-intensity shuttle running', *Journal of Sports Sciences,* 16 (7), 677-86.

National Fire Protection Association (2015), 'Understanding fire behavior: Structural vs. Wildland fire operations', *Firewise Communities Program* 13/04/2015.

Nielsen, B and Nybo, L (2003), 'Cerebral changes during exercise in the heat', *Sports Medicine,* 33 (1), 1-11.

NSW Rural Fire Service (2011), 'Community Fire Unit Training Manual ', (NSW Rural Fire Service).

Nybo, L and Nielsen, B (2001), 'Hyperthermia and central fatigue during prolonged exercise in humans', *Journal of Applied Physiology,* 91 (3), 1055.

Nybo, L, Rasmussen, P, and Sawka, MN (2014), 'Performance in the heat—physiological factors of importance for hyperthermia-induced fatigue', *Comprehensive Physiology,* 4, 657-89.

Parkin, JM, Carey, MF, Zhao, S, and Febbraio, MA (1999), 'Effect of ambient temperature on human skeletal muscle metabolism during fatiguing submaximal exercise', *Journal of Applied Physiology,* 86 (3), 902-08.

Parsons, KC (1999), 'International standards for the assessment of the risk of thermal strain on clothed workers in hot environments', *Annals of Occupational Hygiene,* 43 (5), 297-308.

Payne, WR, Portier, B, Fairweather, I, Zhou, S, and Snow, R (1994), 'Thermoregulatory response to wearing encapsulated protective clothing during simulated work in various thermal environments', *American Industrial Hygiene Association Journal,* 55 (6), 529-36.

Pechony, O and Shindell, DT (2010), 'Driving forces of global wildfires over the past millennium and the forthcoming century', *Proceedings of the National Academy of Sciences of the United States of America* (107), 19167-70.

Périard, JD, Cramer, MN, Chapman, PG, Caillaud, C, and Thompson, MW (2011), 'Neuromuscular function following prolonged intense self-paced exercise in hot climatic conditions', *European Journal of Applied Physiology,* 111 (8), 1561-69.

Perroni, F, Tessitore, A, Cortis, C, Lupo, C, D'Artibale, E, Cignitti, L, and Capranica, L (2010), 'Energy cost and energy sources during a simulated firefighting activity', *The Journal of Strength & Conditioning Research,* 24 (12), 3457-63.

Peter, J and Wyndham, CH (1966), 'Activity of the human eccrine sweat gland during exercise in a hot humid environment before and after acclimatization', *The Journal of Physiology,* 187 (3), 583-94.

Phillips, M, Payne, W, Lord, C, Netto, K, Nichols, D, and Aisbett, B (2012), 'Identification of physically demanding tasks performed during bushfire suppression by Australian rural firefighters', *Applied Ergonomics,* 43 (2), 435-41.

Phillips, M, Netto, K, Payne, W, Nichols, D, Lord, C, Brooksbank, N, Onus, K, Jefferies, S, and Aisbett, B (2011), 'Frequency, intensity and duration of physical tasks performed by Australian rural firefighters during bushfire suppression', in Thornton RP (ed.), *Bushfire CRC & AFAC Conference* (Sydney, Australia), 205-13.

PWC (2011), 'Protecting human health and safety during severe and extreme heat events - A national framework', (Department of Climate Change and Energy and Efficiency), 86.

Raines, J, Snow, R, Nichols, D, and Aisbett, B (2015), 'Fluid intake, hydration, work physiology of wildfire fighters working in the heat over consecutive days', *Annals of Occupational Hygiene*, 1-12.

Raines, J, Snow, R, Petersen, A, Harvey, J, Nichols, D, and Aisbett, B (2012), 'Pre-shift fluid intake: effect on physiology, work and drinking during emergency wildfire fighting', *Applied Ergonomics,* 43 (3), 532-40.

Raines, J, Snow, R, Petersen, A, Harvey, J, Nichols, D, and Aisbett, B (2013), 'The effect of prescribed fluid consumption on physiology and work behavior of wildfire fighters', *Applied Ergonomics,* 44 (3), 404-13.

Rodríguez-Marroyo, J, López-Satue, J, Pernía, R, Carballo, B, García-López, J, Foster, C, and Villa, J (2012), 'Physiological work demands of Spanish wildland firefighters during wildfire suppression', *International Archives of Occupational & Environmental Health,* 85 (2), 221-28.

Rodríguez-Marroyo, JA, Villa, JG, López-Satue, J, Pernía, R, Carballo, B, García-López, J, and Foster, C (2011), 'Physical and thermal strain of firefighters according to the firefighting tactics used to suppress wildfires', *Ergonomics,* 54 (11), 1101-08.

Romet, T and Frim, J (1987), 'Physiological responses to fire fighting activities', *European Journal of Applied Physiology,* 56 (6), 633-38.

Rossi, R (2003), 'Fire fighting and its influence on the body', *Ergonomics,* 46 (10), 1017-33.

Rowlinson, S, YunyanJia, A, Li, B, and ChuanjingJu, C (2014), 'Management of climatic heat stress risk in construction: a review of practices, methodologies, and future research', *Accident Analysis & Prevention,* 66, 187-98.

Ruby, BC, Shriver, TC, Zderic, TW, Sharkey, BJ, Burks, C, and Tysk, S (2002), 'Total energy expenditure during arduous wildfire suppression', *Medicine & Science in Sports & Exercise,* 34 (6), 1048-54.

Sawka, MN and Wenger, CB (1988), 'Physiological responses to acute exercise-heat stress', (Natick, MA: U.S. Army Research Institute of Environmental Medicine), 84.

Sawka, MN, Wenger, CB, and Pandolf, KB (2011), 'Thermoregulatory responses to acute exercise - heat stress and heat acclimation', *Comprehensive Physiology.*

Schlader, Z, Raman, A, Morton, R, Stannard, S, and Mündel, T (2011), 'Exercise modality modulates body temperature regulation during exercise in uncompensable heat stress', *European Journal of Applied Physiology,* 111 (5), 757-66.

Schmuck, G, San-Miguel-Ayanz, J, Camia, A, Durrant, T, Boca, R, Liberta, G, Petroliagkis, T, Di Leo, M, Rodrigues, D, and Boccacci, F (2014), 'Forest fires in Europe, Middle East and North Africa 2013', (Italy: Joint Research Centre, Institute for Environment and Sustainability.).

Seiler, S and Sjursen, JE (2004), 'Effect of work duration on physiological and rating scale of perceived exertion responses during self-paced interval training', *Scandinavian Journal of Medicine & Science in Sports,* 14 (5), 318-25.

Sharkey, B (2001), 'Wildland firefighter health & safety report: Heat stress', (Missoula Technology and Development Center).

Shults, RA, Noonan, GP, and Turner, NL (1992), 'Investigation of a heat stress-related death of a fire fighter', *Fire Technology,* 28, 317-31.

Sköldström, B (1987), 'Physiological responses of fire fighters to workload and thermal stress', *Ergonomics,* 30 (11), 1589-97.

Smith, DL (2008), 'Firefighter fatalities and injuries: the role of heat stress and PPE', (Illinois: Firefighter Life Safety Research Center, Illinois Fire Service Institute).

Smith, DL and Petruzzello, SJ (1998), 'Selected physiological and psychological responses to live-fire drills in different configurations of firefighting gear', *Ergonomics,* 41 (8), 1141-54.

Smith, DL, Petruzzello, SJ, Kramer, JM, and Misner, JE (1997), 'The effects of different thermal environments on the physiological and psychological responses of firefighters to a training drill', *Ergonomics,* 40 (4), 500-10.

Smith, DL, Petruzzello, SJ, Chludzinski, MA, Reed, JJ, and Woods, JA (2001), 'Effect of strenuous live-fire fire fighting drills on hematological, blood chemistry and psychological measures', *Journal of Thermal Biology,* 26 (4-5), 375-79.

Snook, SH and Ciriello, VM (1974), 'The effects of heat stress on manual handling tasks', *American Industrial Hygiene Association Journal,* 35 (11), 681-85.

Stocks, BJ, Fosberg, MA, Lynham, TJ, Mearns, L, Wotton, BM, Yang, Q, Jin, JZ, Lawrence, K, Hartley, GR, Mason, JA, and McKenney, DW (1998), 'Climate change and forest fire potential in Russian and Canadian boreal forests', *Climatic Change,* 38 (1), 1-13.

Taylor, NAS (2006), 'Challenges to temperature regulation when working in hot environments', *Industrial Health,* 44 (3), 331-44.

Teague, B, McLeoud, R, and Pascoe, S (2010), '2009 Victorian Bushfires Royal Commission', (Parliament of Victoria).

Tucker, R (2009), 'The anticipatory regulation of performance: the physiological basis for pacing strategies and the development of a perception-based model for exercise performance', *British Journal of Sports Medicine,* 43 (6), 392-400.

Tucker, R and Noakes, TD (2009), 'The physiological regulation of pacing strategy during exercise: a critical review', *British Journal of Sports Medicine,* 43 (6).

Tucker, R, Rauch, L, Harley, YXR, and Noakes, TD (2004), 'Impaired exercise performance in the heat is associated with an anticipatory reduction in skeletal muscle recruitment', *European Journal Of Physiology,* 448 (4), 422-30.

Tucker, R, Marle, T, Lambert, EV, and Noakes, TD (2006), 'The rate of heat storage mediates an anticipatory reduction in exercise intensity during cycling at a fixed rating of perceived exertion', *The Journal of Physiology,* 574 (3), 905-15.

USFA (2008), 'Emergency incident rehabilitation', (US Fire Administration, Federal Emergency Management Agency).

Wendt, D and van Loon, LJC (2007), 'Thermoregulation during exercise in the heat: strategies for maintaining health and performance', *Sports Medicine,* 37 (8), 669-82.

Westerling, AL and Bryant, BP (2008), 'Climate change and wildfire in California', *Climatic Change,* 87 (1), 231-49.

Westerling, AL, Hidalgo, HG, Cayan, DR, and Swetnam, TW (2006), 'Warming and earlier spring increase western U.S. forest wildfire activity', *Science,* 313 (5789), 940-43.

Wilson, BD, Gisolfi, CV, and Smith, TF (1975), 'Thermal responses to intermittent work in selected environments', *American Industrial Hygiene Association Journal*, 648-52.

Wyndham, CH (1967), 'Effect of acclimatization on the sweat rate-rectal temperature relationship', *Journal of applied physiology,* 22 (1), 27-30.

Wyndham, CH, Strydom, NB, Morrison, JF, DuToit, FD, and Kraan, JG (1954), 'A new method of acclimatization to heat', *Arbeitsphysiologie,* 15 (5), 373-82.

Chapter 3: Study One

Paper One

Effect of heat on firefighters' work performance and physiology

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3.1 ABSTRACT

This study compared wildland firefighters' work performance and physiology during simulated wildland firefighting work in hot (32°C, 43% RH) and temperate (19°C, 56% RH) conditions. Firefighters (n = 38), matched and allocated to either the CON (n = 18) or HOT (n = 20) condition, performed simulated self-paced wildland fire suppression tasks (e.g., hose rolling/dragging, raking) in firefighting clothing for 6 hours, separated by dedicated rest breaks. Task repetitions were counted (and converted to distance or area). Core temperature (T_c), skin temperature (T_{sk}), and heart rate were recorded continuously throughout the protocol. Urine output was measured before and during the protocol, and urine specific gravity (USG) analysed, to estimate hydration. Ad libitum fluid intake was also recorded. There were no differences in overall work output between conditions for any physical task. Heart rate was higher in the HOT (55 ± 2% HR_{max}) compared to the CON condition (51 ± 2% HR_{max}) for the rest periods between bouts, and for the static hose hold task (69 ± 3% HR_{max} versus 65 ± 3% HR_{max}). T_c and T_{sk} were 0.3 ± 0.1°C and 3.1 ± 0.2°C higher in the HOT compared to the CON trial. Both pre- and within- shift fluid intake were increased two-fold in the heat, and participants in the heat recorded lower USG results than their CON counterparts. There was no difference between the CON and HOT conditions in terms of their work performance, and firefighters in both experimental groups increased their work output over the course of the simulated shift. Though significantly hotter, participants in the heat also managed to avoid excessive cardiovascular and thermal strain, likely aided by the frequent rest breaks in the protocol, and through doubling their fluid intake.

3.2 INTRODUCTION

Wildfire suppression typically occurs in hot, dry weather conditions (Aisbett et al. 2012). However, firefighters have also been reported to perform their duties under mild to cool (15.8°C) environmental temperatures (Raines et al. 2012). As such, understanding the effect of various ambient temperatures on firefighters' safety and work efficiency would benefit fire agencies. For example, quantifying firefighters' work behaviour during different ambient environments may be important for the fire industry in forecasting the expected productivity of their crews. Additionally, understanding firefighters' physiological and behavioural responses (e.g., changes in fluid consumption) in hot conditions could help fire agencies better understand the factors that may induce or moderate heat illness in their personnel.

The effect of heat on exercise performance has been well researched in a sporting context for many years (Fink et al. 1975; Galloway and Maughan 1997; Parkin et al. 1999; Périard et al. 2011; Tucker et al. 2004), while few have investigated how hotter ambient temperatures immediately impact occupation-specific, manual-handling work performance. Descriptive field research has been conducted in wildland firefighters performing work in various ambient conditions (Apud and Meyer 2011; Budd et al. 1997a; Cuddy et al. 2015; Raines et al. 2015; Rodríguez-Marroyo et al. 2011; Rodríguez-Marroyo et al. 2012). However, the fact that work tasks are not standardised in the field, coupled with the lack of a control group, makes it difficult to precisely quantify the effect of heat on work performance and physiology. Further, factors such as temperature, humidity, wind, instruction/pressure from supervisors, and the severity of the emergency situation are highly variable, and will all play a role in dictating the work output of fire suppression personnel. So it is not possible, using field data, to precisely understand the effect of ambient heat on manual-handling work performance. While there are some limitations to using simulations (e.g., difficulty replicating the urgency of a fireground scenario), standardising the work tasks and working conditions (using information collected in the field) allows for the accurate measurement of changes in firefighter work performance in the heat, which at this stage is not well understood in this cohort. The existing laboratory research suggests that lifting, carrying, and pushing performance (Snook and Ciriello 1974), as well as work tolerance time when performing a walking and carrying task (McLellan et al. 1993), are all reduced in hotter conditions. However, the generic movement patterns (e.g., box-lifting), predominantly continuous work protocols, and relatively short durations (30 – 90 minutes) may not serve as the ideal proxy for wildfire suppression work. During campaign fires, firefighters commonly work shifts that last 8–12 hours and comprise intermittent, self-paced work tasks (Phillips et al. 2012). However, depending on the fire severity and time of ignition, firefighters may also perform their fire suppression duties for shorter durations (Rodríguez-Marroyo et al. 2012).

From a physiological and perceptual standpoint, it appears that indices of thermal stress, exertion, and perceived effort all increase during work in hot ambient environments (Smith et al. 1997; Snook and Ciriello 1974), though such effects may not be observed if the work is of a low intensity (Payne et al. 1994). Behaviourally, Australian wildland firefighters in various ambient conditions have been observed to arrive dehydrated to the fireground (Raines et al. 2012; Raines et al. 2015), yet consume adequate fluid over the course of the day to complete their shift in a euhydrated state (at least under cool – moderately hot ambient conditions) (Raines et al. 2012). More recently, due to substantial water turnover, US wildland firefighters have been observed to maintain their body mass across three days of fire suppression (Cuddy et al. 2015). While the field data suggests that firefighters are able to self-manage their drinking behaviour and avoid excessive thermal and cardiovascular strain (Cuddy et al. 2015; Raines et al. 2012), there have also been numerous documented cases of heat-related illness and even death on the fireground (Baldwin and Hales 2010, 2012, 2014; Cuddy and Ruby 2011; Jackson 2006; Karter 2012; Smith 2008). Furthermore, these field studies have not been designed to assess the differences (if any) in drinking behaviour according to environmental temperature. Thus, the precise interplay between hydration, physiology, and manual-handling work output during hot conditions warrants investigation in a controlled environment.

It is clear that no existing laboratory research has utilised a protocol that encompasses the work intensities, durations, work to rest ratios, and modes of exercise that make up wildland firefighting. Further, physiological, behavioural, and perceptual responses that may influence the effort given to this type of work are yet to be quantified in a controlled environment. Therefore, the present study aimed to compare firefighters' self-selected work output, physiology, behavioural, and perceptual responses to simulated wildland firefighting work in a hot compared to a temperate environment. It was hypothesised, based on the limited research investigating manual-handling performance in the heat, that the firefighters' work performance would be impeded in the hot environment. It was also hypothesised that firefighters would experience an increase in both physiological and perceived thermal stress and exertion in the heat, but that this increase would be somewhat moderated through adaptive behaviours (e.g., increased fluid consumption, reduced work output).

3.3 MATERIALS AND METHODS

3.3.1 Participants

Thirty-nine male and female volunteer and career firefighters volunteered for this study (see recruitment flyer; Appendix B). Power analyses (Hopkins 2011) was conducted using relevant research investigating performance (Galloway and Maughan 1997; Parkin et al. 1999; Périard et al. 2011; Snook and Ciriello 1974), thermal stress (McLellan et al. 1993; Payne et al. 1994; Périard et al. 2011; Snook and Ciriello 1974) and exertion (Mohr et al. 2006; Snook and Ciriello 1974) during exercise in the heat. The results of one outlier (Snook and Ciriello 1974) sway the analysis to predict 78 participants as the required number. However, once this outlier is removed, the required number of participants in each condition is 10. Testing 78 participants in each condition was not feasible given the nature of the protocol. Thus, the present research allocated 39 participants (across both experimental conditions) in an effort to capture all meaningful differences as significant. Participants average age across both groups was 37 years and only 16% were female, which closely reflects Australia's firefighting population (McLennan and Birch 2005). Participants were matched by age, then gender, and body mass index (BMI) in order to minimise variation between groups. A self-report measure of habitual physical activity was collected from participants in order to glean an indication of their aerobic fitness levels, given this is a factor known to influence exercise performance in the heat (Cheung et al. 2000). Unfortunately, due to time and cost constraints, direct measures of aerobic fitness were unable to be conducted. Participants were then randomly allocated to either the CON (n = 18; 32°C, 43% RH) or the HOT (n = 21; 19°C, 56% RH) condition. One participant in the HOT withdrew from the study before completing the full protocol (after the second work bout), citing a general feeling of unwell. Their data did not change any of the results of the statistical analysis, and thus, the data was removed to capture only those who completed the full protocol (n = 20). Firefighters from hotter climates (e.g., Northern Australia) were excluded in order to control a potentially confounding variable (heat acclimation), and reduce variation in the subject pool. Data collection took place during the cooler autumn and winter months to minimise the effect of heat acclimation. Participants provided written informed consent (Appendix C) and filled out a medical questionnaire (Appendix D) prior to commencement of the study, to ensure they were physically able to perform the protocol. Ethical approval was obtained for this study through the Deakin University Human Research Ethics Committee (Appendix E).

Prior to testing, participants' height was measured and recorded without shoes using a stadiometer (Fitness Assist, England), and body mass was measured (in underwear only) using an electronic scale (A and D, Japan). In all trials, participants wore their own firefighting personal protective clothing (PPC), including a jacket and trouser set made from Proban® cotton fabric (Protex®, Australia), suspenders, boots, gloves, helmet, and goggles (amounting to ~5 kg), which meet the performance requirements for wildland firefighting clothing as stipulated by the International Organization for Standardization (ISO 15384:2003).

3.3.2 Experimental Protocol

On the day prior to testing, participants were familiarised with the physical work tasks, as well as the rating of perceived exertion (RPE; Appendix F) and thermal sensation (Appendix G) scales (Borg 1998; Young et al. 1987). Participants were then made aware of the condition to which they had been allocated. Firefighters were also provided with standardized food items (if not quantity), sleeping environment, and activity conditions (e.g., no exercise aside from task familiarisation) in the 24 hours prior to the trial. Participants ingested a core temperature capsule (Jonah, Minimitter, Oregon) prior to lights out (10:00 pm) the night prior to testing to allow adequate time for the capsule to pass through the stomach, thereby limiting inaccurate readings occurring as a result of ingested food or liquid (Lee et al. 2000).

Testing took place in a windowless, climate-controlled room measuring 9 × 13 metres. Air temperature was maintained through the use of split cycle air conditioners (Panasonic, Japan) and portable heaters (Sunbeam, Australia). Both air temperature (accurate to ± 0.2°C) and relative humidity (accurate to ± 2.5%) were continuously measured and logged using three temperature nodes (Onset Computer Corporation, USA). Radiant heat was not simulated in the present study. It has been previously shown that radiant heat (either from the sun or in some cases, fire) plays a relatively small role in the thermal stress encountered by firefighters, accounting for less than a third of firefighters' total heat load when controlling a live fire, and close to zero when performing work tasks away from the fire (Budd et al. 1997a). The majority of tasks incorporated in the current study design are those performed either during fire preparation or post-fire 'clean-up' work, which comprises a large portion of the work performed by wildland firefighters when on duty (FEMA 2002). Thus, radiant heat was not the primary focus of this study. However, it must be noted that the heat load imposed during the present study, and the ensuing results, may be more applicable to tasks performed away from the fire-front.

Participants were tested in groups of five (or less). Prior to the commencement of testing, participants had heart rate monitors (accurate to ± 1 beat.min^{-1}; Polar, Finland) and skin temperature patches (VitalSense, Minimitter, Oregon) affixed. The core temperature capsules and skin temperature patches utilised have a temperature sensing accuracy of ± 0.1°C, and recorded on a data logger continuously throughout testing (VitalSense, Minimitter, Oregon). Testing commenced at 12:30 pm.

The three work 'circuits' each lasted two hours, and comprised 55 minutes of physical work, 20 – 25 minutes of physiological data collection, 20 – 25 minutes of cognitive testing, and a 15 – 20-minute passive rest period. The suite of cognitive tests used was part of a broader study; thus, the methods surrounding these protocols and the ensuing results will not be described. The work to rest ratios that made up each two-hour circuit were designed to mimic actual fireground work (Aisbett and Nichols 2007; Cuddy et al. 2007; Raines et al. 2012), and the physical tasks to directly simulate the movements and fitness components of fire suppression in the field (Phillips et al. 2011; Phillips et al. 2012). Australian wildland firefighters in the field spend 51 – 66% of their shift in the sedentary activity range (Cuddy et al. 2007; Raines et al. 2013). For each 2-hour circuit in the current protocol, 50 minutes were spent intermittently working and 70 minutes were spent resting (including physiological and cognitive testing), which equates to spending 58% of the time in the sedentary range. Each participant performed the same circuit of work; however the starting position (task) was staggered to allow multiple participants to be tested at once (Appendix H). Once allocated to a circuit order, participants followed the same sequence in all work bouts (and circuit sequence was matched across the two groups).

Participants were allowed to drink room temperature water ad libitum throughout testing. Prior consultation with fire agencies determined that participants were also supplied with sachets of flavoured electrolyte supplement, and a 'ration pack' of snack foods (e.g., muesli bars, crackers, and confectionary) similar to that which they would receive on the fireground. Types, quantities, and timing of ingested food and liquid were recorded throughout testing.

3.3.3 Physical Work Circuit

The work circuit comprised six physical tasks, which were chosen on the basis of being the most physically demanding performed by Australian rural firefighters (Phillips et al. 2012). These tasks are also considered amongst the most important in achieving operational outcomes (Phillips et al. 2012), and have been shown to be the most frequent, and/or longest and most intense, tasks performed during wildfire suppression (Phillips et al. 2011). The repetitions completed during each work task (except for static hose hold) were recorded through the use of a specially designed iPad application (Good Dog Design, Australia). In analysing the data, repetitions were converted into distance (m), or area (m^2) in the case of the rakehoe task.

Firefighters moved through the circuit in five-minute increments, which allowed for the completion of each task, plus time to move to the next 'station'. Task frequency (e.g., the number of times each task was performed) was determined according to the frequency in which these tasks are performed in the field (Phillips et al. 2011). Task frequency and the work to rest ratios that made up each task are described in Table 1. All hose tasks employed in the protocol were performed using 38-mm hoses with branch attached. The suite of physical tasks included:

Rakehoe work

Involved raking 29-kg of material (large and small rubber tyre crumb) from one end of a rectangular wooden box (2 × 0.9 m) to the other, using a rakehoe (a specialised combination rake and hoe), to simulate building a firebreak (Budd et al. 1997b; Phillips et al. 2012).

Blackout hose work

This task involved walking the perimeter of a 2.5- × 2.5-m square, stopping at each corner for three seconds (as timed by a metronome). Whilst walking, participants dragged a 15-kg weight attached to a 2-m hose. This task simulates the 'stop-start' action of dragging a charged hose when dousing smouldering debris with water during post-fire clean-up work (Phillips et al. 2012).

Hose rolling

A common task performed during pack up, this task required participants to roll up a 16-m hose (folded in half to a length of 8 m) to an operational standard (Phillips et al. 2012).

Lateral hose repositioning

Involved walking in an arc (3.5-m radius; 11-m length), carrying a 3.5-m hose. The hose was attached to a weighted stand centred at the base of the arc. Two platforms (68 × 28 × 15 cm; Spalding, Australia) served as 'obstacles' (e.g., logs, fallen debris), that participants had to manoeuvre. This task simulated moving a charged fire hose sideways from a fixed point, such as a water source (Phillips et al. 2012).

Charged hose advance

This task simulated walking forwards with a hose filled with pressurised liquid (Phillips et al. 2012). Participants dragged a 15-kg weighted tyre attached to a 2-m hose, up and down a marked distance of 8 metres.

Static hose hold

This task involved pointing a 3.5-m hose (attached to a weighted stand via an elastic strap, to provide resistance) at a target (with laser pointer attached). Participants were instructed to hold the laser within the target for five minutes, or until exhaustion. If the laser moved out of the target, or if the hose touched the ground, for more than two seconds, participants' performance time was recorded at that point. This simulated holding a charged hose in position for an extended period when dousing a fire (Phillips et al. 2012). All participants in both conditions were able to complete the maximum time of five minutes, so performance results for this task will not be reported.

Table 1. Task frequencies and work to rest ratios

Task name	Work to rest ratio	Times performed each circuit
Rakehoe work	90 s work : 60 s rest : 90 s work	1
Blackout hose work	90 s work : 60 s rest : 90 s work	2
Hose rolling	60 s work : 60 s rest : 60 s work	1
Lateral hose repositioning	30 s work : 30 s rest × 4	4
Charged hose advance	65 s work : 55 s rest : 65 s work	1
Static hose hold	5 minutes continuous work	1
Dedicated rest break	5 minutes	1

3.3.4 Analytical Procedures

Core temperature, skin temperature, and heart rate were recorded continuously throughout testing. High-resolution data was then averaged and analysed per physical work circuit. Maximum heart rate (HR_{max}) was predicted using the formula 207 – 0.7 × age (Gellish et al. 2007) to account for substantial variation in participant age (ranging from 18 – 60 years). Skin temperature was recorded at four sites on the right side of the body; the chest, thigh, upper arm and calf (Payne et al. 1994). Mean skin temperature was calculated using the formula $0.3(T_{chest} + T_{arm}) + 0.2(T_{thigh} + T_{leg})$ (Ramanathan 1964). The type and quantity of ingested food and liquid were recorded both before and throughout testing, and the daily energy consumption data was extracted using the FoodWorks 7 nutrition software (Xyris Software Pty Ltd, Australia). Estimating hydration status from changes in body mass can be problematic during long duration work for a number of reasons (e.g., respiratory water losses, though significant, cannot be accounted for) (Maughan et al. 2007). Thus, all urine was measured, and urine specific gravity (USG) was analysed using a portable refractometer (Atago, Japan), to approximate hydration status. 'Pre-shift' USG was assessed by calculating average USG values from wakening until the start of the first work circuit (at 12:30 pm). Participants were also asked to provide RPE (Borg 1998) and thermal sensation (Young et al. 1987) ratings after each individual physical task (i.e., every five minutes). Finally, performance data were calculated by measuring the distance covered in each task (or area raked, in the case of the rakehoe task), and multiplying by the number of repetitions performed.

3.3.5 Statistical Analysis

All statistical analyses were carried out using the program Statistical Package for the Social Sciences (SPSS V.21.0, Champaign, Ill). The distribution of the data was evaluated using Shapiro-Wilk tests. All variables were normally distributed, with the exception of USG, fluid intake, and urine output. The normally distributed variables were analysed using mixed analyses of variance (ANOVA), with condition (CON or HOT) as the between subject factor, and time (or circuit) as the within-participant factor. When the ANOVA detected a significant interaction, simple effects analyses were used to isolate where the significant difference occurred. Hydration markers (USG, fluid intake, and urine output) were not normally distributed, and this was unable to be corrected via transformation of the data. Thus, non-parametric analyses were performed on these variables. Pre-shift USG, fluid intake, and urine output were analysed using Mann-Whitney U tests. The change score in USG between the start (Circuit 1) and end of the simulated shift was then analysed to assess whether there was a difference in the rate of change in participants' hydration status over time. Statistical significance was set at $P < 0.05$. All normally distributed data were presented as means ± standard deviations, while median values (interquartile range; IQR) were reported for non-parametrically analysed data (where IQR = the difference between the upper and lower quartiles).

3.4 RESULTS

There was no difference between groups for any of the participant characteristics ($P \geq 0.413$; Table 2). Ambient temperature was 19.3 ± 0.1°C in the CON trial compared to 31.8 ± 1.8°C in the HOT ($P < 0.001$). Relative humidity was also different between conditions ($P < 0.001$), reaching 56.3 ± 1.4% in the CON and 42.7 ± 1.8% in the HOT. There was no difference ($P = 0.989$) in the amount of energy consumed between the CON (9361 ± 2936 kJ) and HOT (9349 ± 2515 kJ) groups over the course of the day.

Table 2. Participant characteristics

	CON	HOT
n	18	20
Age (years)	39 ± 16	35 ± 13
Male (n)	15	16
Female (n)	3	4
Height (m)	1.78 ± 0.08	1.78 ± 0.08
Weight (kg)	84.9 ± 17.8	87.1 ± 17.9
BMI	26.7 ± 4.9	27.3 ± 3.5
Years of service	8.7 ± 9.3	9.3 ± 7.6
Habitual physical activity (sessions per week)	3.2 ± 3.0	3.2 ± 2.4

CON = control group; HOT = hot group; BMI = body mass index. All data are reported as means ± SD

3.4.1 Work performance

There was a condition × circuit interaction observed ($P = 0.012$) for the lateral hose reposition task. Participants in the CON group covered 51 ± 33 m more distance in the last compared to the first circuit of the lateral repositioning task, whereas the difference between the first and third circuit was only 20 ± 58 m in the HOT condition. No interactions between condition and circuit, and no main effects for condition, were observed for any of the other physical work tasks (Table 3; $P \geq 0.150$). However, main effects for time were observed for all tasks ($P \leq 0.032$), indicating that all participants increased their work output over the course of the simulated work shift.

3.4.2 Heart rate

There was no main effect for condition (P = 0.433), circuit (P = 0.123), and no condition × circuit interaction (P = 0.087), observed for participants' relative average heart rate (HR_{max}) over the three work circuits (Table 4). There was also no difference between conditions when just the 55-minute work periods were analysed, with participants averaging 66 ± 2% HR_{max} in the control condition, and 67 ± 2% HR_{max} in the hot condition (P = 0.723). Conversely, there was a condition × circuit interaction (P = 0.013) observed for the 65-minute 'rest' periods (including physiological and cognitive testing), such that participants' heart rate increased slightly (1 ± 6% HR_{max}) in the HOT condition, and decreased slightly (2 ± 10% HR_{max}) in the CON trial. There were, however, no differences observed between the two conditions ($P \geq 0.088$) at individual time points. Heart rate data was also analysed by physical task (Table 3). There was a condition × circuit interaction observed (P = 0.021) for the static hose holding task. Participants' heart rate in the HOT was relatively consistent between the first (71 ± 10% HR_{max}) and last (68 ± 11% HR_{max}) circuits, whereas the CON participants' heart rate was higher at the start (70 ± 13% HR_{max}) compared to the end of the 'shift' (62 ± 14% HR_{max}).

3.4.3 Core and skin temperature

Core and skin temperature were on average 0.3 ± 0.1°C and 3.1 ± 0.2°C hotter, respectively, in the HOT compared to the CON trial (Table 3). Peak core temperature was also significantly higher in the HOT (P = 0.001), reaching 38.2 ± 0.3°C compared to an average of 37.9 ± 0.3°C in the CON trial. The same relationship was observed for peak skin temperature, which reached 37.0 ± 0.5°C in the HOT compared to 34.4 ± 0.5°C in the CON environment ($P < 0.001$).

3.4.4 Perceptual responses

With the exception of the rakehoe task ($P = 0.434$), thermal sensation ratings were higher ($P \leq 0.024$) for all tasks in the HOT compared to those in the CON trial (Table 3). Conversely, there was no difference in RPE values between conditions for most tasks ($P \geq 0.122$), with the exception of hose rolling (Table 3). Interestingly, participants reported higher RPE ratings for this task in the CON trial ($P = 0.002$). This between-condition difference was statistically significant during circuit one ($P = 0.003$) and two ($P = 0.020$), but fell short of reaching significance during the third circuit ($P = 0.060$). Lastly, a main effect for time was also observed for the charged hose advance task ($P < 0.001$), as participants' RPE ratings increased progressively over the course of the simulated work shift during both conditions.

Table 3. Daily mean work performance, heart rate, RPE, and thermal sensation data across the CON and HOT conditions

			Work performance			Heart Rate (% HR_{max})			RPE			Thermal sensation		
			Circuit			Circuit			Circuit			Circuit		
TASK			1	2	3	1	2	3	1	2	3	1	2	3
Blackout hose	CON	Mean	157.6*	167.9*	170.8*	67	65	64	12.7	12.1	12.2	5.0	4.8	4.8
		SD	12.7	16.1	14.9	14	12	14	1.3	1.2	0.9	0.6	0.4	0.6
	HOT	Mean	166.3*	183.9*	178.8*	67	65	67	12.3	12.1	12.2	5.6#	5.6#	5.6#
		SD	30.6	36.8	26.2	10	18	10	1.2	1.3	1.9	0.5	0.8	0.7
Charged hose advance	CON	Mean	94.9*	103.8*	105.6*	78	77	76	14.9	15.4	15.9	6.0	5.6	5.7
		SD	20.6	21.3	20.9	13	14	15	1.4	1.2	1.8	0.8	0.9	1.2
	HOT	Mean	99.4*	105.5*	105.2*	76	72	76	14.3	14.7	15.3	6.2#	6.1#	6.4#
		SD	22.8	27.3	30.1	10	20	10	1.6	1.7	2.1	0.6	0.8	0.8
Lateral hose repositioning	CON	Mean	595.2*	623.6*	644.8*	67	65	64	11.6	11.4	11.2	4.7	4.7	4.6
		SD	91.9	97.0	92.5	12	12	12	0.9	0.9	0.9	0.5	0.5	0.6
	HOT	Mean	616.2^*	662.5^*	636.0^*	65	63	66	11.2	11.0	10.9	5.5#	5.5#	5.4#
		SD	88.4	117.4	112.7	8	18	9	1.4	1.6	1.6	0.5	0.7	0.6

Table 3 cont.

TASK			Work performance			Heart Rate (% HR_{max})			RPE			Thermal sensation		
			Circuit			Circuit			Circuit			Circuit		
			1	2	3	1	2	3	1	2	3	1	2	3
Hose rolling	CON	Mean	16.1*	17.8*	19.7*	67	66	65	12.6#	12.2#	12.3#	4.9	4.8	4.8
		SD	3.7	4.7	6.0	13	12	12	1.2	1.2	1.3	0.6	0.6	0.8
	HOT	Mean	15.1*	18.7*	19.8*	62	66	67	10.3	11.1	11.6	5.1#	5.4#	5.5#
		SD	5.3	6.6	8.1	18	11	11	2.8	1.5	1.0	1.4	0.6	0.8
Rakehoe work	CON	Mean	4.8*	5.0*	5.0*	75	73	72	14.5	14.6	14.9	5.6	5.7	5.8
		SD	1.3	1.4	1.4	10	12	11	1.2	1.1	1.2	0.6	0.7	0.8
	HOT	Mean	4.7*	4.9*	5.2*	74	74	74	14.1	14.3	13.9	6.2	6.0	5.6
		SD	1.3	1.1	1.2	9	10	9	1.9	1.8	3.7	0.6	0.9	2.0
Static hose hold	CON	Mean	-	-	-	70	64	62	13.7	13.7	13.7	5.4	5.4	5.5
		SD	-	-	-	13	14	14	1.9	2.4	2.1	0.8	1.0	1.1
	HOT	Mean	-	-	-	70^	69^	68^	12.5	12.8	12.9	6.2#	6.2#	6.2#
		SD	-	-	-	10	11	11	2.5	2.0	1.8	0.8	0.7	0.8

*# main effect for condition ($P \le 0.024$), * main effect for time ($P \le 0.032$), ^ interaction ($P \le 0.021$). CON = control group; HOT = hot group; SD = standard deviation; % HR_{max} = percentage of age-predicted heart rate maximum; RPE = rating of perceived exertion. Work performance is reported as distance (m) for all tasks except rakehoe work, which is reported in area (m^2)*

Table 4. Mean heart rate, core temperature, and skin temperature over the three work circuits

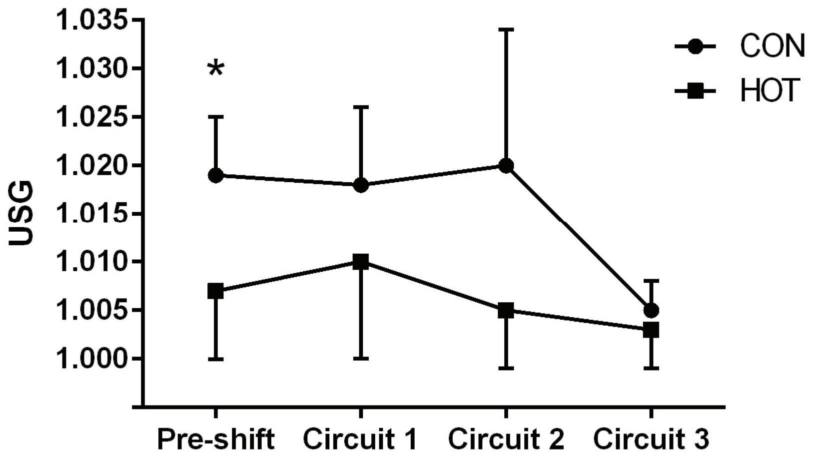
	Circuit 1		Circuit 2		Circuit 3	
	CON	HOT	CON	HOT	CON	HOT
Heart rate (%HR$_{max}$)	60 ± 10	60 ± 8	58 ± 11	60 ± 9	59 ± 11	63 ± 9
Core temperature (°C)	37.4 ± 0.3	37.7 ± 0.2$^{\#}$	37.5 ± 0.3	37.8 ± 0.2$^{\#}$	37.5 ± 0.4	37.8 ± 0.3$^{\#}$
Skin temperature (°C)	32.7 ± 0.6	35.7 ± 0.6$^{\#}$	32.7 ± 0.6	35.7 ± 1.0$^{\#}$	32.33 ± 1.05	35.6 ± 1.0$^{\#}$

$^{\#}$ main effect for condition ($P \leq 0.001$). CON = control group; HOT = hot group; % HR$_{max}$ = percentage of age-predicted heart rate maximum; SD = standard deviation. All data are reported as means ± SD

3.4.5 Hydration markers

Prior to starting the simulated work shift, there was a significant difference in USG between groups (P = 0.006), with the CON group eliciting a median USG of 1.019 (0.006), compared to 1.007 (0.007) in the HOT. USG remained higher in the CON compared to the HOT condition throughout the 'shift' (Figure 1), thus, there was no difference in the USG change scores from the first circuit to the end of the trial (P = 0.093). Participants in the CON trial had a decrease in USG by a median of 0.009 (0.010) across the course of the shift, compared to a decrease of 0.002 (0.008) in the HOT trial. Fluid intake was significantly higher in the HOT both pre-shift (P = 0.002) and across the course of the shift (P < 0.001). Fluid intake prior to starting work was 1138 (516 mL) in the CON trial compared to 1950 (970 mL) in the HOT. This difference was even more pronounced during the work shift, with CON participants consuming only 600 (301 mL) per 2-hour circuit in comparison with 1222 (707 mL) of fluid per circuit in the HOT trial. Pre-shift urine output was also significantly higher in the HOT (P < 0.001), reaching a median of 1468 (495 mL) compared to only 485 (434 mL) in the CON trial. This difference did not, however, persist during the shift. The difference in urine output per circuit between the HOT (338 [304 mL]) and CON (230 [217 mL]) trials was not significant (P = 0.169).

Figure 1. USG pre-shift and over the three work circuits



* *P < 0.005. USG = urine specific gravity; CON = control group; HOT = hot group.*

3.5 DISCUSSION

Contrary to our primary hypothesis, work output during the simulated wildfire suppression tasks was largely unaffected by the heat. The secondary hypothesis was partially supported; participants in the HOT condition experienced higher core and skin temperatures and thermal sensation values, and adapted their behaviour by increasing their fluid consumption both prior and during the work shift. However, heart rate was only elevated in the heat during select periods, and there was little difference observed in ratings of perceived exertion across the work bouts.

Work performance was maintained (or even improved) throughout the duration of the 'shift' during both experimental conditions. This is perhaps due, at least in part, to the frequent rest breaks and task rotation incorporated into the experimental design. Previous research investigating heat and manual-handling performance has been continuous and of relatively short duration (McLellan et al. 1993; Snook and Ciriello 1974). Thus, prior to the current study, the effect of heat on intermittent, self-paced manual-handling work had yet to be identified. There is some evidence in the sporting literature to suggest that athletes performing self-paced, intermittent-intensity exercise in the heat can maintain their performance (Almudehki et al. 2012; Kay and Marino 2003), or at the very least, maintain high-intensity efforts while preserving energy during the lower intensity tasks (Aughey et al. 2014; Morris et al. 1998). While such research holds little relevance to firefighting in terms of their modes of exercise, the premise that individuals performing physical work in the heat would strive to maintain the most 'important' or high-intensity tasks is one that could reasonably extend itself to occupational work. Where athletes have been shown to use the lower intensity (e.g., walking) exercise phases of a sport to recover (Aughey et al. 2014; Morris et al. 1998), participants in the present study had allocated rest periods in which to conserve their energy. Wildfire suppression work is commonly intermittent, and comprises an array of tasks of varying intensity (Phillips et al. 2011). Hence, participants in the present study were exposed to frequent task rotation (every five minutes) and rest periods (both within and between tasks). It is likely that these two factors contributed to firefighters being able to sustain their work output across the simulated shift.

It is also possible that, as participants did not warm up before completing the protocol, the improved work output over time may have partly reflected the beneficial effects of warming up during the performance of the tasks (Bishop 2003). However, any warming-up benefit afforded to participants would have been relatively short-lived relative to the duration of the protocol (i.e., restricted to the earliest tasks performed in the circuit sequence), and therefore it is unlikely that this played a major role in firefighters increasing their work output over time. The work was self-paced, and thus, firefighters could select their own work output according to the instruction "pace yourselves as you would in the field". It is possible, then, that they paced themselves (according to internal feedback) in a way that allowed them to increase their work output over the course of the day. It is also possible that there was an 'end-bout' effect, in which the firefighters increased their productivity as they realised they were nearing completion of the protocol.

Interestingly though, participants in the HOT condition slightly reduced their work output on the lateral hose repositioning task during the final work bout, whereas the CON group steadily increased their work output across the course of the day. Given that this task was the most frequently performed, and was one of the lowest intensity tasks, it is possible that participants in the hot condition were beginning to conserve energy in order to maintain productivity on the other, higher intensity, fire suppression tasks (e.g., rakehoe work). It's conceivable that, should firefighters perform longer work shifts, or undergo consecutive days of work in the heat (such as during multiple-day campaign fires), that this relationship between conserving energy on the 'easier' tasks in order to preserve work performance on the higher-intensity tasks may become more pronounced.

It is also possible that the tasks used in the physical work simulation were too 'noisy' to detect small changes in performance. However, it is unlikely that any undetected changes in performance would convert into meaningful differences in the field. A small, unpublished reliability study conducted by our group found that the simulated firefighting tasks had a relatively high level of error (mean typical error = 16.9%), as task validity was prioritised over reliability in order to maximise the transferability of results to the fireground. Steps were taken to ensure that the protocol was run with a high level of rigour, in the hope that this would 'wash-out' some of the intrinsic task noise. This included precise recording of time intervals, having the same researchers count repetitions, having repetitions clearly marked out (to the nearest quarter), and using a metronome where appropriate (e.g., the blackout hose task). Physical data was also analysed as a percentage improvement or decline from the first bout of work, in an attempt to 'normalise' the data and account for any individual variation. The results from this analysis were consistent with the raw data; thus, for brevity and interpretability only the raw data was reported. Therefore, while it would be remiss not to mention the possibility of task variability or individual differences influencing the data, it is not likely that any small, undetected changes in performance would translate into a meaningful effect on the fireground.

As expected, firefighters exposed to the HOT condition experienced greater increases than the CON group across all measures of thermal stress; namely, core temperature, skin temperature, and perceived thermal sensation. This is in concert with previous findings, who have observed higher core (Snook and Ciriello 1974) and skin (Payne et al. 1994) temperatures in those performing manual-handling work in the heat compared to temperate environments. There was also one participant who withdrew from the study before completing the full protocol in the heat, and a small number of others who, anecdotally, experienced minor heat-illness symptoms (e.g., headache). However, for the most part, firefighters were able to perform the work without experiencing any major signs of heat-related illness or fatigue. This is likely due to the fact that, despite having higher mean and peak core temperature values than the CON group, participants' core temperature peaked at 38.2 ± 0.3°C during the heat exposure, which suggests that the heat load was compensable (Cheung et al. 2000). In fact, no participant in either group reached a core temperature of 39°C at any stage during the 'shift'. These fall well within the recommendations set by the International Organization for Standardization, which suggest an upper core temperature of no more than 38.5°C (ISO 2004). As with work output, it is possible that the frequent rest periods employed during the protocol allowed participants to maintain a thermal steady state.

Previous research has observed higher heart rates when performing manual work in the heat (Payne et al. 1994; Snook and Ciriello 1974), however participants in the present research only elicited marginally higher heart rates during the static hose hold task and the rest periods between work bouts. Similarly, there were no differences in RPE for the majority of work tasks. There is a small possibility that between-group differences (e.g., in cardiorespiratory fitness) may partially explain why larger increases in heart rate and RPE were not observed. Although firefighters were matched for age, gender, height, weight, and BMI, and there was no difference in self-reported physical activity (in sessions per week), no objective measure of fitness was used when allocating participants to a condition. Thus, it is a possibility that there may have been a small bias towards higher cardiorespiratory fitness in the HOT group. The increased fluid consumption in the heat potentially also played a role in moderating participants perception of exertion (McGregor et al. 1999;

Montain and Coyle 1992), however higher RPE were likely not reported due to firefighters not actually finding the work more exerting in the heat (as supported by the majority of the heart rate findings). This close correlation between heart rate and RPE has been previously documented (Gamberale 1972). Strangely, participants in the CON group rated the hose-rolling task higher for perceived exertion than the HOT group. A possible explanation for this finding is that the hose rolling task was very skill based, relative to the other tasks. It is possible, despite having been familiarised with the scale (and the task), that participants may have rated this task higher if they found it difficult (rather than exerting), which could, at least in part, explain the unexpected results.

The hydration results show promise that firefighters are able to self-manage their hydration status in the heat (at least when forewarned of the ambient conditions). US wildfire fighters have reported high water turnover during multi-day wildfire suppression, which has allowed them to maintain their body mass across consecutive days (Cuddy et al. 2015). Australian firefighters have been observed to arrive hypohydrated to the fireground (Raines et al. 2012; Raines et al. 2015), but have been able to consume enough fluids across the workday to complete their shift in a euhydrated state, at least in cool – moderately hot conditions (Raines et al. 2012). In hot ambient temperatures (peak of 37 °C), the same cohort exhibited a hypohydrated state upon completion of the work shift (Raines et al. 2015). In the current study, however, firefighters increased their fluid intake from the moment they were told they would be participating in the HOT condition (the night prior to testing), which resulted in these participants being significantly more hydrated (according to USG results) upon arrival (USG: 1.007 ± 0.007) than the CON group (USG: 1.019 ± 0.006). It is likely that the laboratory setting that the firefighters were accommodated in on the night prior to testing aided them in applying their knowledge of pre-hydration, as they did not have any 'distractions' that would be present in 'real life' (e.g., work, family, food preparation). It is also probable that the increased fluid consumption observed in participants in the HOT condition aided in reducing the onset of heat-illness symptoms. Previous research has shown that adequate fluid replacement during exercise in the heat aids in blunting increases in core body temperature (Montain and Coyle 1992) and ratings of perceived exertion (McGregor et al. 1999; Montain and Coyle 1992), as well as minimising cardiovascular drift (Hamilton et al. 1991; Hargreaves 2008; McGregor et al. 1999). Thus, it is likely that through the current ad-libitum drinking protocol there was interplay between increased fluid consumption in the heat and all other physiological and perceptual variables. While both CON and HOT participants were classified as hydrated both prior and throughout the simulated shift (Kenefick and Cheuvront 2012; Sawka et al. 2007), the CON group was often times nearing dehydration (USG > 1.020; Figure 1). It is plausible that this difference in fluid intake, and subsequently hydration status (or a proxy thereof), played a role in aiding the HOT participants to maintain work performance and record heart rate and RPE values comparable to their CON counterparts.

3.6 CONCLUSIONS

Wildland firefighters' work performance was sustained (or even improved) across both the temperate and hot environmental conditions. It is likely that the maintenance of work output across the 'shift' was facilitated by the frequent rest breaks and task rotation employed through the protocol. Similarly, despite reaching significantly higher core and skin temperatures, participants in the heat were able to self-manage (e.g., through doubling their fluid intake) in order to prevent the development of fatigue and heat-related illness. While these findings are positive from an agency standpoint, it is unclear whether the same would hold true if firefighters were exposed to multiple days of physical work in the heat, or during the more extreme ambient temperatures that can occur during wildfire suppression (Aisbett et al. 2012; Cuddy and Ruby 2011). Nevertheless, these findings indicate that with adequate rest and unlimited access to fluids, wildland firefighters performing self-paced firefighting work in the heat can produce similar physical work outputs as under temperate conditions. Moreover, they can do so without inducing excessively high cardiovascular or thermal strain.

3.7 REFERENCES

Aisbett, B and Nichols, D (2007), 'Fighting fatigue whilst fighting bushfire: an overview of factors contributing to firefighter fatigue during bushfire suppression', *The Australian Journal of Emergency Management,* 22 (3), 31-39.

Aisbett, B, Wolkow, A, Sprajcer, M, and 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), 916-25.

Almudehki, F, Girard, O, Grantham, J, and Racinais, S (2012), 'Hot ambient conditions do not alter intermittent cycling sprint performance', *Journal of Science and Medicine in Sport,* 15 (2), 148-52.

Apud, E and Meyer, F (2011), 'Factors influencing the workload of forest fire-fighters in Chile', *Work: A Journal of Prevention, Assessment and Rehabilitation,* 38 (3), 203-09.

Aughey, RJ, Goodman, CA, and McKenna, MJ (2014), 'Greater chance of high core temperatures with modified pacing strategy during team sport in the heat', *Journal of Science and Medicine in Sport,* 17 (1), 113-18.

Baldwin, T and Hales, T (2010), 'Fire fighter trainee suffers fatal exertional heat stroke during physical fitness training – Texas', (NIOSH Fire Fighter Fatality Investigation and Prevention Program).

Baldwin, T and Hales, T (2012), 'Wildland fire fighter dies from hyperthermia and exertional heatstroke while conducting mop-up operations - Texas', (NIOSH Fire Fighter Fatality Investigation Team,).

Baldwin, T and Hales, T (2014), 'Captain dies from hyperthermia and exertional heatstroke while performing advanced survival training - Texas', (NIOSH Fire Fighter Fatality Investigation and Prevention Program).

Bishop, D (2003), 'Warm up II', *Sports Medicine,* 33 (7), 483-98.

Borg, G (1998), *Borg's perceived exertion and pain scales* (Human kinetics).

Budd, GM, Brotherhood, JR, Hendrie, AL, Jeffery, SE, Beasley, FA, Costin, BP, Zhien, W, Baker, MM, Cheney, NP, and Dawson, MP (1997a), 'Project Aquarius 10. Effects of work, weather, and fire on the energy expenditure, strain, and productivity of men suppressing wildland fires', *International Journal of Wildland Fire,* 7 (2), 167-80.

Budd, GM, Brotherhood, JR, Hendrie, AL, Jeffery, SE, Beasley, FA, Costin, BP, Zhien, W, Baker, MM, Cheney, NP, and Dawson, MP (1997b), 'Project Aquarius 1. Stress, strain, and productivity in men suppressing Australian summer bushfires with hand tools: background, objectives, and methods', *International Journal of Wildland Fire,* 7 (2), 69-76.

Cheung, SS, McLellan, TM, and Tenaglia, S (2000), 'The thermophysiology of uncompensable heat stress: physiological manipulations and individual characteristics', *Sports Medicine,* 29 (5), 329-59.

Cuddy, JS and Ruby, BC (2011), 'High work output combined with high ambient temperatures caused heat exhaustion in a wildland firefighter despite high fluid intake', *Wilderness & Environmental Medicine,* 22 (2), 122-25.

Cuddy, JS, Sol, JA, Hailes, WS, and Ruby, BC (2015), 'Work patterns dictate energy demands and thermal strain during wildland firefighting', *Wilderness & Environmental Medicine,* 26 (2), 221-26.

Cuddy, JS, Gaskill, SE, Sharkey, BJ, Harger, SG, and Ruby, BC (2007), 'Supplemental feedings increase self-selected work output during wildfire suppression', *Medicine & Science in Sports & Exercise,* 39 (6), 1004-12.

FEMA (2002), 'Introduction to wildland/urban interface firefighting for the structural company officer', (Federal Emergency Management Agency, U.S. Department of Homeland Security).

Fink, WJ, Costill, DL, and Van Handel, PJ (1975), 'Leg muscle metabolism during exercise in the heat and cold', *European Journal of Applied Physiology & Occupational Physiology,* 34 (3), 183-90.

Galloway, SD and Maughan, RJ (1997), 'Effects of ambient temperature on the capacity to perform prolonged cycle exercise in man', *Medicine & Science in Sports & Exercise,* 29 (9), 1240-49.

Gamberale, F (1972), 'Perceived exertion, heart rate, oxygen uptake and blood lactate in different work operations', *Ergonomics,* 15 (5), 545-54.

Gellish, RL, Goslin, BR, Olson, RE, McDonald, A, Russi, GD, and Moudgil, VK (2007), 'Longitudinal modeling of the relationship between age and maximal heart rate', *Medicine & Science in Sports & Exercise,* 39 (5), 822-29.

Hamilton, MT, Gonzalez-Alonso, J, Montain, SJ, and Coyle, EF (1991), 'Fluid replacement and glucose infusion during exercise prevent cardiovascular drift', *Journal of Applied Physiology,* 71 (3), 871-77.

Hargreaves, M (2008), 'Physiological limits to exercise performance in the heat', *Journal of Science and Medicine in Sport,* 11 (1), 66-71.

Hopkins, W (2011), 'A new view of statistics. http://www.sportsci.org/resources/stats/index.html', retrieved 31st October 2012.

ISO (2004), 'ISO 9886: Ergonomics - Evaluation of thermal strain by physiological measurements', (Geneva: International Organization for Standardization).

Jackson, JS (2006), 'Fatality assessment and control evaluation report: Recruit fire fighter suffers heat stroke during physical fitness training and dies nine days later in Florida', (NIOSH Fire Fighter Fatality Investigation and Prevention Program).

Karter, MJ (2012), 'Patterns of firefighter fireground injuries', (Quincy, MA: National Fire Protection Association Fire - Analysis and Research Division).

Kay, D and Marino, FE (2003), 'Failure of fluid ingestion to improve self-paced exercise performance in moderate-to-warm humid environments', *Journal of Thermal Biology,* 28, 29-34.

Kenefick, RW and Cheuvront, SN (2012), 'Hydration for recreational sport and physical activity', *Nutrition Reviews,* 70, 137-42.

Lee, SMC, Williams, WJ, and Schneider, SM (2000), 'Core temperature measurement during submaximal exercise: Esophageal, rectal, and intestinal temperatures', (National Aeronautics and Space Administration).

Maughan, RJ, Shirreffs, SM, and Leiper, JB (2007), 'Errors in the estimation of hydration status from changes in body mass', *Journal of Sports Sciences,* 25 (7), 797-804.

McGregor, SJ, Nicholas, CW, Lakomy, HK, and Williams, C (1999), 'The influence of intermittent high-intensity shuttle running and fluid ingestion on the performance of a soccer skill', *Journal of Sports Sciences,* 17 (11), 895-903.

McLellan, TM, Jacobs, I, and Bain, JB (1993), 'Influence of temperature and metabolic rate on work performance with Canadian Forces NBC clothing', *Aviation, Space, And Environmental Medicine,* 64 (7), 587-94.

McLennan, J and Birch, A (2005), 'A potential crisis in wildfire emergency response capability? Australia's volunteer firefighters', *Environmental Hazards,* 6, 101-07.

Mohr, M, Rasmussen, P, Drust, B, Nielsen, B, and Nybo, L (2006), 'Environmental heat stress, hyperammonemia and nucleotide metabolism during intermittent exercise', *European Journal of Applied Physiology,* 97 (1), 89-95.

Montain, SJ and Coyle, EF (1992), 'Influence of graded dehydration on hyperthermia and cardiovascular drift during exercise', *Journal of Applied Physiology,* 73 (4), 1340-50.

Morris, GJ, Nevill, ME, Lakomy, HKA, Nicholas, C, and Williams, C (1998), 'Effect of a hot environment on performance of prolonged, intermittent, high-intensity shuttle running', *Journal of Sports Sciences,* 16 (7), 677-86.

Parkin, JM, Carey, MF, Zhao, S, and Febbraio, MA (1999), 'Effect of ambient temperature on human skeletal muscle metabolism during fatiguing submaximal exercise', *Journal of Applied Physiology,* 86 (3), 902-08.

Payne, WR, Portier, B, Fairweather, I, Zhou, S, and Snow, R (1994), 'Thermoregulatory response to wearing encapsulated protective clothing during simulated work in various thermal environments', *American Industrial Hygiene Association Journal,* 55 (6), 529-36.

Périard, JD, Cramer, MN, Chapman, PG, Caillaud, C, and Thompson, MW (2011), 'Neuromuscular function following prolonged intense self-paced exercise in hot climatic conditions', *European Journal of Applied Physiology,* 111 (8), 1561-69.

Phillips, M, Payne, W, Lord, C, Netto, K, Nichols, D, and Aisbett, B (2012), 'Identification of physically demanding tasks performed during bushfire suppression by Australian rural firefighters', *Applied Ergonomics,* 43 (2), 435-41.

Phillips, M, Netto, K, Payne, W, Nichols, D, Lord, C, Brooksbank, N, Onus, K, Jefferies, S, and Aisbett, B (2011), 'Frequency, intensity and duration of physical tasks performed by Australian rural firefighters during bushfire suppression', in Thornton RP (ed.), *Bushfire CRC & AFAC Conference* (Sydney, Australia), 205-13.

Raines, J, Snow, R, Nichols, D, and Aisbett, B (2015), 'Fluid intake, hydration, work physiology of wildfire fighters working in the heat over consecutive days', *Annals of Occupational Hygiene*, 1-12.

Raines, J, Snow, R, Petersen, A, Harvey, J, Nichols, D, and Aisbett, B (2012), 'Pre-shift fluid intake: effect on physiology, work and drinking during emergency wildfire fighting', *Applied Ergonomics,* 43 (3), 532-40.

Raines, J, Snow, R, Petersen, A, Harvey, J, Nichols, D, and Aisbett, B (2013), 'The effect of prescribed fluid consumption on physiology and work behavior of wildfire fighters', *Applied Ergonomics,* 44 (3), 404-13.

Ramanathan, NL (1964), 'A new weighting system for mean surface temperature of the human body', *Journal of Applied Physiology,* 19 (3), 531-33.

Rodríguez-Marroyo, J, López-Satue, J, Pernía, R, Carballo, B, García-López, J, Foster, C, and Villa, J (2012), 'Physiological work demands of Spanish wildland firefighters during wildfire suppression', *International Archives of Occupational & Environmental Health,* 85 (2), 221-28.

Rodríguez-Marroyo, JA, Villa, JG, López-Satue, J, Pernía, R, Carballo, B, García-López, J, and Foster, C (2011), 'Physical and thermal strain of firefighters according to the firefighting tactics used to suppress wildfires', *Ergonomics,* 54 (11), 1101-08.

Sawka, MN, Burke, LM, Eichner, ER, Maughan, RJ, Montain, SJ, and Stachenfeld, NS (2007), 'American College of Sports Medicine position stand: Exercise and fluid replacement', *Medicine & Science in Sports & Exercise,* 39 (2), 377-90.

Smith, DL (2008), 'Firefighter fatalities and injuries: the role of heat stress and PPE', (Illinois: Firefighter Life Safety Research Center, Illinois Fire Service Institute).

Smith, DL, Petruzzello, SJ, Kramer, JM, and Misner, JE (1997), 'The effects of different thermal environments on the physiological and psychological responses of firefighters to a training drill', *Ergonomics,* 40 (4), 500-10.

Snook, SH and Ciriello, VM (1974), 'The effects of heat stress on manual handling tasks', *American Industrial Hygiene Association Journal,* 35 (11), 681-85.

Tucker, R, Rauch, L, Harley, YXR, and Noakes, TD (2004), 'Impaired exercise performance in the heat is associated with an anticipatory reduction in skeletal muscle recruitment', *European Journal Of Physiology,* 448 (4), 422-30.

Young, AJ, Sawka, MN, Epstein, Y, DeCristofano, B, and Pandolf, KB (1987), 'Cooling different body surfaces during upper and lower body exercise', *Journal of Applied Physiology,* 63 (3), 1218-23.

Chapter 4: Study Two

Paper Two

Multiple days of heat exposure on firefighters' work performance and physiology

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4.1 ABSTRACT

This study assessed the accumulated effect of ambient heat on the performance of, and physiological and perceptual responses to, intermittent, simulated wildfire fighting tasks over three consecutive days. Firefighters (n = 36) were matched and allocated to either the CON (19°C; 58% RH) or HOT (33°C; 40% RH) condition. They performed three days of intermittent, self-paced simulated firefighting work, interspersed with physiological testing. Task repetitions were counted (and converted to distance or area) to determine work performance. Participants were asked to rate their perceived exertion and thermal sensation after each task. Heart rate, core temperature (T_c), and skin temperature (T_{sk}) were recorded continuously throughout the simulation. Fluids were consumed ad-libitum. Urine volume was measured throughout, and urine specific gravity (USG) analysed, to estimate hydration. All food and fluid consumption was recorded. There was no difference in work output between experimental conditions. However, significant variation in performance responses between individuals was observed. All measures of thermal stress were significantly elevated in the HOT, with core and skin temperature reaching, on average, 0.24 ± 0.08°C and 2.81 ± 0.20°C higher than the CON group. Participants' doubled their fluid intake in the HOT condition, and this was reflected in the USG scores, where the HOT participants reported significantly lower values. Heart rate was comparable between conditions at nearly all time points, however the peak heart rate reached each circuit was 7 ± 3 % higher in the CON trial (P = 0.029). Likewise, RPE was slightly elevated in the CON trial for the majority of tasks. Participants' work output was comparable between the CON and HOT conditions, however the performance change over time varied significantly between individuals. It is likely that the increased fluid replacement in the heat, in concert with frequent rest breaks and task rotation, assisted with the regulation of physiological responses (e.g., heart rate, core temperature).

4.2 INTRODUCTION

Wildfires can last hours, days, or weeks (Aisbett et al. 2012; Rodríguez-Marroyo et al. 2011), depending on their severity. As a result, firefighters can be required to work long shifts (8 – 14 hours) over consecutive days (Aisbett et al. 2012; Cater et al. 2007; Cuddy et al. 2007; Raines et al. 2012), while performing a range of physically demanding tasks (Phillips et al. 2012). While some of these tasks involve the presence of a live fire, the majority of tasks performed during wildfire suppression are performed away from the fire, either during preparation for, or 'mopping-up' after, a fire event (Phillips et al. 2012). In addition to the physical demand imposed by firefighting work (Aisbett and Nichols 2007; Rodríguez-Marroyo et al. 2011), wildland firefighters frequently perform their duties under a range of environmental conditions (Aisbett et al. 2012; Raines et al. 2013). Australian firefighters performing recovery operations after a major fire event (the Victorian 'Black Saturday' Bushfires, 2009) have been observed to do so in peak ambient conditions ranging from 18.6 – 33.9°C (Raines et al. 2013). During hot weather days, firefighters responding to a multi-day 'campaign' fire may also sleep under warm conditions, in temporary accommodation at (or near) the fireground (Aisbett et al. 2012; Cater et al. 2007). Given this combination of potentially fatiguing factors, it is important for policy makers in the fire industry to understand the physiological impact of performing consecutive work shifts in the heat. Understanding the physiological and subjective responses to such work is important for fire agencies in preserving the health and safety of their personnel. Further, if firefighters cannot sustain their work performance over multiple work days it may have negative implications for the wildfire suppression effort as a whole. Slowed productivity may result in an increase in the time taken to control a wildfire, which may ultimately place firefighters, civilians, and their property at undue risk.

To date, there is a paucity of research examining the cumulative effect of heat exposure over multiple days, particularly in an occupational context. Research investigating construction workers performing three days of work under hot – very hot ambient conditions (ranging from 32.5 – 49.0°C) showed no difference in physiological variables (including USG, aural temperature and heart rate), either within or between shifts (Bates and Schneider 2008). The authors' suggest that the workers were able to self-regulate their work output and fluid intake in order to avoid adverse physiological consequences (e.g., dehydration, heat stress); however, no measure of work performance was reported in this study. In contrast to these findings, sport acclimation research suggests, for the most part, that short-term (e.g., 4 days) repeated heat exposures will actually improve performance and decrease the thermal stress and exertion elicited during exercise (Castle et al. 2011; Garrett et al. 2009; Garrett et al. 2012).

Relying on the existing in-field or laboratory research to inform fireground workplace practices is problematic for several reasons. Laboratory studies that examine the relationship between heat and manual-handling performance have observed decrements in lifting, carrying, and pushing performance (Snook and Ciriello 1974), and work tolerance time (McLellan et al. 1993). However, the short durations utilised (30 to 90 minutes) do not provide insight into the fatiguing effects of heat over longer work periods, or over consecutive days. The available multi-day heat acclimation studies typically use a pre-post design, where the focus is on performance adaptations that occur following a period of heat acclimation (Castle et al. 2011; Garrett et al. 2009), rather than during successive days in hot temperatures. These heat-acclimation protocols also commonly use cycling (Castle et al. 2011; Garrett et al. 2009) or rowing (Garrett et al. 2012) as their measure of performance, and are most often restricted to 90 minutes (or less) of heat exposure per day. Wildland firefighters in the field perform intermittent-intensity (Aisbett and Nichols 2007; Cuddy et al. 2007; Rodríguez-Marroyo et al. 2011), manual-handling work tasks such as digging, raking, carrying and dragging (Phillips et al. 2012), and work in shifts that typically last ~10 hours (Aisbett et al. 2012; Cater et al. 2007; Cuddy et al. 2007; Raines et al. 2012). The exercise modes, intensities, durations, and work to rest ratios are so vastly different to that utilised in the heat acclimation protocols that it is difficult to extrapolate these findings to wildland firefighters' performance on the fireground. The existing field research more closely resembles the long-duration, manual-handling work profile of wildfire fighting, but does not report worker performance (Bates and Schneider 2008). Thus, it is not possible to use this research to determine the effect of multiple days of heat exposure on firefighters' work output.

As such, this study aims to assess and describe the accumulated effect of ambient heat on the performance of repeated, long-duration simulated wildland firefighting tasks over consecutive days. Further, this study aims to quantify the effect of consecutive days of heat exposure on physiological and subjective responses during simulated wildland firefighting work. Although multiple-day heat research is not yet developed enough to support a firm hypothesis, the current authors predict that performance of the simulated firefighting work will be negatively impacted by consecutive days of heat exposure. Specifically, that firefighters will decrease their rate of work on each task in the heat when compared to a temperate control condition, and that work output will be further reduced on the second and third days of heat exposure when compared to the first day. Secondly, it is predicted that this decrease in work productivity will regulate physiological and subjective responses so that they remain comparable to that observed in a more temperate environment.

4.3 MATERIALS AND METHODS

4.3.1 Participants

Male and female volunteer and career firefighters (n = 36) participated in this study (~14% female, similar to the ratios observed within Australia's firefighting population; McLennan and Birch 2005). This study utilised almost the same participant cohort as Study One (see Section 3.3.1), although two participants in the HOT trial did not complete the three-day protocol, and thus were not included in the analysis for this study. The power analysis used to inform Study One was also used to inform the present study, given that no existing research reports performance and physiology changes over multiple days of long-duration heat exposure. Participants in each group were matched (in order of priority) by age, gender, and body mass index (Haskell et al. 2007) in order to minimise variation between groups. Participants were also matched according to the sequence in which they completed the physical work circuit (see Section 4.3.2 for details; Appendix H). A self-report measure of habitual physical activity was also collected from each participant in order to glean an indication of their aerobic fitness levels, given this is a factor known to influence exercise performance in the heat (Cheung et al. 2000). Unfortunately direct measures of aerobic fitness were unable to be conducted due to time and cost constraints. Firefighters from hotter climates (e.g., Northern Australia) were excluded from the study in order to control a potentially confounding variable (heat acclimation), and reduce variation in the participant cohort. Data collection also took place during the cooler autumn and winter months in Southern Australia to minimise the effect of heat acclimation. Participants provided written informed consent (Appendix C) and filled out a medical questionnaire (Appendix D) prior to commencement of the study to ensure they were physically able to perform the work protocol without medical supervision. Ethical approval was obtained for this study by Deakin University (DUHREC 2014-040; Appendix E).

Prior to testing, participants' height was measured and recorded using a stadiometer (Fitness Assist, England), and semi-nude body mass (i.e., underwear only) was measured using an electronic scale (A and D, Japan). In all trials, participants wore firefighting personal protective clothing (PPC). This included a two-piece jacket and trouser set made from Proban® cotton fabric (Protex®, Australia), suspenders, boots, gloves, and helmet (amounting to ~5 kg), which meet the performance requirements for wildland firefighting clothing as stipulated by the International Organization for Standardization (ISO 15384:2003).

4.3.2 Experimental Protocol

Participants were allocated to either a control (CON; 19°C, 58% RH) or hot (HOT; 33°C, 40% RH) environmental condition to reflect the different ambient environments often faced on the fireground (Raines et al. 2013), and were tested in groups of five (or less). Ambient temperature was maintained through the use of split cycle air conditioners

(Panasonic, Japan) and portable ceramic disk heaters (Micro Furnace, Sunbeam, Australia), and was continuously measured and logged using three temperature nodes (Onset Computer Corporation, USA). Room temperature and relative humidity data over the three-day simulation was analysed at 10-minute intervals. Participants were required to perform three days of simulated wildfire suppression work, including physical work as well as physiological and cognitive tests. The suite of cognitive tests was part of a broader study; thus, the methods surrounding these protocols and the ensuing results will not be described.

Testing took place in a windowless, climate-controlled room measuring 9 × 13 m. The distance between the various workstations was precisely measured during each testing session to ensure a consistent standard was being met between participant groups. Firefighters were familiarised with the physical work tasks, as well as the rating of perceived exertion (RPE; Appendix F) and thermal sensation (Appendix G) scales (Borg 1998; Young et al. 1987), on the day prior to the commencement of testing. Participants were also then made aware of the condition to which they'd been allocated (CON or HOT). Participants ingested a core temperature capsule (Jonah, Minimitter, Oregon) prior to lights out (10:00 pm) to allow adequate time for the capsule to pass through the stomach, thereby preventing inaccurate readings occurring as a result of ingested food or liquid (Lee et al. 2000). Core temperature pills were administered each consecutive night throughout the protocol, in order to capture accurate core temperature readings during the following day of simulated work.

Prior to the commencement of testing each day, participants had heart rate monitors (Polar, Finland) and skin temperature patches (VitalSense/Jonah, Minimitter, Oregon) affixed. Core and skin temperature recorded continuously on a data logger (VitalSense, Minimitter, Oregon); therefore 'pre-work' readings were extracted from the data post-testing. Participants then dressed in their firefighting PPC, and began testing at 12:30 pm (on day one) in both conditions.

On day one, participants performed three work 'circuits', each lasting two hours (six-hour total work period), and comprising 55 minutes of physical work, 20 – 25 minutes of physiological data collection, 20 – 25 minutes of cognitive testing and a 15 – 20 minute passive rest period. On days two and three, participants performed five of the two-hour testing circuits (10-hour work periods) to simulate the often-long work shifts performed during a campaign fire deployment (Aisbett et al. 2012; Cater et al. 2007; Cuddy et al. 2007; Raines et al. 2012). Thus, over the thee-day simulation, all firefighters performed 13 work circuits in total. Participants were allowed a half-hour lunch break in the middle of the workday (on days two and three).

The work to rest ratios that made up each two-hour circuit mimic the ratios of actual fireground work (Aisbett and Nichols 2007; Cuddy et al. 2007; Raines et al. 2012), and the physical tasks were designed to simulate the movements and fitness components of fire suppression tasks in the field (Phillips et al. 2011; Phillips et al. 2012). Each participant had the same work opportunity each circuit; however the starting position (task) was staggered to allow multiple participants to be tested at once. Once allocated to a circuit order, participants followed the same sequence in all 13 work circuits.

Participants were allowed to drink room temperature water ad libitum throughout testing. Prior consultation with fire agencies determined that participants were also supplied with sachets of flavoured electrolyte supplement, and a ‘ration pack’ of snack foods (e.g., muesli bars, crackers, and confectionary) similar to that which they would receive on the fireground. Food and drink consumption was only permitted during the rest periods between tasks, not during the performance of the physical work tasks.

4.3.3 Physical Work Circuit

The work circuit comprised six physical tasks, which were chosen on the basis of being the most physically demanding tasks performed by Australian rural firefighters (Phillips et al. 2012). These tasks are also considered the most important tasks in achieving operational outcomes (Phillips et al. 2012), and have been shown to be the most frequent, and/or longest and most intense, tasks performed during wildfire suppression work (Phillips et al. 2011).

All hose tasks employed in the protocol were performed using 38-mm hoses with branch attached. The tasks included:

Rakehoe work

Involved raking 29-kg of material (large and small tyre crumb) from one end of a rectangular wooden box (2 × 0.9 m) to the other, using a rakehoe, to simulate building a firebreak (Budd et al. 1997b; Phillips et al. 2012).

Blackout hose work

Involved walking the perimeter of a 2.5- × 2.5-m square, stopping at each corner for three seconds (as timed by a metronome). Whilst walking, participants dragged a 15-kg weight attached to a 2-m hose. This task simulates the 'stop-start' dragging of a charged hose when dousing smouldering debris with liquid during post-fire clean-up work (Phillips et al. 2012).

Hose rolling

A common task performed during pack up (Phillips et al. 2012), this task required participants to roll up a 16-m hose (folded in half to a length of 8 m) to an operational standard.

Lateral hose repositioning

Involved walking in an arc (3.5-m radius; 11-m length), carrying a 3.5-m hose. The hose was attached to a weighted stand centred at the base of the arc. Two platforms (68 × 28 × 15 cm; Spalding, Australia) served as 'obstacles' (e.g., logs, fallen debris), that participants had to manoeuvre. This task simulated moving a charged fire hose sideways from a fixed point, such as a water source (Phillips et al. 2012).

Charged hose advance

Simulated walking forwards with a hose filled with pressurised liquid (Phillips et al. 2012). Participants dragged a 15-kg weighted tyre attached to a 2-m hose, up and down a marked distance of 8 metres.

Static hose hold

Involved pointing a 3.5-m hose (attached to a weighted stand via an elastic strap, to provide resistance) at a target (with laser pointer attached). Participants were instructed to hold the laser within the target for five minutes, or until exhaustion. If the laser moved out of the target, or if the hose touched the ground, for more than two seconds, participants' performance time was recorded at that point. This simulated holding a charged hose in position for an extended period when dousing a fire (Phillips et al. 2012). All participants in both conditions were able to complete the maximum time of five minutes, so performance results for this task will not be reported.

Five minutes was allocated to each task (inclusive of the time taken to move from one station to the next); however, the work to rest ratios within that time varied between tasks, according to the work to rest ratios observed for each task in the field (Phillips et al. 2011) (see Table 1; Chapter 3). Accordingly, some tasks were performed only once in each 55-minute physical work period, whereas others were performed multiple times according to their frequency in the field (Phillips et al. 2011) (Table 1; Chapter 3). While the work and rest periods were standardised across groups, firefighters could self-select their work output within the work periods (e.g., by increasing or decreasing the number of repetitions performed in the given time frame). The repetitions completed during each work task were recorded through the use of a specially designed iPad application (Good Dog Design, Australia). In analysing the data, repetitions were converted into distance (m), or area (m^2) in the case of the rakehoe task. Each of the physical work tasks was analysed individually, based on the amount of work that was performed at each station during each of the physical work circuits (circuits 1 – 13). For brevity, daily mean performance data will be presented in the Results.

4.3.4 Overnight Protocol

Over the three days of testing, participants 'lived' in the simulated environment at the testing facility, and adhered to a strict schedule throughout their stay. This included set meal, sleep, and physical, physiological, and cognitive testing times throughout each day. Caffeine and cigarettes was permitted; however participants were encouraged to consume them only as they would during a multi-day campaign fire, and only during rest periods (i.e., not during physical or physiological testing). All food and drink was provided to participants, based on the standard food items that would be available to wildland firefighters on the fireground (according to consultation with industry). This included a hot breakfast (bacon, eggs, baked beans, and toast), sandwiches for lunch, and a hot dinner (e.g., pasta, meat, and vegetables).

Testing concluded at 6:30 pm on each of the three testing days. On nights one and two, participants then ate dinner in the testing environment (on the third night 6:30 pm represented the conclusion of testing). After dinner, participants left the testing environment briefly to shower and prepare for bed. Once showered and dressed for bed, firefighters had approximately 2.5 hours of 'free time' (within the testing environment), where they were permitted to watch movies, read, or play card/board games. Participants were in bed by 9:45 pm, with lights out at 10:00 pm. Overnight temperature was maintained at 18°C during the control trial, and 23°C during the hot condition. This simulated the often-warm sleeping environment firefighters experience on a campaign tour (Aisbett et al. 2012; Cater et al. 2007).

Participants were woken at 6:00 am on days two and three, where they dressed and prepared for the day. After breakfast, participants were again fitted with a heart rate monitor and skin temperature patches, and 'pre-work' physiological measures were recorded. During this time, the temperature was increased to 33°C in time to commence the 'workday' at 8:00 am.

4.3.5 Physiological and Subjective Measurements

Core temperature, skin temperature, and heart rate were recorded continuously throughout the three simulated work 'shifts'. Maximum heart rate (HR_{max}) was predicted using the formula 207 – 0.7 × age (Gellish et al. 2007) in order to account for the substantial variation in participant age (range: 18 – 60 years). Skin temperature was recorded at four sites on the left side of the body; the middle of the chest, thigh, upper arm and calf (Payne et al. 1994). Mean skin temperature was calculated using the formula $0.3(T_{chest} + T_{arm}) + 0.2(T_{thigh} + T_{leg})$ (Ramanathan 1964). The types and quantities of ingested food and liquid were recorded throughout testing, and food and drink data was extracted using the FoodWorks 7 nutrition software (Xyris Software Pty Ltd, Australia). All urine was measured for volume, and USG was analysed using a portable refractometer (Atago, Japan), to approximate hydration status. Given that day one was shorter than days two and three, all fluids ingested and urine expelled were expressed relative to the number of circuits each day. Finally, participants were asked to provide RPE (Borg 1998) and thermal sensation (Young et al. 1987) ratings after each individual physical task (i.e., every five minutes).

4.3.6 Statistical Analyses

Statistical analyses were carried out using the IBM Statistical Package for the Social Sciences (SPSS V.22.0.0, Champaign, Illinois) and Stata 12.0 (StataCorp, Texas, USA). The distribution of the data was tested for normality using visual inspection of Q-Q plots, formal testing (Shapiro Wilk tests), and by calculating skewness and kurtosis (Field 2007). All variables met assumptions of normality with the exception of ingested and expelled fluids, as 1) Q-Q plots deviated substantially from the line of identity, 2) the Shapiro Wilk tests were significant ($P < 0.05$), and 3) they fell outside the acceptable range for kurtosis values (i.e., kurtosis > 2 or < -2) (Westfall and Henning 2013). Participant characteristics, ambient temperature, relative humidity, energy, smoking status, and caffeine consumed were analysed using independent-samples t-tests to determine differences between the two experimental conditions. For all other variables, the Generalized Linear Latent and Mixed Model approach was used (*gllamm* software, version 2.3.20) (Rabe-Hesketh et al. 2002, 2005).

The GLMM modelling procedure more accurately accounts for the serial correlation of data points over time, and is therefore increasingly preferred over repeated-measures ANOVA for these types of data sets (Molenberghs and Verbeke 2001). This generalised technique allows for non-normal distributions to be specified if the data does not meet the assumption of normality (McCulloch 2003). Thus, models were constructed with a gamma distribution for the ingested and expelled fluid variables, but did not converge. Therefore, models with a normal distribution were used. The implications of fitting normal models to non-normally distributed data will be further explored in the Discussion section of the manuscript. The *gllamm* software also provides valid estimates in the presence of missing data, and uses maximum likelihood estimation with adaptive quadrature for more reliable parameter estimates than quadrature (Rabe-Hesketh et al. 2002). In the current study, < 2% of performance, heart rate, perceptual, and hydration data was missing. For core and skin temperature variables, 20% of the data was missing due to device malfunction, and thus was treated as missing-at-random. Mixed effects models incorporate fixed effects to assess the influence of the experimental intervention, as well as random effects that factor in the unique responses of individuals (e.g., individual differences in response to heat exposure) (Van Dongen et al. 2004). Thus, mixed models are able to differentiate between-subject from within-subject effects. The construction of the mixed models followed the iterative framework recommended by Singer (1998), where the fixed effects of Condition (categorical variable), Circuit (continuous variable), and Condition × Circuit were analysed, with random intercepts and random slopes that varied at the Participant level. Given that the circuits were performed with only brief breaks in between, it is likely that the physiological responses and/or physical fatigue accrued during one circuit would impact the following circuit (e.g., if core body temperature was increased after the first circuit of work, it is possible that values would not return to baseline levels before the beginning of the subsequent circuit). Therefore, performance and physiological responses were treated as time-series data because of the likely serial dependency between consecutive circuits. In this way, GLMMs allow rates of change to be assessed, rather than conceptualising time points as discrete categories of time (Cnaan et al. 1997; Tasca and Gallop 2009).

As all dependent variables were treated as having a Gaussian (e.g., normal) distribution, the 'identity' link function was specified (Kachman 2000). The CON and HOT groups were coded 1 and 0, respectively. Therefore, a positive beta (β) value for the effect of Condition indicates that HOT > CON, and a negative β value indicates that CON > HOT. For Circuit (time) effects, a positive β value indicates an increase over time (e.g., over successive circuits), and a negative β value indicates a decrease. Thus, when using the GLMM method, parameter estimates (presented as β values) reflect the magnitude of the difference between groups (or over time). The random effects explain the variance due to inter-individual differences at baseline (random intercept) and over time (random slopes). In selecting the optimal model for each variable, Akaike weights (which determine the relative likelihood of the model, given the data) were compared between models as per the procedure outlined in Burnham and Anderson (2002). The final parameter estimates for all GLMM variables are reported as β coefficient ± standard error of the estimate (SE). Statistical significance was set at $P \leq 0.05$, and all other data are presented as means ± standard deviations.

4.4 RESULTS

There was no difference between the CON and HOT groups for participants' age, height, weight, BMI, the ratio of males to females, self-reported habitual caffeine consumption, or physical activity ($P \geq 0.481$; Table 5). Two participants in the CON group were smokers, whereas all participants in the HOT group were non-smokers ($P = 0.154$). There was also no difference ($P = 0.605$) in the amount of energy consumed each day between the CON (14,706 ± 3774 kJ) and HOT (15,080 ± 3489 kJ) groups. There was, however, a significant difference ($P = 0.019$) in the amount of caffeine consumed each day during the simulation. The CON and HOT groups consumed on average 80 ± 75 and 121 ± 97 mg per day, respectively. Average room temperature and relative humidity (%) during the simulated shifts were also different between conditions ($P < 0.001$), reaching 32.50 ± 1.30°C and 39.56 ± 2.80 % in the HOT group, compared to 19.16 ± 0.25°C and 58.26 ± 2.78 % in the CON group.

Table 5. Characteristics of firefighters in the CON and HOT conditions

	CON	HOT
n	18	18
Age (years)	39 ± 16	36 ± 13
Height (cm)	178 ± 8	178 ± 9
Weight (kg)	84.9 ± 17.8	88.0 ± 18.0
BMI ($kg.m^{-2}$)	26.7 ± 4.9	27.5 ± 3.5
Males: Females	15: 3	14: 4
Habitual daily caffeine intake (mg)	183 ± 126	196 ± 130
Habitual physical activity (sessions per week)	3.2 ± 3.0	3.2 ± 2.4

CON = control group; HOT = hot group. All data are reported as means ± SD.

4.4.1 Work performance

Data for all task-based variables, including daily mean performance (per circuit), are presented for ease of comparison between conditions (Table 6). All participants completed the 5-minute maximum static hose hold, thus performance data are not reported for this task. For all of the physical work tasks, the fixed effect of Condition did not explain a significant amount of variance in work performance ($P \geq 0.321$). Random slope models best explained the variance in work performance for all tasks ($P < 0.001$), highlighting the individual variability in both an individual's starting point and their performance responses over time.

Table 6. Daily mean work performance, heart rate, RPE, and thermal sensation data across the CON and HOT conditions

			Work performance			Heart Rate (% HR_{max})			RPE			Thermal sensation		
				Day			Day			Day			Day	
TASK			1	2	3	1	2	3	1	2	3	1	2	3
Blackout hose	CON	Mean	165.5	168.7	166.8	65	62	62	12.1	11.9	12.1	4.9	4.7	4.8
		SD	12.7	12.8	12.8	12	10	10	0.9	0.8	0.9	0.4	0.6	0.5
	HOT	Mean	180.2	171.6	175.0	68	61	60	12.0	11.5	11.5	5.6	5.5	5.6
		SD	27.8	23.0	22.6	10	8	7	1.0	0.9	0.8	0.6	0.5	0.5
Charged hose advance	CON	Mean	104.9	111.2	116.6	77	74	73	15.5	15.4	16.1	5.6	5.5	5.5
		SD	24.2	24.0	28.7	13	14	13	1.4	1.3	1.7	1.0	1.0	1.1
	HOT	Mean	106.0	112.1	114.5	76	71	70	14.7	14.6	14.5	6.2	6.0	6.0
		SD	25.9	32.7	27.0	10	9	7	1.6	1.5	1.4	0.6	0.7	0.7
Lateral hose repositioning	CON	Mean	617.2	656.8	688.0	65	63	63	11.3	11.3	11.5	4.7	4.6	4.7
		SD	91.1	83.1	86.1	11	10	10	0.7	0.8	0.9	0.5	0.6	0.5
	HOT	Mean	646.5	628.9	624.2	66	60	59	11.0	10.7	10.7	5.5	5.4	5.4
		SD	103.7	97.8	104.9	9	8	7	1.1	1.3	1.1	0.5	0.4	0.4

Table 6 cont.

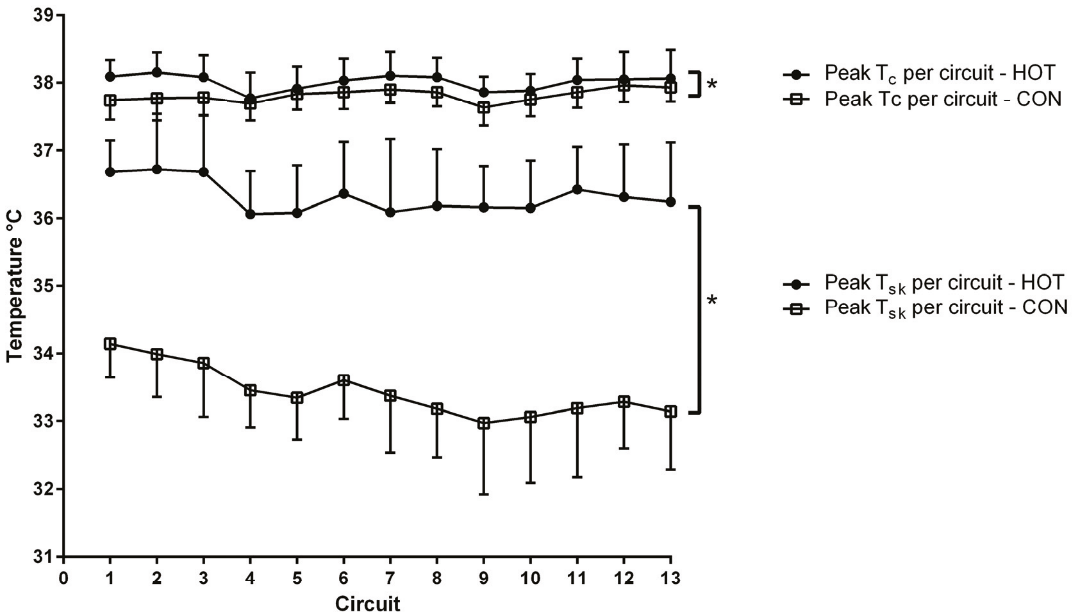
			Work performance			Heart Rate (% HR_{max})			RPE			Thermal sensation		
			Day			Day			Day			Day		
TASK			1	2	3	1	2	3	1	2	3	1	2	3
Hose rolling	CON	Mean	17.9	21.6	24.6	66	65	64	12.3	12.3	12.8	4.8	4.7	4.8
		SD	4.1	5.0	7.1	11	10	10	1.1	1.2	1.5	0.6	0.7	0.7
	HOT	Mean	17.9	21.5	23.8	67	63	61	11.0	11.3	11.6	5.3	5.4	5.5
		SD	6.1	8.0	7.9	11	10	8	0.9	0.5	0.8	0.5	0.5	0.4
Rakehoe work	CON	Mean	4.9	5.4	5.6	73	71	70	14.6	14.5	14.9	5.7	5.5	5.7
		SD	1.3	1.4	1.4	10	8	9	0.9	1.3	1.3	0.6	0.7	0.7
	HOT	Mean	4.9	5.3	5.7	76	69	67	14.3	14	14.1	5.9	6.0	6.1
		SD	1.1	1.1	1.3	10	8	8	1.7	1.4	1.8	0.7	0.6	0.6
Static hose hold	CON	Mean	-	-	-	65	60	59	13.7	13.1	13.2	5.4	5.3	5.5
		SD	-	-	-	13	11	11	2.0	1.9	1.8	0.9	0.9	0.7
	HOT	Mean	-	-	-	69	61	59	12.7	12.0	11.5	6.1	6.0	5.8
		SD	-	-	-	11	8	7	1.7	1.4	1.3	0.6	0.7	0.7

CON = control group; HOT = hot group; SD = standard deviation; % HR_{max} = percentage of age-predicted heart rate maximum; RPE = rating of perceived exertion Work performance is reported as distance (m) for all tasks except rakehoe work, which is reported in area (m^2).

4.4.2 Core and skin temperature

The variance in average core and mean skin temperature each circuit was best explained by the full model. For mean skin temperature there was a Condition × Circuit effect, which showed that participants in the HOT condition were hotter, and that this difference increased each successive circuit (β = 0.03 ± 0.01°C; P = 0.014). Both core and mean skin temperature also displayed significant fixed effects for Condition (β = 0.30 ± 0.08 and 3.07 ± 0.27, respectively; P < 0.001). The conditional growth model with random slopes explained the greatest amount of variance in peak core and mean skin temperature per circuit. As such, peak core and mean skin temperature were significantly higher in the HOT when compared to the CON condition (P ≤ 0.002), reaching on average 0.24 ± 0.08°C and 2.81 ± 0.20°C higher, respectively (Figure 2).

Figure 2. Peak core and skin temperature over the 13 work circuits



** indicates that HOT significantly higher (P < 0.05) than CON. CON = control group; HOT = hot group; Tc = core temperature; Tsk = mean skin temperature. All data are presented as means ± SD.*

4.4.3 Heart rate

Daily mean heart rate data per work task is presented in Table 6. For all physical work tasks, the fixed effect of Condition did not explain a significant amount of the variance in firefighters' heart rate ($P \geq 0.477$). The variance in heart rate across all tasks was best explained by the random slope models ($P < 0.001$), highlighting a large amount of individual variation. Similarly, there was no effect of Condition on average heart rate during the 2-hour circuits ($P = 0.986$), or when the 55-minute work circuits ($P = 0.717$) or 65-minute rest periods ($P = 0.660$) were analysed individually (data presented in Table 7). Again, random slope models best explained the variance in heart rate during each of these periods ($P < 0.001$). Conversely, the peak heart rate reached each circuit was best explained by the conditional growth model with random slopes ($\beta = -6.79 \pm 3.11$; $P = 0.029$), with a fixed effect indicating that participants in the CON condition reached a higher peak heart rate when compared to their HOT trial counterparts.

Table 7. Daily heart rate data across the CON and HOT conditions

	Mean heart rate per circuit (% HR_{max})			Peak heart rate per circuit (% HR_{max})			Mean heart rate per 55-minute work bout (% HR_{max})			Mean heart rate per 65-minute rest period (% HR_{max})		
	Day			Day			Day			Day		
	1	2	3	1	2	3	1	2	3	1	2	3
CON	59 ± 10	56 ± 8	56 ± 8	91 ± 11	87 ± 11	88 ± 11	66 ± 11	63 ± 9	63 ± 10	52 ± 9	50 ± 8	49 ± 7
HOT	61 ± 9	56 ± 7	54 ± 6	87 ± 10	82 ± 9	82 ± 7	68 ± 9	62 ± 8	60 ± 7	55 ± 8	50 ± 7	49 ± 6

CON = control group; HOT = hot group. Heart rate data are expressed as a percentage of age-predicted maximum (% HR_{max}). All data are reported as means ± SD.

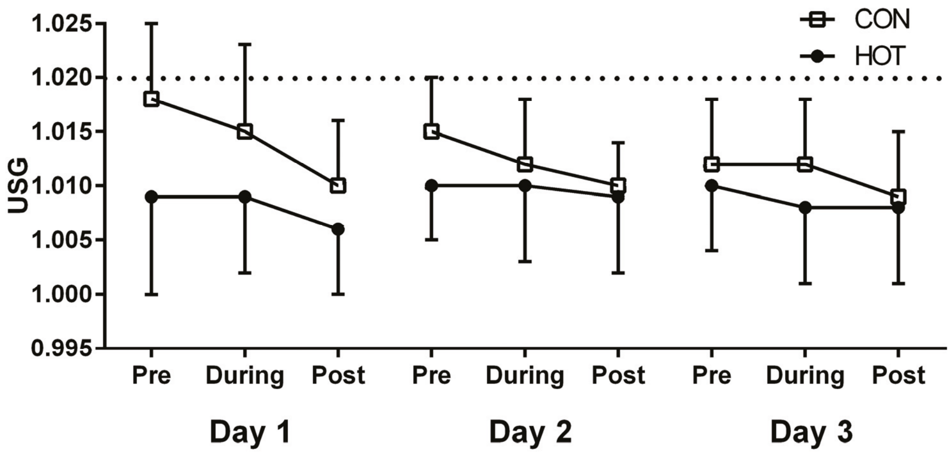
4.4.4 Perceptual responses

All mean daily RPE and thermal sensation data are presented in Table 6. The conditional growth model with random slopes best explained the variance in thermal sensation for the blackout hose, charged hose advance, hose rolling, and static hose hold tasks. For these tasks, thermal sensation was significantly higher in the HOT trial, despite significant variations in individual response ($P \leq 0.029$). For the lateral hose repositioning task, the conditional growth model best explained the variance in thermal sensation ($\beta = 0.78 \pm 0.15$; $P < 0.001$), again indicating that, on average, firefighters felt hotter when performing this task in the HOT trial. Alternatively, the Circuit (time) only model best explained the variance in thermal sensation responses during the rakehoe task ($\beta = 0.02 \pm 0.01$; $P < 0.016$), which demonstrates that participants reported higher thermal sensation values as the trial progressed, irrespective of condition. For firefighters' RPE scores, random slope models explained the most amount of variance for the raking and lateral hose repositioning tasks ($P < 0.001$). However, for the blackout hose ($\beta = -0.53 \pm 0.16$; $P = 0.001$), charged hose advance ($\beta = -0.95 \pm 0.45$; $P = 0.033$), static hose hold ($\beta = -1.34 \pm 0.53$; $P = 0.012$), and hose rolling ($\beta = -1.19 \pm 0.28$; $P < 0.001$) tasks, conditional growth models with random slopes reported main effects of Condition, highlighting that participants rated these tasks as more exerting in the CON trial.

4.4.5 Hydration

The variance in daily fluid consumption was best explained by the full model, with significant fixed effects for Condition ($\beta = 930.91 \pm 207.57$; $P < 0.001$). Firefighters in the CON trial consumed 1175 ± 412 mL, 917 ± 242 mL, and 831 ± 287 mL per circuit on days one, two, and three, compared to 2141 ± 838 mL, 1501 ± 354 mL, and 1660 ± 432 mL in the HOT condition. The full model also best explained firefighters' USG values, with significant effects of Condition ($\beta = -0.007 \pm 0.002$; $P < 0.001$) and Circuit ($\beta = -0.001 \pm 0.000$; $P < 0.001$; Figure 3). The variance in urine output volume across all tasks was best explained by the random slope models ($P < 0.001$), indicating that there was a high level of individual variation. Average urine volume per circuit (across the three days) was 604 ± 283 mL in the CON, compared to 829 ± 419 mL in the HOT.

Figure 3. Pre, during, and post-shift USG values over the three days



** The dotted line denotes that the threshold for dehydration is > 1.020 (Sawka et al. 2007). CON = control group; HOT = hot group; USG = urine specific gravity.*

4.5 DISCUSSION

Contrary to the authors' predictions, work performance across all physical work tasks was unaffected by the heat. Rather, it was observed that, irrespective of experimental condition, initial performance was different between individuals, and the time course of performance change was also individual-specific. The secondary prediction, that physiological and subjective responses would be moderated by work output, and thus, comparable between conditions, was also not supported by the findings. While there was little difference in average heart rate values between groups, all measures of thermal stress (core temperature, skin temperature, and thermal sensation) were elevated in the HOT condition. Conversely, USG values were significantly elevated during the CON trial, as were RPE scores for the majority of work tasks.

Despite its occupational relevance, there is a distinct lack of research investigating the effect of heat on work performance over consecutive days. Thus, in predicting performance outcomes in the present study the authors had to draw upon the (albeit limited) research that has examined the relationship between heat and manual-handling performance over short durations. In these studies, manual-handling work performance was decreased in hot relative to more temperate ambient conditions (McLellan et al. 1993; Snook and Ciriello 1974), a finding that was not replicated in the present study. Random slopes models best explained the variation in the current data set, highlighting the significant individual variability in performance responses over time. In other words, irrespective of experimental condition, some individuals improved their performance, some maintained performance, and some recorded performance decrements. It is well established that a multitude of factors determine how an individual will respond to exercise heat stress (e.g., gender, body composition, age, acclimation status) (Cheung et al. 2000; Hargreaves 2008). While the current data set is underpowered to allow for the inclusion of more factors into the model, assessing the contribution of individual characteristics and how they impact physical performance in this population warrants further research. In a practical setting, this could allow fire agencies to tailor work strategies according to individual characteristics that moderate the influence of heat on firefighters' physical performance. Nevertheless, at a group level, the present findings suggest that firefighters are able to perform similarly in both temperate and moderately hot conditions. This is an encouraging finding for fire agencies, as it indicates that firefighters can be equally effective (in terms of their wildfire suppression efforts) under varying environmental conditions. However, whether this finding would persist in even hotter ambient environments, as occasionally encountered during wildfire suppression (Teague et al. 2010), remains unknown. Likewise, it is possible that firefighters performing single tasks extending over longer durations (e.g., > 5 minutes) under hot conditions may eventually succumb to physical fatigue.

Firefighters in the HOT condition experienced greater increases than the CON group across all measures of thermal stress (core temperature, skin temperature, and thermal sensation). Previously, construction workers performing three days of work under hot-very hot ambient conditions have been observed to maintain their physiological responses (including aural temperature), both within and between shifts (Bates and Schneider 2008). However, no control group was used in this study. Thus, it is highly possible that, even though the workers' physiological responses were relatively stable over a three-day period, they may have been significantly elevated relative to workers in a more temperature environment (as in the present research). It should be noted that, although the difference in peak skin temperature between groups in the current study was relatively substantial (2.81 ± 0.20°C), peak core temperature in the HOT condition was only 0.24 ± 0.08°C higher per circuit than in the CON trial, and was consistently < 38.20°C (see Figure 2). Therefore, while this difference between groups was statistically significant, the heat load was compensable and may not translate to a meaningful effect on the fireground. It is possible that the regular rest periods utilised throughout the protocol, as well as adaptive behaviours (e.g., increased fluid intake, jacket and helmet removal during rest breaks), allowed participants to maintain manageable core temperature values across the course of the protocol.

Firefighters in the HOT condition almost doubled their fluid consumption (per circuit) relative to the CON group over the course of the three-day simulation. However, fluid consumption results must be interpreted with caution, given that models with a normal distribution were fitted to the data (which was not normally distributed) due to a lack of convergence when using gamma models. This particular data set was leptokurtic (kurtosis > +2), which means that the curve of the data displayed a higher peak and fatter tails than a normal distribution (DeCarlo 1997). Thus, the parameters of the models are likely to underestimate true probabilities about the mean, and at extreme values (DeCarlo 1997). In the absence of skewness, data with a leptokurtic curve will still provide valid parameter estimates (i.e., mean values), however the variance in the data may be biased (i.e., SE may be under- or over- estimated) (Neuhaus et al. 2013). The difference in mean fluid consumption between groups was reflected in firefighters USG findings, in which the HOT group recorded consistently lower values than their CON trial counterparts (see Figure 3) from the beginning of the three-day protocol. This difference in pre-shift USG values was evident even on day one, which indicates that participants in the HOT group had an anticipatory increase in fluid consumption leading into the protocol (e.g., the night prior). While it must be noted that both HOT and CON groups were classified as 'hydrated' throughout the simulation (Kenefick and Cheuvront 2012; Sawka et al. 2007), the observed difference in both fluid consumption and USG values likely played a role in moderating all physiological variables in the heat. Previous heat research has shown that adequate fluid replacement during exercise assists with moderating heat-induced increases in core temperature (Montain and Coyle 1992), ratings of perceived exertion (McGregor et al. 1999; Montain and Coyle 1992), and minimises cardiovascular drift (Hamilton et al. 1991; Hargreaves 2008; McGregor et al. 1999). In the current study, firefighters' heart rate was comparable at all times with the exception of the peak heart rate achieved each circuit, which was higher in the CON group. Similarly, RPE values were higher in the CON group for four of the six physical work tasks. It is likely, then, that the increased fluid replacement observed in the HOT condition played a role in blunting both heart rate and RPE responses. There is also a small possibility that the elevated caffeine consumption in the heat (relative to the CON group) dampened firefighters' perception of exertion (Doherty and Smith 2005). However, firefighters in both groups consumed less caffeine during the protocol than their self-reported daily habitual caffeine consumption. Given this, and that the amount of caffeine consumed fell well below the 3 $mg.kg^{-1}$ commonly associated with exercise benefits (Burke 2008), it is unlikely that caffeine played an influential role on RPE or work performance in the current research. Irrespective of cause, the average difference in RPE between conditions across all tasks (and days) was 0.8 units. On a 6–20 point scale, a difference of this magnitude is unlikely to transfer to a meaningful difference during actual wildfire suppression.

There is a small possibility that intra-group differences (e.g., cardiorespiratory fitness) may also partially explain the observed RPE and heart rate findings. Although firefighters across the two experimental groups were matched for age, gender, and BMI, and there was no difference in participants self-report physical activity (in sessions per week), no objective measure of 'fitness' was utilised when matching participants. Therefore, it is possible that some of the firefighters allocated to the HOT condition had higher cardiorespiratory fitness levels relative to their CON group counterparts, and thus found the work less exerting. Nevertheless, the generalised mixed models used in the analysis factored in the unique responses of individuals to an intervention (Van Dongen et al. 2004), and thus, should have been robust enough to account for the effects of individual subject variability. It is, however, important to note that the study design may have some other limitations that prevent direct extrapolation of the results to the fireground. Firstly, while conducting a laboratory study allowed for the accurate quantification of performance, physiological, and perceptual responses during heat exposure, it is likely that the artificial environment was not entirely representative of wildfire suppression in the field. Care was taken to ensure that the protocol 'mimicked' a campaign fire environment wherever possible (e.g., in the physical work tasks chosen, the food provided, types of bedding used etc.). However, the variability of an outdoor environment (e.g., changes in wind speed and direction) and the urgency of certain aspects of wildfire suppression were unable to be captured in a simulated setting. Further, radiant heat was not simulated in the present study design. However, it has been observed that radiant heat (from the sun or fire) accounts for very little of the total heat load placed on firefighters, particularly during tasks performed away from the fire (Budd et al. 1997a), which makes up a substantial proportion of wildfire fighting work (Budd 2001; FEMA 2002). Given that the majority of tasks in the present study protocol simulated either preparatory or post-fire 'clean-up' work, replicating radiant heat load was not considered a primary objective of this research. However, segregating the effects of radiant heat from air temperature may be an avenue for future research. Lastly, while the physical work tasks used in the protocol were highly representative of actual wildfire suppression work (based on both field research and exhaustive consultation with industry experts), it is possible that the tasks were not sensitive enough to detect small changes in performance during heat exposure. Task validity was prioritised over reliability in the current research in order to maximise the transferability of results to the fireground. Therefore, while there is a possibility that task variability may have influenced the data, it is not likely that any undetected changes in performance would translate into a measureable performance difference in the field.

4.6 CONCLUSIONS

There was no difference in firefighters' work output between the CON and HOT conditions. Rather, performance responses over time varied significantly from individual to individual. While all measures of thermal stress were significantly elevated in the HOT trial, the heat load was compensable in both conditions, and the small (though significant) difference in core temperature between experimental groups would unlikely lead to any adverse health outcomes in an applied setting. Firefighters doubled their fluid consumption in the HOT trial, and thus recorded significantly lower USG values relative to the CON group (though both groups fell within the 'hydrated' range). It is likely that this increased fluid replacement in the heat, in concert with the frequent rest breaks and task rotation employed in the study, assisted with the regulation of physiological responses. These findings are promising from a fire agency perspective; not only were firefighters observed to be equally as operationally effective in both temperate and moderately hot ambient conditions, but they did so without experiencing negative health outcomes (e.g., dehydration, heat illness). Future research should endeavour to determine whether this remains true in even hotter ambient conditions, or when individual tasks are performed over more prolonged durations. Further, assessing which individual characteristics are important in moderating the performance response of firefighters in the heat may allow for the implementation of tailored workplace strategies.

4.7 REFERENCES

Aisbett, B and Nichols, D (2007), 'Fighting fatigue whilst fighting bushfire: an overview of factors contributing to firefighter fatigue during bushfire suppression', *The Australian Journal of Emergency Management,* 22 (3), 31-39.

Aisbett, B, Wolkow, A, Sprajcer, M, and 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), 916-25.

Bates, GP and Schneider, J (2008), 'Hydration status and physiological workload of UAE construction workers: A prospective longitudinal observational study', *Journal of Occupational Medicine & Toxicology,* 3, 1-10.

Borg, G (1998), *Borg's perceived exertion and pain scales* (Human kinetics).

Budd, GM (2001), 'How do wildland firefighters cope? Physiological and behavioural temperature regulation in men suppressing Australian summer bushfires with hand tools', *Journal of Thermal Biology,* 26, 381-86.

Budd, GM, Brotherhood, JR, Hendrie, AL, Jeffery, SE, Beasley, FA, Costin, BP, Zhien, W, Baker, MM, Cheney, NP, and Dawson, MP (1997a), 'Project Aquarius 6. Heat load from exertion, weather, and fire in men suppressing wildland fires', *International Journal of Wildland Fire,* 7 (2), 119-31.

Budd, GM, Brotherhood, JR, Hendrie, AL, Jeffery, SE, Beasley, FA, Costin, BP, Zhien, W, Baker, MM, Cheney, NP, and Dawson, MP (1997b), 'Project Aquarius 1. Stress, strain, and productivity in men suppressing Australian summer bushfires with hand tools: background, objectives, and methods', *International Journal of Wildland Fire,* 7 (2), 69-76.

Burke, LM (2008), 'Caffeine and sports performance', *Applied Physiology, Nutrition, & Metabolism,* 33 (6), 1319-34.

Burnham, KP and Anderson, DR (2002), *Model selection and multimodel inference: a practical information-theoretic approach* (Springer).

Castle, P, Mackenzie, RW, Maxwell, N, Webborn, ADJ, and Watt, PW (2011), 'Heat acclimation improves intermittent sprinting in the heat but additional pre-cooling offers no further ergogenic effect', *Journal of Sports Sciences,* 29 (11), 1125-34.

Cater, H, Clancy, D, Duffy, K, Holgate, A, Wilison, B, and Wood, J (2007), 'Fatigue on the fireground: The DPI Experience', *Australasian Fire Authorities Council/Bushfire Co-Operative Research Centre Annual Conference* (Hobart, Australia).

Cheung, SS, McLellan, TM, and Tenaglia, S (2000), 'The thermophysiology of uncompensable heat stress: physiological manipulations and individual characteristics', *Sports Medicine,* 29 (5), 329-59.

Cnaan, A, Laird, NM, and Slasor, P (1997), 'Tutorial in biostatistics: Using the general linear mixed model to analyse unbalanced repeated measures and longitudinal data', *Statistics in Medicine,* 16, 2349-80.

Cuddy, JS, Gaskill, SE, Sharkey, BJ, Harger, SG, and Ruby, BC (2007), 'Supplemental feedings increase self-selected work output during wildfire suppression', *Medicine & Science in Sports & Exercise,* 39 (6), 1004-12.

DeCarlo, LT (1997), 'On the meaning and use of kurtosis', *Psychological Methods,* 2 (3), 292.

Doherty, M and Smith, PM (2005), 'Effects of caffeine ingestion on rating of perceived exertion during and after exercise: a meta-analysis', *Scandinavian Journal of Medicine & Science in Sports,* 15 (2), 69-78.

FEMA (2002), 'Introduction to wildland/urban interface firefighting for the structural company officer', (Federal Emergency Management Agency, U.S. Department of Homeland Security).

Field, A (2007), *Discovering statistics using SPSS (3rd ed)* (Thousand Oaks, CA: Sage Publications).

Garrett, A, Creasy, R, Rehrer, N, Patterson, M, and Cotter, J (2012), 'Effectiveness of short-term heat acclimation for highly trained athletes', *European Journal of Applied Physiology,* 112 (5), 1827-37.

Garrett, AT, Goosens, NG, Rehrer, NG, Patterson, MJ, and Cotter, JD (2009), 'Induction and decay of short-term heat acclimation', *European Journal of Applied Physiology,* 107 (6), 659-70.

Gellish, RL, Goslin, BR, Olson, RE, McDonald, A, Russi, GD, and Moudgil, VK (2007), 'Longitudinal modeling of the relationship between age and maximal heart rate', *Medicine & Science in Sports & Exercise,* 39 (5), 822-29.

Hamilton, MT, Gonzalez-Alonso, J, Montain, SJ, and Coyle, EF (1991), 'Fluid replacement and glucose infusion during exercise prevent cardiovascular drift', *Journal of Applied Physiology,* 71 (3), 871-77.

Hargreaves, M (2008), 'Physiological limits to exercise performance in the heat', *Journal of Science and Medicine in Sport,* 11 (1), 66-71.

Haskell, WL, Lee, IM, Pate, RR, Powell, KE, Blair, SN, Franklin, BA, Macera, CA, Heath, GW, Thompson, PD, and Bauman, A (2007), 'Physical activity and public health: Updated recommendation for adults from the American College of Sports Medicine and the American Heart Association', *Circulation,* (116), 1081-93.

Kachman, SD (2000), 'An introduction to generalized linear mixed models', *Proceedings of a symposium at the organizational meeting for a NCR coordinating committee on "Implementation Strategies for National Beef Cattle Evaluation"* (Athens), 59-73.

Kenefick, RW and Cheuvront, SN (2012), 'Hydration for recreational sport and physical activity', *Nutrition Reviews,* 70, 137-42.

Lee, SMC, Williams, WJ, and Schneider, SM (2000), 'Core temperature measurement during submaximal exercise: Esophageal, rectal, and intestinal temperatures', (National Aeronautics and Space Administration).

McCulloch, CE (2003), *Generalized linear mixed models* (NSF-CBMS Regional Conference Series in Probability and Statistics, 7: Institute of Mathematical Statistics) 1-84.

McGregor, SJ, Nicholas, CW, Lakomy, HK, and Williams, C (1999), 'The influence of intermittent high-intensity shuttle running and fluid ingestion on the performance of a soccer skill', *Journal of Sports Sciences,* 17 (11), 895-903.

McLellan, TM, Jacobs, I, and Bain, JB (1993), 'Influence of temperature and metabolic rate on work performance with Canadian Forces NBC clothing', *Aviation, Space, And Environmental Medicine,* 64 (7), 587-94.

McLennan, J and Birch, A (2005), 'A potential crisis in wildfire emergency response capability? Australia's volunteer firefighters', *Environmental Hazards,* 6, 101-07.

Molenberghs, G and Verbeke, G (2001), 'A review on linear mixed models for longitudinal data, possibly subject to dropout', *Statistical Modelling,* 1 (4), 235-69.

Montain, SJ and Coyle, EF (1992), 'Influence of graded dehydration on hyperthermia and cardiovascular drift during exercise', *Journal of Applied Physiology,* 73 (4), 1340-50.

Neuhaus, JM, McCulloch, CE, and Boylan, R (2013), 'Estimation of covariate effects in generalized linear mixed models with a misspecified distribution of random intercepts and slopes', *Statistics in Medicine,* 32 (14), 2419-29.

Payne, WR, Portier, B, Fairweather, I, Zhou, S, and Snow, R (1994), 'Thermoregulatory response to wearing encapsulated protective clothing during simulated work in various thermal environments', *American Industrial Hygiene Association Journal,* 55 (6), 529-36.

Phillips, M, Payne, W, Lord, C, Netto, K, Nichols, D, and Aisbett, B (2012), 'Identification of physically demanding tasks performed during bushfire suppression by Australian rural firefighters', *Applied Ergonomics,* 43 (2), 435-41.

Phillips, M, Netto, K, Payne, W, Nichols, D, Lord, C, Brooksbank, N, Onus, K, Jefferies, S, and Aisbett, B (2011), 'Frequency, intensity and duration of physical tasks performed by Australian rural firefighters during bushfire suppression', in Thornton RP (ed.), *Bushfire CRC & AFAC Conference* (Sydney, Australia), 205-13.

Rabe-Hesketh, S, Skrondal, A, and Pickles, A (2002), 'Reliable estimation of generalized linear mixed models using adaptive quadrature', *The Stata Journal,* 2 (1), 1-21.

Rabe-Hesketh, S, Skrondal, A, and Pickles, A (2005), 'Maximum likelihood estimation of limited and discrete dependent variable models with nested random effects', *Journal of Econometrics,* 128 (2), 301-23.

Raines, J, Snow, R, Petersen, A, Harvey, J, Nichols, D, and Aisbett, B (2012), 'Pre-shift fluid intake: effect on physiology, work and drinking during emergency wildfire fighting', *Applied Ergonomics,* 43 (3), 532-40.

Raines, J, Snow, R, Petersen, A, Harvey, J, Nichols, D, and Aisbett, B (2013), 'The effect of prescribed fluid consumption on physiology and work behavior of wildfire fighters', *Applied Ergonomics,* 44 (3), 404-13.

Ramanathan, NL (1964), 'A new weighting system for mean surface temperature of the human body', *Journal of Applied Physiology,* 19 (3), 531-33.

Rodríguez-Marroyo, JA, Villa, JG, López-Satue, J, Pernía, R, Carballo, B, García-López, J, and Foster, C (2011), 'Physical and thermal strain of firefighters according to the firefighting tactics used to suppress wildfires', *Ergonomics,* 54 (11), 1101-08.

Sawka, MN, Burke, LM, Eichner, ER, Maughan, RJ, Montain, SJ, and Stachenfeld, NS (2007), 'American College of Sports Medicine position stand: Exercise and fluid replacement', *Medicine & Science in Sports & Exercise,* 39 (2), 377-90.

Singer, JD (1998), 'Using SAS PROC MIXED to fit multilevel models, hierarchical models, and individual growth models', *Journal of Educational and Behavioral Statistics,* 23 (4), 323-55.

Snook, SH and Ciriello, VM (1974), 'The effects of heat stress on manual handling tasks', *American Industrial Hygiene Association Journal,* 35 (11), 681-85.

Tasca, GA and Gallop, R (2009), 'Multilevel modeling of longitudinal data for psychotherapy researchers: I. The basics', *Psychotherapy Research,* 19 (4-5), 429-37.

Teague, B, McLeoud, R, and Pascoe, S (2010), '2009 Victorian Bushfires Royal Commission', (Parliament of Victoria).

Van Dongen, HPA, Olofsen, E, Dinges, DF, and Maislin, G (2004), 'Mixed-model regression analysis and dealing with interindividual differences', *Essential Numerical Computer Methods*, 225.

Westfall, P and Henning, KSS (2013), *Understanding advanced statistical methods* (Florida: CRC Press).

Young, AJ, Sawka, MN, Epstein, Y, DeCristofano, B, and Pandolf, KB (1987), 'Cooling different body surfaces during upper and lower body exercise', *Journal of Applied Physiology,* 63 (3), 1218-23.

Chapter 5: Study Three

Paper Three

Simulated firefighting task performance and physiology under very hot conditions

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5.1 ABSTRACT

This study assessed the impact of very hot and dry (45°C; 27% RH) conditions on the performance of, and physiological responses to, a wildland firefighting manual-handling task compared to the same work in a temperate environment (18°C; 56% RH). Ten male volunteer firefighters performed a 3-hour protocol in both 18°C (CON) and 45°C (VH). Participants intermittently performed 12 × 1-minute bouts of raking, 6 × 8-minute bouts of low-intensity stepping, and 6 × 20-minute rest periods. Work performance was determined by the area cleared during the raking task. Core temperature, skin temperature, and heart rate were measured continuously. Participants also periodically rated their perceived exertion and thermal sensation, and firefighters consumed water ad libitum. Urine specific gravity and changes in body mass determined hydration status. Firefighters raked 19% less debris during the VH condition. Core and skin temperature were 0.99 ± 0.20°C and 5.45 ± 0.53°C higher, respectively, during the VH trial, and heart rate was 14 – 36 beats.min^{-1} higher in the VH trial. Firefighters consumed 2950 ± 1034 mL of water in the VH condition, compared to 1290 ± 525 in the CON trial. Estimated sweat losses were higher in the VH trial, though both groups were hydrated upon protocol completion. Participants felt they were working harder, and felt hotter, after each rake bout in the VH trial. Despite performing less work in the VH trial, firefighters' experienced increases in thermal stress and exertion. These results should prompt wildland fire agencies to consider how to minimise reductions in work output in very hot temperatures, while still protecting individual health and safety.

5.2 INTRODUCTION

Performing physical work under very hot ambient conditions has been documented as dangerous, potentially even fatal, for wildland fire personnel (Baldwin and Hales 2012; Cuddy and Ruby 2011). Given future climate predictions, it is likely that firefighters will be exposed to such hazardous conditions on a more regular basis (Coumou and Rahmstorf 2012; Hanna et al. 2011; Liu et al. 2010). For instance, the 2009 Black Saturday bushfires (in Victoria, Australia) were accompanied by temperatures of 46.4°C and extremely low humidity levels, and were preceded by a record-breaking heat wave of three days above 43°C (Teague et al. 2010). Even so, little policy exists in the fire industry around extreme heat and wildland firefighting practice in Australia. An operations bulletin was released by the Victorian Country Fire Authority (CFA) in 2012 (Appendix A), which provides generalised guidelines around the management of heat stress in 'extreme' weather conditions (e.g., rotate crews where possible, drink fluids at regular intervals) (Country Fire Authority 2012). However, the document reflects 'common-sense' recommendations, rather than policy derived from a scientific evidence-base. Thus, rigorous research on the effects of high ambient heat on firefighters' and their work performance is warranted, as such research could underpin future heat policies for fire agencies.

There is a breadth of knowledge surrounding heat and exercise physiology (Cheuvront et al. 2010; Nybo et al. 2014). However, most research has focused on temperatures ranging from 30 to 40°C; fewer have explored the more 'extreme' ambient conditions (e.g., 45°C) firefighters may be exposed to on the fireground. Select groups who have researched extremely hot ambient temperatures (e.g., 41.8 – 125°C) have done so over very short durations (≤ 15 minutes; (Duncan et al. 1979), have used modes of exercise far removed from wildland firefighting work (e.g., cycling; (Caldwell et al. 2012), or have not compared their findings to a more temperate control condition (Bennett et al. 1993; Walker et al. 2014). The small body of relevant research suggests that heart rate (Rowell et al. 1966; Sköldström 1987; Wilson et al. 1975), perceived exertion (Sköldström 1987), core temperature (Rowell et al. 1966; Sköldström 1987; Wilson et al. 1975), skin temperature (Sköldström 1987), sweat rate

(Wilson et al. 1975), and fluid intake (Wilson et al. 1975) are all elevated when treadmill walking in extremely hot ambient conditions (40 – 50°C) when compared to more temperate ambient environments (15 – 25.6°C). However, wildland firefighting work is also characterised by manual-handling actions such as dig, rake, and drag (Phillips et al. 2012), and thus, treadmill walking may not serve as the best proxy when quantifying the effect of high heat on the performance and physiological responses during fire suppression work. In an urban structure firefighting protocol, ambient temperatures of up to 89°C significantly increased heart rate, tympanic temperature, and perceived exertion compared with performing the same fire drills under cool conditions (13°C) (Smith et al. 1997). Conversely, construction workers in the United Arab Emirates have been observed to maintain steady heart rate, tympanic temperature, fluid intake and urine specific gravity (USG) values when working in temperatures ranging from 32.5 – 49°C (Bates and Schneider 2008). However, work productivity was not monitored during these studies (Bates and Schneider 2008; Smith et al. 1997), which prohibits understanding of the potential trade-off between physiological homeostasis and the maintenance of work performance in very hot ambient conditions.

The aim of the present study was to assess the impact of very hot (45°C) and dry conditions on the performance of, and physiological and subjective responses to, a simulated wildland firefighting manual-handling task when compared to the same work in a temperate environment (18°C). It is extremely likely that, in concert with past research, significant increases in thermal stress and exertion will be observed in the heat. However, quantifying the magnitude of these changes when performing intermittent, firefighting-specific work tasks is paramount when developing evidence-based health and safety policy. No research to date has utilised a moderate duration, intermittent manual-handling protocol to investigate the performance changes that may occur during very hot conditions. Therefore, the true novelty of the study lies in understanding the impact of very hot ambient environments on simulated wildland firefighting work performance. Such information is vital for fire agencies in managing their human resources, and ensuring wildfires are controlled as efficiently and safely as possible.

5.3 MATERIALS AND METHODS

5.3.1 Participants

Ten healthy male volunteer wildland firefighters participated in the study (Appendix I). Power analyses (Hopkins, 2011) based on existing research on exercise physiology and subjective responses in extreme heat (Sköldström 1987; Smith et al. 1997; Rowell et al. 1966; Duncan et al. 1979; Caldwell et al. 2012) indicated that $<$ two participants would be sufficient to detect changes in thermal stress and exertion. However, research was unavailable to analyse the required number of participants to detect changes in performance. Thus, the present study conservatively utilised 10 participants in a crossover design. Participants provided written informed consent (Appendix J), and filled out a medical questionnaire (Appendix K) to ensure they were physically able to perform the work protocol. Ethical approval was obtained from the Deakin University Human Ethics Committee (Appendix L). Participant's height was measured and recorded without shoes using a stadiometer (Fitness Assist, England). Semi-nude body mass (i.e., in underwear only) was measured using an electronic scale (Tanita, USA) pre- and post-exercise. In all trials, participants wore their own firefighting protective clothing, including a two-piece jacket and trouser set made from Proban® cotton fabric (Protex®, Australia), suspenders, boots, gloves, and helmet (amounting to ~5 kg). All testing took place during the winter months to limit heat acclimatisation, which could have potentially confounded results.

5.3.2 Experimental protocol

Participants were familiarised with the physical tasks, as well as the rating of perceived exertion (RPE; Appendix F) and thermal sensation (Appendix G) scales, in a separate session within a week of testing (in 18°C) in order to minimise the chance of a learning effect (Hopkins et al. 2001). During the familiarisation session, participants performed two sets of the 60-second rake bout (and thereafter provided practice RPE and thermal sensation ratings), and one 8-minute step test (see *Raking task* and *Step test*). In the 24 hours prior to testing, participants documented their activities (e.g., diet, sleep, and exercise behaviours), and were asked to replicate the same behaviours as closely as possible prior to their second trial. Participants were instructed to abstain from alcohol and hard exercise, and to ensure they received adequate fluid intake and sleep, in order to minimise the risk of heat illness (Armstrong et al. 2007).

Participants ingested a core temperature capsule (Jonah, Minimitter, Oregon), a method of core temperature measurement that has been validated against both rectal and oesophageal temperature (O'Brien et al. 1998), 6 – 8 hours prior to testing. This allowed adequate time for the pill to pass through the stomach into the intestines, to minimise inaccurate readings occurring as a result of ingested food or liquid (Lee et al. 2000). Core temperature results recorded on a data logger (worn in firefighters' jacket pocket) at 1-minute epochs throughout the testing period (VitalSense, Minimitter, Oregon). Firefighters were also instructed to slowly consume water (~5 – 7 $mL.kg^{-1}$) in the 4 hours prior to testing, to promote adequate hydration (Sawka et al. 2007). Upon arrival to the testing facility, participants had heart rate monitors (Polar, Finland) and skin temperature patches (VitalSense/Jonah, Minimitter, Oregon) affixed. Skin temperature was recorded at four sites on the left side of the body; the chest, thigh, upper arm, and calf (Payne et al. 1994).

Participants performed the protocol on two separate occasions, separated by at least one week to allow full recovery between trials. One session was conducted in a temperate environment (CON), and the other under very hot and dry conditions (VH). Trial order was counterbalanced. All testing was conducted in a climate chamber (Vötsch, Germany) which displayed ambient temperature and humidity readings (recorded at 10-minute intervals). The climate chamber temperature was 18.0 ± 0.0°C in the CON trial and 45.0 ± 0.3°C in the VH trial ($P < 0.001$). Ambient humidity was 55.7 ± 1.2% in the CON trial, compared to 26.9 ± 2.0% in the VH condition ($P < 0.001$). A fan was used to provide a light breeze, to more realistically simulate an outdoor environment. Wind speed (measured at four sites in the chamber, and averaged) was maintained at < $1 m.s^{-1}$ across both trials. Participants performed three hours of intermittent, simulated rakehoe work (see *Raking task*) interspersed with a low-intensity stepping test (Siconolfi et al. 1985). A 3-hour protocol was used as a compromise between simulating long-duration wildland firefighting work, and ensuring participants' safety when performing physical work in very hot temperatures. Participants consumed water ad libitum throughout testing. Drinking water was maintained at 14.7 ± 0.6°C and 15.2 ± 0.5°C in the CON and VH conditions, respectively ($P = 0.074$).

Raking task

The raking task simulated building a firebreak using a rakehoe. Rakehoe work was chosen due to its prevalence in different types of wildland firefighting work (Phillips et al. 2011). Job task analysis research describes this task as short but intense, typically lasting 38 – 461 seconds on average (Budd et al. 1997; Phillips et al. 2011). The task simulation involved raking 29-kg of rubber tire crumb from one end of a rectangular (2 × 0.9 m) wooden box to the other repetitively, using a rakehoe. One 'repetition' comprised participants raking the vast majority of the tire crumb from one half of the box (over a dividing line in the middle) into the other half. Participants had to wait until the researcher was satisfied that they had cleared enough material before progressing to the next end. The same researcher counted the repetitions for each participant, to ensure a consistent standard was being met. Rakehoe work performance was evaluated and compared between the CON and VH trials based on the number of repetitions participants were able to complete within the work periods (to the nearest quarter). Repetitions were converted to area (m^2) for analysis.

Step test

The present research utilised a modified version of a sub-maximal step test (Siconolfi et al. 1985), to simulate the lighter intensity activity (e.g., periodic walking/hiking) performed on the fireground (Aisbett and Nichols 2007; Raines et al. 2013). Only the lowest intensity phase of the test was utilised, as the energy expenditure of walking 'with purpose' has been estimated at 4 METs (Powers and Howley 2008). The test comprised repeatedly stepping up and down a 25-cm platform at a rate of 17 steps.min^{-1} (Siconolfi et al. 1985), as timed by a metronome. Participants who completed both trials were able to perform all of the prescribed stepping bouts in full. Thus, stepping performance was not included in the analysis.

Work to rest ratios

Over the course of a work shift, wildfire fighters have been observed to have periods of predominantly sedentary activity interspersed with brief spurts of moderate/vigorous activity (Cuddy et al. 2007; Raines et al. 2013). For example, mean time spent in the sedentary range for any given two-hour block of a 12-hour workday has been observed to be 60.9 – 79.5 min.2h^{-1} (Cuddy et al. 2007; Raines et al. 2013), which equates to spending 51 – 66% in the sedentary range. Further, 43.2 ± 24.2 minutes of any two-hour period is spent performing light intensity activity (Raines et al. 2013), with only 3.9 – 8.3 min.2h^{-1} spent in the moderate/vigorous intensity range (Cuddy et al. 2007; Raines et al. 2013).

In order to simulate the varied-intensity, intermittent nature of wildland firefighting work (Aisbett and Nichols 2007; Cuddy et al. 2007), the current protocol was broken up into three one-hour bouts (T1, T2, and T3). During each hour, participants spent four minutes intermittently performing the rakehoe task (4 × 1-minute bouts), 16 minutes intermittently performing the stepping task (2 × 8-minute bouts), and 40 minutes resting in the testing environment (2 × 20 minutes). These rest breaks equate to spending 67% in the sedentary range, which is close to the upper limit observed during fire suppression work (Cuddy et al. 2007; Raines et al. 2013). However, previous research investigating work intensity on the fireground was conducted in more mild ambient conditions (e.g., peak temperatures ranging from 18.6 – 33.9°C) (Raines et al. 2013). It is reasonable to assume that rest periods could increase in hotter ambient temperatures. Similarly, the present study employed only 1-minute raking bouts, as it is likely that rest breaks could be taken more frequently when performing this task under very hot environmental temperatures.

Participants were allowed to remove their helmet and jacket during the 20-minute rest periods, as is common during rest breaks on the fireground (Raines et al. 2012). Participants left the climate chamber only to go to the toilet, or if heat illness symptoms presented. Any time spent outside of the environmental condition was recorded.

5.3.3 Physiological and subjective measurements

Core temperature, skin temperature, and heart rate were recorded continuously throughout testing. Mean skin temperature was calculated using the formula $0.3(T_{chest} + T_{arm}) + 0.2(T_{thigh} + T_{leg})$ (Ramanathan 1964). Fluid intake was recorded across the testing period. Urine was sampled pre-, during-, and post-exercise, and USG analysed (using a portable refractometer; Atago, Japan), to approximate changes in hydration status. Pre- and post- body weight was recorded (and adjusted for ingested and expelled liquids) to determine changes in body mass (%), and to estimate sweat loss. Participants were also asked to provide RPE (on a 6 – 20 point scale; Borg 1998) and thermal sensation (on a 0 – 8 point scale; Young et al. 1987) ratings after each rake bout.

5.3.4 Statistical analysis

All statistical tests were carried out using the IBM Statistical Package for the Social Sciences (SPSS V.22.0.0, Champaign, Illinois). The distribution of the data was evaluated using Shapiro-Wilk tests. All data (with the exception of 'time spent outside' the climate chamber and the total number of rake bouts completed) were normally distributed. The difference between conditions in total area raked, ambient temperature and humidity, and drinking water temperature was analysed using paired samples t-tests. Repeated measures analysis of variance (ANOVA) were performed for all other normally distributed variables, with condition (CON or VH) and time as the two within-participant factors. Where the ANOVA revealed a significant interaction, simple effects analyses were used to detect at which point the significant difference occurred. The 'time spent outside' and 'bouts completed' data was not normally distributed, and this could not be corrected via transformation of the data. Thus, Wilcoxin-Signed Rank tests were used to assess the difference in these variables between conditions. These data are presented as median (inter-quartile range), whereas all other data are presented as mean ± SD. Significance was set at $p < 0.05$. For the data analysed using paired t-tests, *t* values were converted into effect sizes (*r*) using the method described by Field (Field 2013). For the non-parametric data analysed using Wilcoxin-Signed Rank test, effect sizes (*r*) were calculated by converting the *z*-score into an effect size estimate (Field 2013). For both of these types of data, .1, .3, and .5 are considered small, medium, and large effect sizes (Field 2013). For all normally distributed variables analysed using ANOVA, partial eta-squared (η^2_p) effect sizes are presented (Lakens 2013). When interpreting partial eta-squared results, .01, .06, and .14 are considered small, medium, and large effect sizes, respectively (Richardson 2011).

5.4 RESULTS

Table 8. Participant details

n	10
Age (years)	41 ± 17
Height (cm)	180.4 ± 9.0
Weight (kg)	89.4 ± 8.8
BMI	27.6 ± 3.1
Firefighting experience (years)	12 ± 12

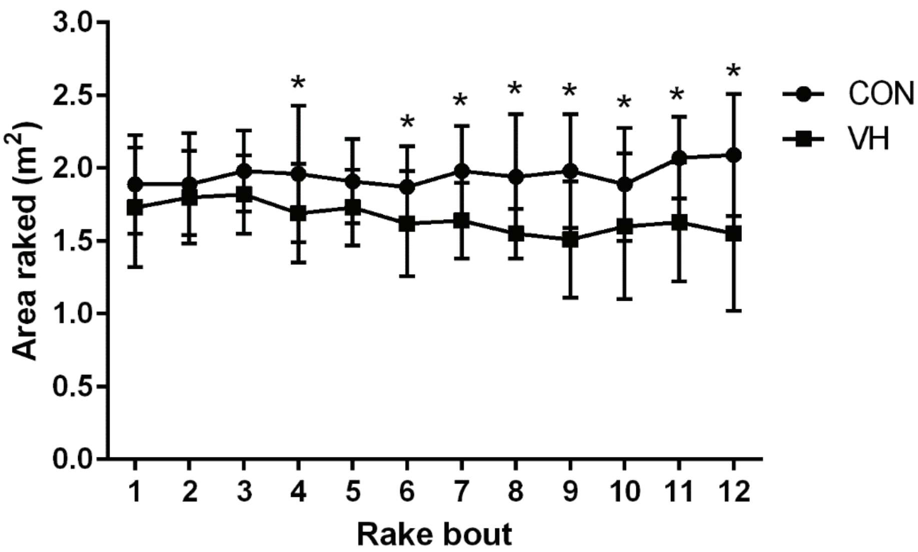
All data are presented as means ± SD.

Participant details are reported in Table 8. There was no difference between conditions ($P = 0.357$; $r = .21$) in the 'time spent outside' data, with firefighters spending a median of 0 (2) and 2 (2) minutes outside the climate chamber (for toilet breaks) in the CON and VH trials, respectively.

5.4.1 Work performance

All participants were able to complete the 3-hour protocol in the CON trial, whereas two participants withdrew from the study due to heat illness symptoms in the VH condition after performing 9 and 10 (out of a possible 12) rake bouts, respectively. The difference in the number of bouts completed between conditions did not reach statistical significance ($P = 0.180$; $r = .30$). However, participants were able to clear 19% more total debris during the rakehoe task in the CON (23.45 ± 3.59 m^2) compared to the VH trial (19.08 ± 4.24 m^2; $P < 0.001$; $r = .88$). An interaction was also observed when the 12 × 60-second rake bouts were analysed individually ($P = 0.014$; $\eta^2_p = 0.11$), with firefighters raking significantly more in the CON compared to the VH condition during bout 4, and during all bouts from 6 onwards ($P < 0.014$; Figure 4).

Figure 4. Rake output (m^2) during the 12 × 60-second rake bouts



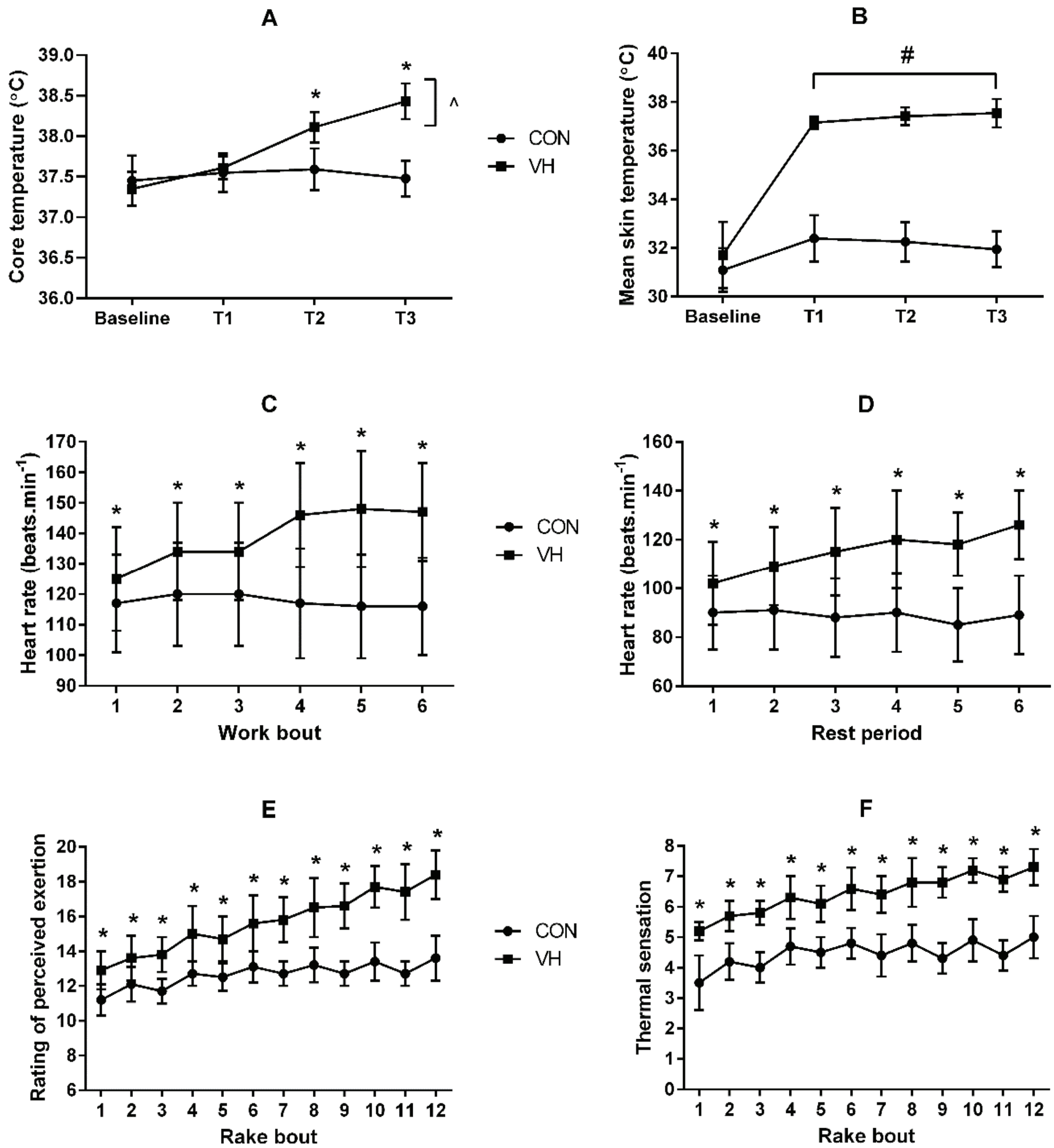
** indicates that VH significantly lower (P < 0.05) than CON at individual time points. CON = control condition; VH = very hot condition.*

5.4.2 Core and skin temperature

Firefighters' baseline core and mean skin temperatures were not different between the CON (37.45 ± 0.31°C and 31.09 ± 0.90°C) and VH (37.37 ± 0.18°C and 31.59 ± 1.34°C) trials ($P \geq 0.240$).

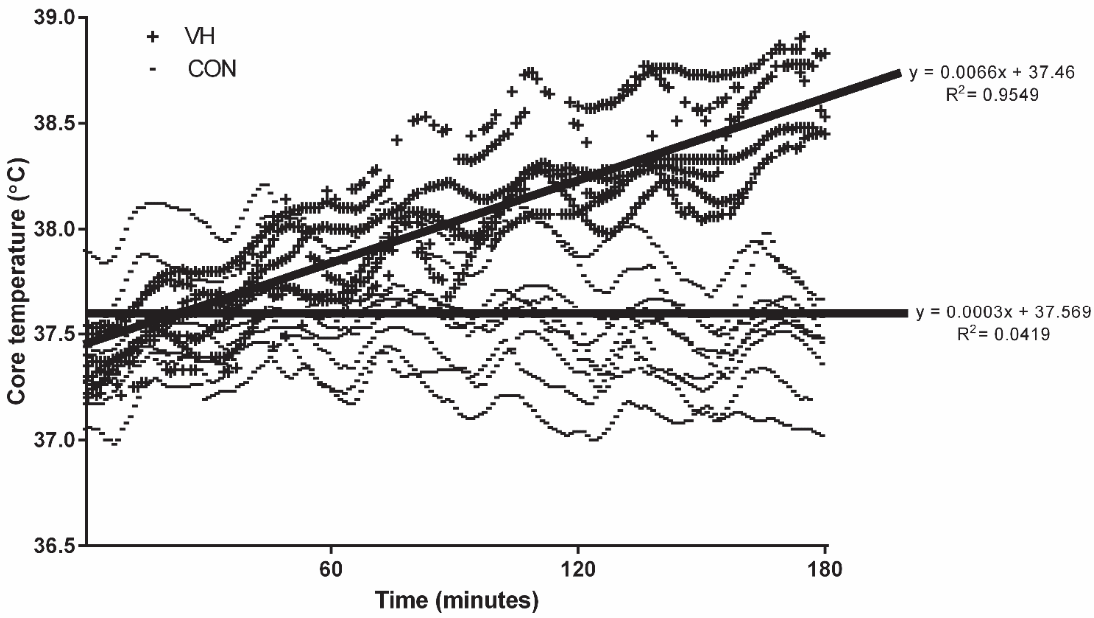
There was, however, a significant interaction for hourly core temperature between conditions ($P < 0.001$; $\eta^2_p = .62$). While there was no difference at T1 ($P = 0.721$), T2 and T3 reached 0.53 ± 0.18°C and 0.95 ± 0.17°C higher in the VH trial, respectively ($P < 0.001$; Figure 5 [A]). Similarly, a significant interaction was observed for the peak core temperature reached each hour ($P < 0.001$; $\eta^2_p = .50$). Again, the increase observed in the VH condition fell short of reaching significance during T1 (0.16 ± 0.21°C; $P = 0.109$), but was on average 0.63 ± 0.21°C and 0.99 ± 0.20°C higher during T2 and T3 ($P < 0.001$; Table 9) when compared to the CON trial. There was no interaction between conditions for hourly mean skin temperature ($P = 0.072$; $\eta^2_p = .11$), however there was a main effect observed for condition, such that firefighters mean skin temperature was on average 5.14 ± 0.48°C hotter across the VH compared to the CON trial ($P < 0.001$; $\eta^2_p = .98$; Figure 5 [B]). Conversely, a significant interaction was observed for the peak mean skin temperature reached each hour ($P = 0.044$; $\eta^2_p = .13$). In this instance, the increase observed in the VH condition was significant at all time-points ($P < 0.001$), with participants reaching 4.57 ± 0.53°C, 5.07 ± 0.53°C, and 5.45 ± 0.53°C higher during T1, T2, and T3 in the VH when compared to the CON trial (Table 9). Individual core temperature data was also plotted in Figure 6.

Figure 5. Differences between the CON and VH conditions in: A) hourly core temperature, B) hourly mean skin temperature, C) heart rate during the 10-minute work bouts, D) heart rate during the 20-minute rest periods, E) RPE after the 60-second rake bouts, and F) thermal sensation after the 60-second rake bouts



** indicates that VH significantly higher (P < 0.05) than CON at individual time points, ^ indicates significant increase from T1 to T2, and T2 to T3 (P ≤ 0.004) in the VH, # indicates VH higher than CON (main effect; P < 0.001). CON = control condition; VH = very hot condition.*

Figure 6. Individual core temperature data over the 3-hour work period



CON = control condition; VH = very hot condition.

5.4.3 Heart rate

There was a significant interaction observed for mean hourly heart rate ($P < 0.001$; $\eta^2_p = .41$), such that participants' heart rate was 100 ± 16 beats.min^{-1}, 98 ± 16 beats.min^{-1}, and 97 ± 15 beats.min^{-1} over T1, T2, and T3 during the CON trial, compared to 114 ± 16 beats.min^{-1}, 126 ± 18 beats.min^{-1}, and 133 ± 14 beats.min^{-1} in the VH condition ($P < 0.001$), respectively. Conversely, no interaction ($P = 0.118$; $\eta^2_p = .09$) and no main effect for time ($P = 0.271$; $\eta^2_p = .06$) were observed for firefighters' peak hourly heart rate. However, a main effect for condition highlighted that participants' peak heart rate was on average 19 ± 8 beats.min^{-1} higher across the VH compared to the CON trial ($P < 0.001$; $\eta^2_p = .68$; Table 9). Heart rate data was also analysed according to the periods of 'work' (including both the rakehoe and stepping tasks) and rest. Time × condition interactions were observed for firefighters' heart rate during both the work and rest phases of the protocol ($P < 0.001$; $\eta^2_p = .46$ and .33, respectively). Firefighters' heart rate was, on average, 22 ± 6 beats.min^{-1} and 27 ± 7 beats.min^{-1} higher in the VH compared to the CON trial for the periods of work (Figure 5 [C]) and rest (Figure 5 [D]), respectively.

5.4.4 Perceptual responses

An interaction was observed for participants' RPE ratings ($P < 0.001$; $\eta^2_p = .27$), such that participants' RPE was significantly higher during the VH compared to the CON trial after each of the 12 rake bouts ($P < 0.001$; Figure 5 [E]). The average RPE for the rake task in the VH condition was 15.6 ± 0.9 and categorised as 'hard/heavy', compared to 12.6 ± 0.9 ('somewhat hard') in the CON trial. Similarly, an interaction was observed for participants' thermal sensation ratings ($P < 0.001$; $\eta^2_p = .16$). Again, this difference was statistically significant at each of the 12 time points ($P < 0.001$; Figure 5 [F]). Firefighters felt hotter during the VH condition, rating their thermal sensation on average as 6.4 ± 0.5, compared to 4.4 ± 0.4 during the CON trial. The average thermal sensation in the VH trial signified 'hot-very hot', whereas average thermal sensation in the CON trial was 'comfortable-warm'.

5.4.5 Hydration

Firefighters consumed 2950 ± 1034 mL of water in the VH condition, compared to only 1290 ± 525 mL in the CON trial ($P = 0.001$). Conversely, there was no difference in urine output between conditions ($P = 0.126$), with firefighters producing 930 ± 783 mL and 634 ± 414 mL of urine in the CON and VH conditions, respectively. Firefighters in the VH condition did, however, have higher ($P < 0.001$) estimated sweat losses, reaching 1886 ± 474 mL compared to only 462 ± 392 mL when in the CON environment. There was no interaction ($P = 0.506$; $\eta^2_p = .04$), and no main effects for condition ($P = 0.170$; $\eta^2_p = .06$) or time ($P = 0.269$; $\eta^2_p = .02$), observed for participants' USG scores pre-, during-, and post-work. Firefighters elicited pre-work USG scores of 1.014 ± 0.008 in both trials. During- and post-work USG scores reached 1.011 ± 0.005 and 1.016 ± 0.006 in the CON trial, compared to 1.017 ± 0.008 and 1.018 ± 1.007 in the VH condition. Thus, firefighters in both conditions were in the 'hydrated' range (< 1.020) at all time-points measured (Sawka et al. 2007). Further, there was no difference in the percentage body mass change between trials ($P = 0.265$). Participants in the CON trial lost 0.1 ± 0.9% of their body mass across the course of the protocol, whereas participants in the VH condition gained 0.5 ± 1.0%.

Table 9. Peak core temperature, skin temperature, and heart rate over the three-hour work period

	T1		T2		T3	
	CON	VH	CON	VH	CON	VH
Peak core temperature (°C)	37.71 ± 0.26	37.89 ± 0.21	37.73 ± 0.25	38.35 ± 0.21*	37.67 ± 0.21	38.65 ± 0.24*
Peak mean skin temperature (°C)	33.20 ± 1.05	37.77 ± 0.31*	32.98 ± 0.84	38.04 ± 0.43*	32.55 ± 0.80	38.12 ± 0.55*
Peak heart rate (beats.min^{-1})	148 ± 22	162 ± 21$^{\#}$	148 ± 21	168 ± 18$^{\#}$	147 ± 21	167 ± 18$^{\#}$

** indicates that VH significantly higher (P < 0.05) than CON at individual time points, # indicates VH higher than CON (main effect; P < 0.001). CON = control condition; VH = very hot condition.*

5.5 DISCUSSION

Firefighters self-selected work output was reduced in the VH compared to the CON trial, which was reflected during both the individual rake bouts and the total amount of debris raked across the course of the protocol. Further, all measures of thermal stress (including core temperature, skin temperature, and thermal sensation) were elevated in the VH compared to the CON trial. Participants' heart rate and RPE were also significantly higher in the VH condition. However, firefighters' hydration status in the VH trial was not significantly different (in terms of their percentage body mass change and USG scores) than the CON trial, despite having higher estimated sweat losses. This difference was offset by increased fluid intake in the VH environment.

To the current authors' knowledge, no previous research has evaluated the effects of very hot ambient temperatures (45°C) on self-paced, manual-handling work performance (such as firefighting). Previous heat research investigating self-paced work (albeit usually employing different modes of exercise to firefighting) has typically observed one of two phenomena; either work output remains the same and physiological measures are elevated, or work output is decreased in an attempt to maintain thermal homeostasis (Cheung and Sleivert 2004; Nybo et al. 2014). However, though participants in the current study performed 19% less work on the rakehoe task in the VH trial, significant increases across all measures of thermal strain (core temperature, skin temperature, thermal sensation) and exertion (heart rate, RPE) were recorded. It is possible, then, that the limits of self-pacing for modulating physiology were reached in the current protocol. It must also be noted that, although not significant between conditions, two (of 10) participants in the VH trial withdrew before the end of the protocol due to experiencing heat illness symptoms (headaches and nausea). If, hypothetically, 20% of firefighters in the field were unable to complete their allocated shift length due to illness, this would have significant adverse follow-on consequences for the fire-suppression effort, as well as straining health support resources. However, unlike the current study, firefighters in the field would often be able to modify the length of their work bouts (as well as their work intensity), which could further assist their ability to stave off heat illness symptoms. Nevertheless, the wildland fire industry must consider the possibility of firefighter 'dropout' when operating under very hot fire weather conditions.

In addition to understanding the effect of very hot conditions on work performance, it is vital that the concurrent physiological changes are also quantified in order to develop policy that promotes and preserves the health and safety of personnel. Participants' core temperature was significantly increased in the VH compared to the CON trial, but perhaps not to the level that was expected based on the previous (albeit extremely limited) research in very hot temperatures (Rowell et al. 1966; Sköldström 1987). Firefighters in the current protocol reached a peak core temperature of 38.65 ± 0.24°C in the third hour of testing. Conversely, Rowell et al (1966) observed core temperatures of 39.4°C after two hours of intermittent treadmill walking in 43.3°C, and Sköldström (1987) reported core temperatures of 38.7°C after just one-hour of low-intensity (3.5 $km.h^{-1}$) treadmill walking in 45°C, while wearing PPC and breathing apparatus. It is likely that the 1:2 work to rest ratio employed in the current protocol somewhat blunted the rise in core temperature, which may partially explain the differences when compared to the 1:1 and continuous work protocols utilised by Rowell et al (1966) and Sköldström (1987), respectively. Firefighters also removed their helmet and opened their jacket during each of the 20-minute rest periods, which would have helped reduce the thermal burden when compared to the fully-encapsulating PPC and BA utilised in the Sköldström (1987) study. Finally, wind speed in these two studies was described as either 'minimal' or < 0.2 $m.s^{-1}$; thus it is possible that the breeze provided by the fan in the present research (< 1 $m.s^{-1}$), in concert with participants' removal of helmets and opening of jackets, may have aided with heat dissipation (Nybo et al. 2014).

The increased fluid intake observed in the VH trial also allowed for significantly higher estimated sweat losses, which in turn would have assisted in modulating core body temperature (Cheung et al. 2000). Indeed, firefighters managed to more than double their fluid intake in the VH condition, which also allowed them to maintain their body mass across the course of the trial. The USG findings recorded in the present study showed that firefighters in both ambient conditions were classified as hydrated (< 1.020) before, during, and after the work protocol. Conversely, Australian wildland firefighters performing their work under hot conditions (peak of 37°C) in the field have been observed to start and finish their shift in a hypohydrated state (albeit with a consistent, not worsening, hydration state across the day) (Raines et al. 2015). Although not measured in the present study, it should be noted that firefighters' in the VH trial may have had altered serum electrolytes as a result of their enhanced fluid consumption (Vrijens and Rehrer 1999). While fluid replacement should be encouraged, over-drinking (particularly of water only) should be cautioned against as it may precipitate the development of hyponatremia (Vrijens and Rehrer 1999).

Despite the somewhat encouraging core temperature and hydration findings in the present study, participants' heart rate values were as much as 36 beats.min^{-1} higher in the VH when compared to the CON trial, even though they were performing significantly less work. Heart rate peaked at 168 ± 18 beats.min^{-1} in T2, which equated to 94 ± 12% of participants age predicted maximum heart rate (using the formula 207 - 0.7 × age; (Gellish et al. 2007). This is high given that the most intense physical task (i.e., raking) was performed in only 1-minute bouts, and totalled only 4-minutes each hour. Recent research has shown that 37% of male volunteer firefighters in Victoria, Australia are considered at 'high risk' of developing coronary heart disease in the next 10 years (Wolkow et al. 2013). Cardiovascular disease related fatalities are the leading cause of on-duty deaths in US firefighters, the majority of which occur in individuals with pre-existing risk factors (Wolkow et al. 2012). The risk-profile of the Victorian wildfire population, coupled with the high levels of physiological exertion experienced by firefighters in the present study, clearly illustrate that close monitoring of firefighter health is necessary and warranted during very hot wildfire conditions.

It is important to note that the current study may have some limitations that prevent direct extrapolation to the fireground. Firstly, the focus of this research was on ambient heat, whereas wildland firefighters in the field may also be exposed to radiant heat from the sun, and in some cases, the fire. If anything, this means that the present findings may underestimate the thermal stress placed on personnel when on duty. Secondly, the wind speed utilised in the current protocol may not reflect the variations in wind speed/direction that would be experienced in an outdoor environment. Finally, though long in duration relative to past research in very hot temperatures, the 3-hour protocol used may not serve as the perfect proxy for a wildland firefighting shift. Although firefighters may not be exposed to ambient temperatures as high as 45°C for longer than a few hours, it is likely that they would perform physical work in hot conditions throughout the course of the day, and would begin their work in the 'extreme' conditions (typically in the afternoon) with a higher starting core temperature and some level of physical or mental fatigue. While participants' core temperature in the VH condition perhaps rose more gradually than expected, it did not plateau; core temperature each hour was significantly hotter than the previous hour (Figure 5 [A]). Thus, it is not unreasonable to assume that firefighters' performing a similar workload over a longer period would reach core temperatures likely to lead to heat exhaustion. For instance, if the trend line equation from Figure 6 was used to extrapolate the data, it is predicted that core temperatures could reach 39.84°C in the VH condition after six hours of work. The wildland firefighting industry must continue to consider and evaluate strategies (e.g., shorter shift lengths, progressively longer rest periods between work bouts) in order to maximise the effectiveness of wildfire suppression efforts in very hot temperatures, while also preserving the health and safety of fire personnel.

5.6 CONCLUSIONS

Firefighters in the present study recorded significantly decreased performance, and higher thermal stress and exertion, in the 45°C condition. The high peak heart rate values were of particular concern, especially when taking into account the age and cardiovascular disease risk profile of the current Australian volunteer firefighting cohort. However, some promising findings were also noted. Firefighters were able to self-regulate their water intake to prevent significant changes in body mass and USG (which served as a proxy for hydration status). Further, the observed elevations in core temperature were relatively moderate when compared to previous research in similar ambient environments. It is likely that the frequent rest breaks employed in the current protocol aided in blunting the rise in core temperature, along with providing the firefighters with ample fluid replacement opportunities. However, given that core temperatures did not plateau over the course of the protocol, it is unlikely that the firefighters would have been able to continue at that rate of work over more extended periods. Wildland fire agencies need to consider how they are going to manage the observed decline in work output in very hot conditions, in order to optimise the effectiveness of wildfire suppression operations and manage individual health and safety.

5.7 REFERENCES

Aisbett, B and Nichols, D (2007), 'Fighting fatigue whilst fighting bushfire: an overview of factors contributing to firefighter fatigue during bushfire suppression', *The Australian Journal of Emergency Management,* 22 (3), 31-39.

Armstrong, LE, Casa, DJ, Millard-Stafford, M, Moran, DS, Pyne, SW, and Roberts, WO (2007), 'American College of Sports Medicine position stand: Exertional heat illness during training and competition', *Medicine & Science in Sports & Exercise,* 39 (3), 556-72.

Baldwin, T and Hales, T (2012), 'Wildland fire fighter dies from hyperthermia and exertional heatstroke while conducting mop-up operations - Texas', (NIOSH Fire Fighter Fatality Investigation Team,).

Bates, GP and Schneider, J (2008), 'Hydration status and physiological workload of UAE construction workers: A prospective longitudinal observational study', *Journal of Occupational Medicine & Toxicology,* 3, 1-10.

Bennett, BL, Hagan, RD, Banta, G, and Williams, F (1993), 'Physiological responses during shipboard firefighting', *Aviation, Space, and Environmental Medicine,* 66 (3), 225-31.

Borg, G (1998), *Borg's perceived exertion and pain scales* (Human kinetics).

Budd, GM, Brotherhood, JR, Hendrie, AL, Jeffery, SE, Beasley, FA, Costin, BP, Zhien, W, Baker, MM, Cheney, NP, and Dawson, MP (1997), 'Project Aquarius 5. Activity distribution, energy expenditure, and productivity of men suppressing free-running wildland fires with hand tools', *International Journal of Wildland Fire,* 7 (2), 105-18.

Caldwell, JN, Patterson, MJ, and Taylor, NAS (2012), 'Exertional thermal strain, protective clothing and auxiliary cooling in dry heat: evidence for physiological but not cognitive impairment', *European Journal of Applied Physiology,* 112 (10), 3597-606.

Cheung, SS and Sleivert, GG (2004), 'Multiple triggers for hyperthermic fatigue and exhaustion', *Exercise & Sport Sciences Reviews,* 32 (3), 100-06.

Cheung, SS, McLellan, TM, and Tenaglia, S (2000), 'The thermophysiology of uncompensable heat stress: physiological manipulations and individual characteristics', *Sports Medicine,* 29 (5), 329-59.

Cheuvront, SN, Kenefick, RW, Montain, SJ, and Sawka, MN (2010), 'Mechanisms of aerobic performance impairment with heat stress and dehydration', *Journal Of Applied Physiology,* 109 (6), 1989-95.

Coumou, D and Rahmstorf, S (2012), 'A decade of weather extremes', *Nature,* 2, 491-96.

Country Fire Authority (2012), 'Management of Heat Stress', *Operations Bulletin* (Fire and Emergency Management), 1-5.

Cuddy, JS and Ruby, BC (2011), 'High work output combined with high ambient temperatures caused heat exhaustion in a wildland firefighter despite high fluid intake', *Wilderness & Environmental Medicine,* 22 (2), 122-25.

Cuddy, JS, Gaskill, SE, Sharkey, BJ, Harger, SG, and Ruby, BC (2007), 'Supplemental feedings increase self-selected work output during wildfire suppression', *Medicine & Science in Sports & Exercise,* 39 (6), 1004-12.

Duncan, HW, Gardner, GW, and Barnard, RJ (1979), 'Physiological responses of men working in fire fighting equipment in the heat', *Ergonomics,* 22 (5), 521-27.

Field, A (2013), *Discovering statistics using IBM SPSS statistics* (4th edn.: Sage Publications Ltd).

Gellish, RL, Goslin, BR, Olson, RE, McDonald, A, Russi, GD, and Moudgil, VK (2007), 'Longitudinal modeling of the relationship between age and maximal heart rate', *Medicine & Science in Sports & Exercise,* 39 (5), 822-29.

Hanna, EG, Kjellstrom, T, Bennett, C, and Dear, K (2011), 'Climate change and rising heat: population health implications for working people in Australia', *Asia-Pacific Journal of Public Health,* 23 (2 Suppl.), 14-26.

Hopkins, WG, Schabort, EJ, and Hawley, JA (2001), 'Reliability of Power in Physical Performance Tests', *Sports Medicine,* 31 (3), 211-34.

Lakens, D (2013), 'Calculating and reporting effect sizes to facilitate cumulative science: a practical primer for t-tests and ANOVAs', *Frontiers in Psychology,* 4.

Lee, SMC, Williams, WJ, and Schneider, SM (2000), 'Core temperature measurement during submaximal exercise: Esophageal, rectal, and intestinal temperatures', (National Aeronautics and Space Administration).

Liu, Y, Stanturf, J, and Goodrick, S (2010), 'Trends in global wildfire potential in a changing climate', *Forest Ecology & Management,* 259 (4), 685-97.

Nybo, L, Rasmussen, P, and Sawka, MN (2014), 'Performance in the heat—physiological factors of importance for hyperthermia-induced fatigue', *Comprehensive Physiology,* 4, 657-89.

O'Brien, C, Hoyt, RW, Buller, MJ, Castellani, JW, and Young, AJ (1998), 'Telemetry pill measurement of core temperature in humans during active heating and cooling', *Medicine & Science in Sports & Exercise,* 30 (3), 468-72.

Payne, WR, Portier, B, Fairweather, I, Zhou, S, and Snow, R (1994), 'Thermoregulatory response to wearing encapsulated protective clothing during simulated work in various thermal environments', *American Industrial Hygiene Association Journal,* 55 (6), 529-36.

Phillips, M, Payne, W, Lord, C, Netto, K, Nichols, D, and Aisbett, B (2012), 'Identification of physically demanding tasks performed during bushfire suppression by Australian rural firefighters', *Applied Ergonomics,* 43 (2), 435-41.

Phillips, M, Netto, K, Payne, W, Nichols, D, Lord, C, Brooksbank, N, Onus, K, Jefferies, S, and Aisbett, B (2011), 'Frequency, intensity and duration of physical tasks performed by Australian rural firefighters during bushfire suppression', in Thornton RP (ed.), *Bushfire CRC & AFAC Conference* (Sydney, Australia), 205-13.

Powers, S and Howley, E (2008), *Exercise physiology: Theory and application to fitness and performance* (7th Ed. edn.: McGraw-Hill).

Raines, J, Snow, R, Nichols, D, and Aisbett, B (2015), 'Fluid intake, hydration, work physiology of wildfire fighters working in the heat over consecutive days', *Annals of Occupational Hygiene*, 1-12.

Raines, J, Snow, R, Petersen, A, Harvey, J, Nichols, D, and Aisbett, B (2012), 'Pre-shift fluid intake: effect on physiology, work and drinking during emergency wildfire fighting', *Applied Ergonomics,* 43 (3), 532-40.

Raines, J, Snow, R, Petersen, A, Harvey, J, Nichols, D, and Aisbett, B (2013), 'The effect of prescribed fluid consumption on physiology and work behavior of wildfire fighters', *Applied Ergonomics,* 44 (3), 404-13.

Ramanathan, NL (1964), 'A new weighting system for mean surface temperature of the human body', *Journal of Applied Physiology,* 19 (3), 531-33.

Richardson, JTE (2011), 'Eta squared and partial eta squared as measures of effect size in educational research', *Educational Research Review,* 6 (2), 135-47.

Rowell, LB, Marx, HJ, Bruce, RA, Conn, RD, and Kusumi, F (1966), 'Reductions in cardiac output, central blood volume, and stroke volume with thermal stress in normal men during exercise', *The Journal Of Clinical Investigation,* 45 (11), 1801-16.

Sawka, MN, Burke, LM, Eichner, ER, Maughan, RJ, Montain, SJ, and Stachenfeld, NS (2007), 'American College of Sports Medicine position stand: Exercise and fluid replacement', *Medicine & Science in Sports & Exercise,* 39 (2), 377-90.

Siconolfi, SF, Garber, CE, Lasater, TM, and Carleton, RA (1985), 'A simple, valid step test for estimating maximal oxygen uptake in epidemiologic studies', *American Journal Of Epidemiology,* 121 (3), 382-90.

Sköldström, B (1987), 'Physiological responses of fire fighters to workload and thermal stress', *Ergonomics,* 30 (11), 1589-97.

Smith, DL, Petruzzello, SJ, Kramer, JM, and Misner, JE (1997), 'The effects of different thermal environments on the physiological and psychological responses of firefighters to a training drill', *Ergonomics,* 40 (4), 500-10.

Teague, B, McLeoud, R, and Pascoe, S (2010), '2009 Victorian Bushfires Royal Commission', (Parliament of Victoria).

Vrijens, DMJ and Rehrer, NJ (1999), 'Sodium-free fluid ingestion decreases plasma sodium during exercise in the heat', *Journal of Applied Physiology,* 86 (6), 1847-51.

Walker, A, Driller, M, Brearley, M, Argus, C, and Rattray, B (2014), 'Cold-water immersion and iced-slush ingestion are effective at cooling firefighters following a simulated search and rescue task in a hot environment', *Applied Physiology, Nutrition, & Metabolism,* 39 (10), 1159-66.

Wilson, BD, Gisolfi, CV, and Smith, TF (1975), 'Thermal responses to intermittent work in selected environments', *American Industrial Hygiene Association Journal*, 648-52.

Wolkow, A, Netto, K, Langridge, P, Green, J, Nichols, D, Sergeant, M, and Aisbett, B (2012), 'Cardiovascular risk screening of volunteer firefighters', *Proceedings of Bushfire CRC & AFAC 2012 Conference Research Forum* (28), 170-84.

Wolkow, A, Netto, K, Langridge, P, Green, J, Nichols, D, Sergeant, M, and Aisbett, B (2013), 'Coronary Heart Disease Risk in Volunteer Firefighters in Victoria, Australia', *Archives of Environmental & Occupational Health,* 69 (2), 112-20.

Young, AJ, Sawka, MN, Epstein, Y, DeCristofano, B, and Pandolf, KB (1987), 'Cooling different body surfaces during upper and lower body exercise', *Journal of Applied Physiology,* 63 (3), 1218-23.

Chapter 6: General Discussion

6.1 BACKGROUND

Wildland firefighters play a critical role in protecting those in rural and regional areas from the annual threat of wildfire (McLennan and Birch 2005). Their role will only become more important in the coming years, as it is predicted that catastrophic heat and fire events will become more frequent (Hennessy et al. 2006; Liu et al. 2010; Lucas et al. 2007). Thus, it is imperative that policy makers in the fire industry better understand the relationship between ambient temperature, worker productivity, and safety. In order to build policy that can be applied to this population, high-quality research that reflects the work demands of firefighting is warranted. An examination of the available literature indicates that previous laboratory studies assessing heat and firefighter performance has been limited by the predominant use of treadmill-walking protocols (McLellan and Selkirk 2006; Selkirk and McLellan 2004), or simulations that reflect structural fires rather than wildfire scenarios (Bilzon et al. 2001; Holmér and Gavhed 2007; Romet and Frim 1987; Smith et al. 2001). To date, little focus has been afforded to the sustained carry, drag, dig, and rake manual-handling tasks that wildland firefighters perform in the field (Phillips et al. 2012). Conversely, the existing field research (which inherently reflects the true work demands of firefighting) is susceptible to factors other than ambient temperature (e.g., severity of the fire, instructions from superiors) that would dictate the effort given to a work task, thereby making it difficult to determine the precise influence of ambient heat on firefighters' work performance. The experimental designs employed in the three current studies were developed in an attempt to overcome these limitations, by balancing the high fidelity of field studies with the rigour of laboratory research.

The general aims of the thesis were:

1. To quantify the effect of ambient heat (32°C) on firefighters' work performance, thermoregulatory responses, perception, and adaptive behaviours during simulated wildfire suppression work compared to the same work under 'control' conditions (19°C; Study 1).

2. To quantify the cumulative effect of multiple, consecutive days of heat exposure (33°C) on firefighters' work behaviour, as well as physiological, perceptual, and adaptive responses, during a simulated wildfire 'campaign' tour (Study 2).

3. To assess firefighters' work output, physiology, perception, and behaviour when performing a simulated fireground task under very hot (45°C) ambient conditions when compared to the same task performed in a temperate ambient environment (18°C; Study 3).

6.2 SUMMARY OF RESEARCH FINDINGS

The effect of ambient heat on wildland firefighters' self-selected work output had, until this point, not been quantified in a controlled environment. Thus, Study 1 was designed to replicate the work intensities, movement patterns, and work to rest ratios exhibited during wildfire suppression in the field (Phillips et al. 2011; Phillips et al. 2012), whilst simultaneously allowing for the quantification of self-selected work output across a range of tasks. It was observed that, despite presenting with significant (though moderate) increases across all measures of thermal stress, firefighters' working in the heat (32°C) maintained a comparable work output relative to those in more temperate conditions (19°C). Furthermore, heart rate was only elevated in the heat during select periods (e.g., during the dedicated rest periods, and the static hose hold task), and there was little difference observed in firefighters' ratings of perceived exertion. It is likely that the frequent rest breaks and task rotation utilised in the protocol facilitated the firefighters' ability to sustain (or even improve) their work output across the simulated 'shift'.

Adaptive behaviours (e.g., increased fluid consumption both prior and during the work shift) in the hot condition also likely played a role in moderating physiological responses and, in turn, aided firefighters in preventing the development of heat-related illness and preserving performance.

While the data from Study 1 suggested that firefighters are able to successfully sustain their work output in hot conditions over one simulated work shift, it remained unknown whether this finding would persist during wildfire suppression spanning multiple days. No previous studies had investigated the effect of repeated daily heat exposures, as is commonplace during wildfire suppression (Aisbett et al. 2012), on manual-handling work performance. Thus, Study 2 used the same design as Study 1 (in terms of work tasks, work intensities, ambient temperature etc.) to assess the cumulative effect of multiple days of heat exposure (33°C) on firefighters work output, physiology, perceptual, and behavioural responses. Once again, it was observed that work performance was unaffected by the heat at a group level, despite firefighters displaying significant increases in core temperature, skin temperature, and thermal sensation ratings relative to their control group counterparts. Interestingly though, there was significant individual variability in work behaviour across both experimental groups, which suggests that individual characteristics may play the key role in moderating work behaviour in this population (above and beyond that of ambient temperature) during long-duration, repeated manual-handling work shifts. As in Study 1, firefighters were also observed to increase their self-selected fluid intake, and in turn recorded significantly lower urine specific gravity values when compared to the control group.

Studies 1 and 2 illustrated that self-paced, intermittent firefighting work performance is comparable during both moderately hot and temperate ambient conditions, for the most part without adverse physiological consequences. Thus, the third objective of the thesis was to assess whether these findings would persist under the very hot (45°C) conditions that firefighters occasionally face during wildland fire suppression (Cuddy and Ruby 2011;

Teague et al. 2010) (Study 3). Due to size constraints of the heat chamber utilised, participants in this study performed only one simulated fireground task (rakehoe work) to represent the upper-body, manual-handling task profile of wildland firefighting in the field (Budd et al. 1997a; Phillips et al. 2012). The study was, however, strengthened by the use of a crossover experimental design, which was permitted because of the substantially shorter time demands placed on participants. Unlike Studies 1 and 2, firefighters in this study reduced their work output during the very hot condition when compared to the control trial (18°C). In spite of the decreased work, all measures of thermal stress and exertion were significantly elevated during the three-hour trial, and the magnitude of these responses suggests that firefighters would be unable to sustain even their reduced rate of work over more extended durations. However, even under the harsh conditions employed in this study, firefighters again self-managed their drinking behaviour to avoid dehydration.

6.3 CONTRIBUTION TO THE LITERATURE

Despite the number of personnel (across various occupations) that perform manual-handling work, there has been a paucity of research that investigates the effect of ambient temperature on manual-handling work performance in a controlled setting. No previous studies have explored the relationship between heat and self-paced manual-handling work performance over extended durations, or over multiple days. Further, the small body of literature investigating the more 'extreme' ambient temperatures faced during wildfire suppression cannot be easily extrapolated to all aspects of wildland firefighting (due to the predominant use of treadmill-walking protocols). Therefore, this thesis represents a valuable addition to the current body of scientific knowledge. We now know that when the heat load is moderate (32 – 33°C, as in Studies 1 and 2), fluids are readily available, and the work is broken up with frequent periods of rest, firefighters are able to successfully maintain a comparable work output as during more temperate working conditions (19°C) over a range of fireground tasks (even over multiple days). Moreover, they can do so with only moderate, compensable increases in markers of thermal strain. However, under very hot ambient conditions (45°C) work output cannot be maintained (relative to temperate conditions), and physiological responses are elevated to a point that may be potentially hazardous to firefighter health.

Given the distinct lack of existing research investigating manual-handling performance, the findings presented in this thesis may also be relevant to other occupations with a similar manual-handling profile (e.g., forestry workers, mining). However, given the inherent differences between these occupations, the application of findings (e.g., changing workplace procedures) must rely on job-specific research and testing. Nevertheless, the current findings may provide a useful starting point in the emerging field of manual-handling research.

6.4 PRACTICAL IMPLICATIONS

Studies 1 and 2 provide evidence that firefighters can successfully sustain their performance on simulated wildfire suppression tasks under moderately hot conditions, even during multiple, consecutive days of heat exposure. This suggests that fire agencies can expect their crews to be similarly productive in both temperate and moderately hot conditions, and thus, need not consider altering their current deployment practices. However, once future research has further examined the role of individual characteristics (e.g., age, fitness) in moderating performance in this population, fire agencies may like to consider the characteristics of their personnel and how they may influence their work productivity. The findings also suggest that most wildland firefighters performing their duties under these ambient conditions can do so without suffering adverse heat-related health consequences. The physiological markers of thermal stress measured in the current studies highlighted that, although significantly elevated when compared to the control groups, firefighters' thermal physiology was relatively stable in the hot conditions, which indicates that the heat load was compensable. It is highly likely that the intermittent work protocol utilised in the studies, which reflected the varying intensity of fire suppression work in the field (Cuddy et al. 2007; Rodríguez-Marroyo et al. 2011), played an important role in the maintenance of work output, as well as assisting with moderating firefighters' physiological response. Fire agencies should, therefore, continue to encourage personnel to take frequent rest breaks and rotate their work tasks where possible.

On the contrary, the findings from Study 3 illustrate that, when faced with a very hot ambient environment, firefighters are unable to perform the same amount of work as under temperate conditions. In addition, firefighters elicited very high heart rate values (e.g. 94 ± 12% of age predicted maximum), and experienced continually increasing core temperatures across the course of the trial, both of which could lead to exhaustion if the work was sustained over longer durations. Indeed, two firefighters (20%) were unable to withstand the work for the entirety of the three-hour trial, despite the majority of this time (66%) being spent in a resting state. From a practical standpoint, these findings suggest that more firefighting crews will be required if agencies expect a comparable productivity rate as during temperate – moderately hot weather conditions. However, it should be noted that the task performed in this study has been shown to be the most physically demanding of all fireground tasks (Phillips et al. 2011), and thus, the thermoregulatory response may have been more pronounced than if firefighters had performed a different wildfire suppression task, or an array of tasks. Nevertheless, emphasis should continue to be placed on monitoring the health of wildland firefighters working in very hot conditions in order to minimise the occurrence of fatigue and/or heat-related illness.

One positive outcome that was shared by all three studies was the firefighters' ability to increase their ad-libitum fluid intake to avoid dehydration, at least according to their recorded urine specific gravity values (and maintenance of body mass in Study 3). Across all studies, firefighters in the heat were either similarly or more hydrated than during the control trials, as a result of substantial increases in fluid consumption. Australian wildland firefighters in the field have been observed to arrive on shift in a hypohydrated state (Raines et al. 2012; Raines et al. 2015). Their hydration status at the end of the work day has varied; in cool – moderately hot conditions personnel have been euhydrated at the completion of their shift (Raines et al. 2012), whereas the same cohort working in hot conditions (37°C) has remained slightly, but consistently, hypohydrated across the work day (Raines et al. 2015). A recent study has reported that current US wildland firefighters display a higher water turnover than the same population 15 years ago (Cuddy et al. 2015). These findings, in concert with the present research outcomes, suggest that fire agencies' attempts to educate their personnel on the importance of adequate hydration are, for the most part, being retained and utilised when necessary. Fire agencies should nevertheless continue to ensure that surplus fluids (water and electrolyte drinks) are supplied during wildfire suppression, particularly on hot weather days, to encourage this increased fluid intake on the fireground.

6.5 LIMITATIONS OF THE RESEARCH

In Studies 1 and 2, different groups of firefighters performed the 'control' and 'hot' trials. Unfortunately, this made it impossible to ensure precise homogeneity across the groups, and there is some possibility that individual variation may have influenced the ensuing results. While a crossover design would have been ideal, the time that firefighters were required to give up to participate in this investigation (five days) without any sort of remuneration (due to strict regulations imposed from various firefighting associations) precluded this from happening. Volunteer firefighters in Australia already truncate their recreation time to serve as firefighters, without any form of financial reparation. These studies were also part of a broader research project, which, in addition to heat (and the control trial), investigated the effects of sleep deprivation, and the combined effects of sleep deprivation and heat. Therefore, should the same participants have been utilised across all experimental conditions, they would have been required to give up 20 days (4 × 5 day trials; inclusive of adaptation and recovery nights) without compensation. This was an unrealistic expectation, and in all likelihood would have led to extreme difficulty in recruiting willing study participants. Thus, different groups of firefighters were utilised. However, in order to reduce variation between experimental groups, firefighters were matched by age, gender, and body mass index, and a subjective measure of physical activity was utilised.

Studies 1 and 2 were also limited by their lack of baseline physiological data, and through the sole use of USG as a proxy for hydration status. Firefighters were exposed to different environmental conditions prior to the commencement of data collection (the heaters were turned on two-hours prior; thus, ambient temperature in the facility was increasing from 19 – 32°C in the hot condition during this period). Additionally, participants did not remain stationary during this time, as should be the case when collecting true baseline measures. Therefore, while the data collected in these studies reflects the magnitude of the difference in physiological responses between conditions, they do not necessarily provide a true magnitude of the increase in physiological responses over time. Upon reflection, preparing participants outside of the testing room would have allowed for the collection of accurate baseline data, which would have strengthened the subsequent findings. Likewise, while measuring changes in body mass (to approximate sweat rate) during prolonged exercise has its own limitations, in hindsight, utilising body mass in concert with USG findings would have provided a more comprehensive picture of firefighters' hydration status. Nevertheless, the lessons learned from these two studies informed the design for Study 3, which subsequently included the collection of both baseline physiological data and post-exercise body mass.

While utilising simulations allowed for the quantification of worker performance, it is likely that the artificial environment created was not entirely representative of wildfire suppression in the field. In particular, radiant heat (either from the sun, or in some cases, the fire), and wind speed were not simulated in the current investigation. While the metabolic heat stored by firefighters as a result of the physical work has been shown to elicit more than twice the heat load from radiant heat (from both the sun and fire; Budd 2001), and wildfire suppression can often times be performed at a considerable distance from the fire (FEMA 2002), it is nevertheless possible that the present findings slightly underestimate the thermal stress placed on wildfire personnel in the field. It is also possible that firefighters in the field experience greater convective and evaporative heat losses as a result of high winds (Havenith 1999). However, the encapsulating personal protective clothing that firefighters wear on duty is known to substantially limit heat loss (Barr et al. 2010; Cheung et al. 2010), and thus, the difference between simulated and actual wildfire conditions (in this respect) may be relatively small. Furthermore, while relative humidity was measured and reported in all studies, the size of the testing facility precluded the direct simulation of wildfire-representative humidity values in both Studies 1 and 2. Finally, firefighters from hotter climates (e.g., Northern Australia) were excluded from participation, and data collection took place during the cooler autumn and winter months, to minimise the effect of heat acclimation. While these criteria were considered necessary to maximise homogeneity between groups, some caution must be exercised when applying the results to fire suppression occurring at the end of the summer season (when firefighters are likely acclimatised).

While study participants were continually instructed to work "as they would on the fireground", the urgency that may be present during actual wildfire suppression was also not replicated in the simulations. Previous research has reported higher heart rate values in wildland firefighters performing tasks performed at the fire-front when compared to tasks performed away from the fire (Rodríguez-Marroyo et al. 2011). However, it should be noted that many of the tasks chosen in the current research designs are those typically performed during fire preparation (e.g., rakehoe work), or during post-fire 'clean-up' work (e.g., blackout hose work) (Phillips et al. 2012). Indeed, wildland fire suppression in the field is often largely comprised of indirect attacks (FEMA 2002). Thus, these tasks may not be performed in an urgent manner even in an operational environment. This limitation of the simulation approach was acknowledged a priori, however in the absence of rigorously controlled work performance data for this population, the balance between task fidelity and scientific rigour fell on the side of scientific rigour (in this instance). Nevertheless, care was taken to ensure that the protocols replicated a true wildland fireground environment wherever possible.

6.6 FUTURE RESEARCH DIRECTIONS

This thesis has identified a number of areas for future research:

- In order to build and implement evidence-based workplace policies, future research should endeavour to explore the effects of each individual environmental stressor (e.g., wind speed, radiant heat, ambient humidity, fire 'urgency') faced during fire suppression (and combinations thereof).

- While the task frequencies, durations, and work to rest ratios were selected (based on field observations) to represent an 'ordinary' period of fire suppression, wildfire suppression is inherently variable. Formally assessing the role of rest periods and task variation in preserving manual-handling work performance could be a potential avenue for future research. For example, rakehoe work in the field typically lasts anywhere from 38 – 461 seconds on average (Budd et al. 1997b; Phillips et al. 2011): would firefighters be able to maintain their performance in the heat should they be asked to build a fireline for almost eight-minutes continuously? Understanding the precise interplay between work, rest, performance, and physiology across a range of task durations would allow fire agencies to make evidence-based decisions surrounding the work tasks that they assign to personnel.

- Assessing the contribution of individual characteristics (such as age, fitness, body composition) and how they impact physical performance in the wildland firefighting population warrants further research. This could allow fire agencies to tailor workplace strategies according to individual characteristics that may moderate the influence of heat on firefighters' physical performance (e.g., firefighters over a certain age and/or with a low level of fitness may be assigned to shorter work shifts to maximise operational effectiveness).

- Participants in the current studies were able to maintain work performance in hot (32 – 33°C) but not very hot (45°C) ambient conditions. Future research should endeavour to explore at what temperature the 'tipping point' occurs, as this information would benefit fire agencies in forecasting the productivity of their crews under different ambient temperatures.

6.7 REFERENCES

Aisbett, B, Wolkow, A, Sprajcer, M, and 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), 916-25.

Barr, D, Gregson, W, and Reilly, T (2010), 'The thermal ergonomics of firefighting reviewed', *Applied Ergonomics,* 41 (1), 161-72.

Bilzon, JLJ, Scarpello, EG, Smith, CV, Ravenhill, NA, and Rayson, MP (2001), 'Characterization of the metabolic demands of simulated shipboard Royal Navy fire-fighting tasks', *Ergonomics,* 44 (8), 766-80.

Budd, GM (2001), 'How do wildland firefighters cope? Physiological and behavioural temperature regulation in men suppressing Australian summer bushfires with hand tools', *Journal of Thermal Biology,* 26, 381-86.

Budd, GM, Brotherhood, JR, Hendrie, AL, Jeffery, SE, Beasley, FA, Costin, BP, Zhien, W, Baker, MM, Cheney, NP, and Dawson, MP (1997a), 'Project Aquarius 1. Stress, strain, and productivity in men suppressing Australian summer bushfires with hand tools: background, objectives, and methods', *International Journal of Wildland Fire,* 7 (2), 69-76.

Budd, GM, Brotherhood, JR, Hendrie, AL, Jeffery, SE, Beasley, FA, Costin, BP, Zhien, W, Baker, MM, Cheney, NP, and Dawson, MP (1997b), 'Project Aquarius 5. Activity distribution, energy expenditure, and productivity of men suppressing free-running wildland fires with hand tools', *International Journal of Wildland Fire,* 7 (2), 105-18.

Cheung, SS, Petersen, SR, and McLellan, TM (2010), 'Physiological strain and countermeasures with firefighting', *Scandinavian Journal of Medicine & Science in Sports,* 20, 103-16.

Cuddy, JS and Ruby, BC (2011), 'High work output combined with high ambient temperatures caused heat exhaustion in a wildland firefighter despite high fluid intake', *Wilderness & Environmental Medicine,* 22 (2), 122-25.

Cuddy, JS, Sol, JA, Hailes, WS, and Ruby, BC (2015), 'Work patterns dictate energy demands and thermal strain during wildland firefighting', *Wilderness & Environmental Medicine,* 26 (2), 221-26.

Cuddy, JS, Gaskill, SE, Sharkey, BJ, Harger, SG, and Ruby, BC (2007), 'Supplemental feedings increase self-selected work output during wildfire suppression', *Medicine & Science in Sports & Exercise,* 39 (6), 1004-12.

FEMA (2002), 'Introduction to wildland/urban interface firefighting for the structural company officer', (Federal Emergency Management Agency, U.S. Department of Homeland Security).

Havenith, G (1999), 'Heat balance when wearing protective clothing', *Annals of Occupational Hygiene,* 43 (5), 289-96.

Hennessy, K, Lucas, C, Nicholls, N, Bathols, J, Suppiah, R, and Ricketts, J (2006), 'Climate change impacts on fire-weather in south-east Australia', in Bureau of Meteorology (ed.), (Canberra: Australian Government).

Holmér, I and Gavhed, D (2007), 'Classification of metabolic and respiratory demands in fire fighting activity with extreme workloads', *Applied Ergonomics,* 38 (1), 45-52.

Liu, Y, Stanturf, J, and Goodrick, S (2010), 'Trends in global wildfire potential in a changing climate', *Forest Ecology & Management,* 259 (4), 685-97.

Lucas, C, Hennessy, K, Mills, G, and Bathols, J (2007), 'Bushfire weather in southeast Australia: Recent trends and projected climate change impacts', in Bushfire CRC & CSIRO (ed.), (Melbourne, Australia: The Climate Institute of Australia).

McLellan, TM and Selkirk, GA (2006), 'The management of heat stress for the firefighter: A review of work conducted on behalf of the Toronto fire service', *Industrial Health,* 44 (3), 414-26.

McLennan, J and Birch, A (2005), 'A potential crisis in wildfire emergency response capability? Australia's volunteer firefighters', *Environmental Hazards,* 6, 101-07.

Phillips, M, Payne, W, Lord, C, Netto, K, Nichols, D, and Aisbett, B (2012), 'Identification of physically demanding tasks performed during bushfire suppression by Australian rural firefighters', *Applied Ergonomics,* 43 (2), 435-41.

Phillips, M, Netto, K, Payne, W, Nichols, D, Lord, C, Brooksbank, N, Onus, K, Jefferies, S, and Aisbett, B (2011), 'Frequency, intensity and duration of physical tasks performed by Australian rural firefighters during bushfire suppression', in Thornton RP (ed.), *Bushfire CRC & AFAC Conference* (Sydney, Australia), 205-13.

Raines, J, Snow, R, Nichols, D, and Aisbett, B (2015), 'Fluid intake, hydration, work physiology of wildfire fighters working in the heat over consecutive days', *Annals of Occupational Hygiene*, 1-12.

Raines, J, Snow, R, Petersen, A, Harvey, J, Nichols, D, and Aisbett, B (2012), 'Pre-shift fluid intake: effect on physiology, work and drinking during emergency wildfire fighting', *Applied Ergonomics,* 43 (3), 532-40.

Rodríguez-Marroyo, JA, Villa, JG, López-Satue, J, Pernía, R, Carballo, B, García-López, J, and Foster, C (2011), 'Physical and thermal strain of firefighters according to the firefighting tactics used to suppress wildfires', *Ergonomics,* 54 (11), 1101-08.

Romet, T and Frim, J (1987), 'Physiological responses to fire fighting activities', *European Journal of Applied Physiology,* 56 (6), 633-38.

Selkirk, GA and McLellan, TM (2004), 'Physical work limits for Toronto firefighters in warm environments', *Journal of Occupational & Environmental Hygiene,* 1 (4), 199-212.

Smith, DL, Petruzzello, SJ, Chludzinski, MA, Reed, JJ, and Woods, JA (2001), 'Effect of strenuous live-fire fire fighting drills on hematological, blood chemistry and psychological measures', *Journal of Thermal Biology,* 26 (4-5), 375-79.

Teague, B, McLeoud, R, and Pascoe, S (2010), '2009 Victorian Bushfires Royal Commission', (Parliament of Victoria).

Chapter 7: Appendices

Operations Bulletin
Fire and Emergency Management

Operations Bulletin 001 / 2012

Management of Heat Stress

Scope	This Operations Bulletin applies to all Operational personnel.
Purpose	To provide information relating to the Management of Heat Stress during all Operational Incidents.
Definitions	Heat-related illness- A spectrum of disorders caused by exposure to extreme temperatures and/ or workload. This includes minor conditions such as heat cramps, heat stress, and heat exhaustion as well as the more severe condition known as heat stroke. Hydration- A process to replenish fluids and electrolytes in the body to maintain vital functions. Water is a vital nutrient for our body because it helps to regulate body temperature, assists with sweating and prevents dehydration by restoring and/or maintaining fluid balance. Electrolyte replacement is important for fluid balance and organ function. Pre-hydrating assists in the prevention of dehydration/heat stress during workload. Rehabilitation- The process of providing rest, recovery, re-hydration, nourishment, and medical evaluation to members who are involved in extended or extreme incident scene operations. To rest and restore the firefighter, prevent further distress and when/where possible return safely to active tasks.
Background	Heat stress has been noted as one of the top three leading causes of injury during bush fire suppression. It is also becoming an increased mechanism of injury during structural fire fighting. Personal Protective Clothing (PPC) provides considerable protection from the external environment during fire suppression. However, PPC restricts the ability to dissipate body heat by the sweating process.
Risks	During incidents as the environment becomes hotter, the body's natural cooling system is compromised. The effectiveness of sweat evaporation from the skin is limited when wearing PPC and when humidity and ambient air temperature is high. In extremely hot and/or humid conditions, the fire fighter will gain heat from the environment, and be unable to effectively shed heat through the evaporation process. The combined effects of prolonged strenuous workload, high temperatures and protective clothing can cause dangerous increases to core body temperature. The human body will tolerate a core body temperature increase of only 3ºC before heat stress could occur. Under high ambient temperature, the body may experience exhaustion, mental confusion, disorientation, loss of consciousness, heart attack and in extreme cases death.

Operations Bulletin
Fire and Emergency Management

Operations Bulletin 001 / 2012

	Excessive sweat loss has detrimental effects on work capacity while wearing protective clothing. Dehydration of one to three percent of body mass is associated with declines in psychological and physical performance. Fluid and electrolyte replacement should equal sweat loss.
Safety Actions	**Hot working conditions.** • Ensure all members are aware of prevention and management of heat related illness (Refer to Bushfire Firefighter Reference Manual/First Aid Manual). • Pre-hydration and nutritional practices should be encouraged. • Incident controller should ensure all crews are monitored for signs of fatigue and heat illness (Refer to Bushfire Firefighter Reference Manual /First Aid Manual). • Ensure extra supplies of water and electrolyte drinks are available- fluid and electrolyte replacement during work in the heat is critical to restore body fluid levels lost when sweating. • Where members are not involved in active fire attack and are in a safe location have them remove coats and when worn remove flash hoods. • Correct PPC for the task should be worn. • Where possible task rotation should be used to assist crews (eg. BA task then swap to light task then back to BA, Refer to BA training manual). • Ensure hydration procedures and rest periods are used (see Schedule 1- Heat Stress Chart). • Implement cooling techniques (see Schedule 2- Heat Stress Active Cooling Techniques). • Pending duration request Ambulance/Health Support Team standby during incident. • In Extreme conditions, under heavy workload, respond extra support Brigade/s to assist with 15-20 min's task rotation. • In Extreme + conditions, under heavy workload, consider task rotation time of 10-15 min's followed by up to 20 min's rest period in shaded area.
Further Information	**OHS Department at CFA Headquarters-** Phone 03 9262 8656 or email ohs@cfa.vic.gov.au **Heat & Dehydration videos-** http://intranet.cfa.vic.gov.au/mycfa/Show?pageId=intraStructuralPeNew
Approval	Chief Officer Euan Ferguson

Schedule 1

Air Temperature C°	Humidity % 20	25	30	35	40	45	50	55	60	65	70	75	80	85	90	95	100
43	47	49	51	54	56												
42	46	48	50	52	54	56											
41	44	46	48	50	52	54	56										
40	43	45	47	49	51	54	56	58									
39	41	43	45	47	49	51	52	54	56	58	59						
38	40	42	43	45	47	49	50	52	54	56	57	59					
37	38	40	42	43	46	47	49	50	52	54	55	57	58				
36	37	38	40	42	43	45	47	49	50	51	53	55	56	58	59		
35	35	37	39	40	42	43	45	46	48	49	51	53	54	56	57	58	
34	34	35	37	39	40	42	43	45	46	47	49	50	52	53	55	56	58
33	33	34	36	37	38	40	41	43	44	46	47	48	50	51	52	54	55
32		33	34	36	37	38	40	41	42	44	45	46	48	49	50	51	53
31		31	33	34	35	37	38	39	40	42	43	44	46	47	48	49	50
30		30	31	32	34	35	36	37	39	40	41	42	43	45	46	47	48
29		29	30	31	32	33	34	35	38	37	38	39	40	41	42	43	46
28			29	30	31	32	33	34	36	36	37	38	39	40	41	42	44
27			27	28	29	30	31	32	33	34	35	36	37	38	39	40	41
26			26	27	28	29	30	31	32	33	34	35	36	36	37	38	39
25				25	26	27	28	29	30	31	32	33	34	35	35	36	37
24				24	25	26	27	28	28	29	30	31	32	33	33	34	35
23				23	24	24	25	26	27	28	28	29	30	31	31	32	33
22				22	22	23	24	25	25	26	27	27	28	29	29	30	31
21					21	22	22	23	24	24	25	26	27	27	28	28	29

- 54+ Extreme danger
- 46-53 Danger
- 40-45 Extreme caution
- 30-39 Caution

safety first

- Based on the average health and fitness levels.
- The level of discomfort will depend on a persons age, health and physical condition, on the type of PPC worn, activity being performed.
- Hydration status, Medication, acclimatisation and diet will also impact on discomfort levels.
- Figures shown in table are 'feels like/perceived' temperature (high humidity increases the feel like temperature).

CFA Fire and Emergency Management

P: 9262 8444
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Bulletin Number: 001 / 2012
Version: 1.0
Date Issued 20 January 2012
Valid to: ongoing
Approved by: Euan Ferguson

Schedule 1

Normal working conditions.

- Incident controller should ensure all crews are monitored for signs of fatigue and heat illness.
- Ensure hydration procedures and rest periods are used

Hot working conditions.

- Incident controller should ensure all crews are monitored for signs of fatigue and heat illness.
- Ensure extra supplies of water and electrolyte fluids are available.
- Task rotation should be used to assist crews (eg. BA task then swap to light task then back to BA, Refer to BA training manual).
- Ensure hydration procedures and rest periods are used.
- Implement cooling techniques.

Extreme working conditions.

- Incident controller should ensure all crews are monitored for signs of fatigue and heat illness.
- Respond extra support Brigade/s to assist with 15-20 min's task rotation.
- Ensure hydration procedures and rest periods are used, 15-20 min's work 20 min's rest in shaded area.
- Ensure extra supplies of water and electrolyte fluids are available.
- Request Ambulance standby during internal structural attack period.
- Use active cooling techniques.

Extreme+ working conditions.

- Incident controller should ensure all crews are monitored for signs of fatigue and heat illness.
- Respond extra support Brigade/s to assist with 10-15 min's task rotation.
- Ensure hydration procedures and rest periods are used, 10-15 min's work 20 min's rest in shaded area.
- Ensure extra supplies of water and electrolyte fluids are available.
- Pending on duration request Ambulance/Health Support Team standby.
- Use active cooling techniques.

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Schedule 2

Heat Stress Active Cooling Techniques.

CFA

Task rotation

Rotate existing crew where possible.

Where conditions require, respond an extra crew to assist with 15-20 min's task rotation.

Ensure hydration procedures and rest periods are used, 15-20 min's work 20 min's rest in shaded area.

Hydration

Ensure all crew members drink fluids at regular intervals.

Follow correct hydration procedures with water and Electrolyte supplement.

Water should not be frozen, approximately 15-20° C is ideal.

Cool shaded area for rehabilitation

Where possible, provide cover under a tree or shelter.

A tarp can be set up to give shelter from the sun..

Do not set up on concrete or road as heat will be transferred from the surface. Use a grassed area where possible.

Where possible fanning using a towel, jacket or fan will assist.

Lower arm cooling

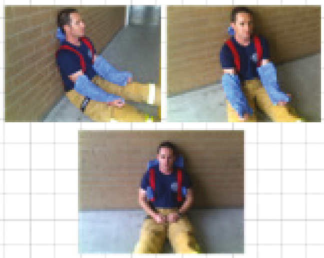
Pour water over lower arms (front and back) from a hose or bottled water.

Where possible, fanning using a towel, jacket or fan will assist.

Blood flow through the arms will be cooled and will return cool blood to the core of the body.

Water should not be frozen, approximately 10-20° C is ideal.

Use of towels to assist cooling



Place cool wet towels under the arm pits and around the neck to assist in cooling circulating blood and return cool blood to the core of the body.

Where possible, fanning using a towel, jacket or fan will assist.

Water should not be frozen, approximately 10-20° C is ideal.

Information sourced from Orange County Fire Dept, Toronto Fire Dept and CFA Medical Officer

Ver 1.2 / December 1, 2010

safety first

Awake, Smoky & Hot:

Workplace stressors when fighting bushfire

We need volunteer firefighters (18-65) to be part of our research study

Do you ever feel sleep deprived, heat stressed or the effects of smoke while on the fireground? Take part in a multi-day (72 h) fireground simulation which aims to capture task performance, physiology, cognition, and sleep quality under different environmental conditions. Information on your usual sleeping patterns will be collected both pre- and post-testing. Participants will be required to 'live' in our simulated testing environment at either Box Hill Town Hall, Melbourne or Brukunga, Adelaide for four nights.

If you are interested in participating or finding out more information, please contact **Brad Smith** at Central Queensland University

b.p.smith@cqu.edu.au

08 8378 4528

Funded by the Bushfire CRC and conducted by researchers at Deakin and Central Queensland University, and the CSIRO

You can also register your interest online http://tinyurl.com/awakesmokyhot

All participants are encouraged to consider a medical check before participating

CQUniversity AUSTRALIA

DEAKIN UNIVERSITY AUSTRALIA Worldly

PLAIN LANGUAGE STATEMENT AND CONSENT FORM

TO: Participant

Plain Language Statement

Date: 28 April 2015

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

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

Student Researcher: N / A

Associate Researcher(s): N / A

Purpose:

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

Methods:

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

Demands:

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

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

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

Potential risks to participants:

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

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

Expected benefits to wider community:

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

Privacy and confidentiality:

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

Dissemination of the research results:

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

Research monitoring:

All research will be monitored by principal investigators Dr Brad Aisbett, Associate Professor Sally Ferguson, Katrina Onus and Dr Sarah Jay.

Payments to participants:

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

Sources of research funding:

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

Should you have any questions, please contact

Katrina Onus
School of Exercise and Nutrition Sciences
Deakin University
Burwood VIC 3125
Phone: 03 9244 6684 Fax: 03 9244 6017
Email: katrina.onus@deakin.edu.au

Complaints

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

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

Please quote project number [2010-170].

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PLAIN LANGUAGE STATEMENT AND CONSENT FORM

TO: Participants

Consent Form

Date: 28.09.2011

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

bushfires

Reference Number: [2010-170].

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

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

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

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

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

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

Signature ……………………………………………………… Date ………………………….

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

Katrina Onus
School of Exercise and Nutrition Sciences
Deakin University
Burwood VIC 3125
Phone: 03 9244 6684 Fax: 03 9244 6017
Email: katrina.onus@deakin.edu.au

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PLAIN LANGUAGE STATEMENT AND CONSENT FORM

TO: Participants

Revocation of Consent Form

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

Date: 28.09.2011

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

bushfires

Reference Number: [2010-170].

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

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

Signature ………………………………………………………………. Date ……………………

Please mail or fax this form to:

Katrina Onus
School of Exercise and Nutrition Sciences
Deakin University
Burwood VIC 3125
Phone: 03 9244 6684 Fax: 03 9244 6017
Email: katrina.onus@deakin.edu.au

MEDICAL SCREENING QUESTIONNAIRE – CFS EXAMPLE

Awake, Smoky and Hot Screening Questionnaire

Name____

1 What is your age?____________ years

2 Gender: Male ☐ Female ☐

3 Domestic status:
- Married / Living with a partner ☐
- Separated / Divorced ☐
- Widowed ☐
- Single ☐

4 Do you have children living at home with you? Yes ☐ No ☐

5 If yes, how many? ______ and how old are they? 1)_______ 2)_______ 3)_______ 4)_______ 5) _______

6 Do you consume caffeinated products (eg coffee, tea, cola, energy drinks, chocolate bars etc)?
Yes ☐ No ☐

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

7 Do you describe yourself as a:

☐ Regular smoker

(I smoke one or more cigarettes per day)

☐ Occasional smoker

(I do not smoke every day)

☐ Ex-smoker

(I used to smoke but not anymore)

☐ Non-smoker

(I have never smoked regularly)

8 How often do you drink alcohol?
☐ Never ☐ Less than once per week ☐ Once or twice per week ☐ Once every two days ☐ Daily

9 On a typical drinking occasion, how many drinks do you have? (One drink equals a glass of beer, a glass of wine or a shot of liquor).
☐ None ☐ Less than 2 drinks ☐ 2-4 drinks ☐ 5-6 drinks

10 Have you travelled overseas in the last four weeks? ☐ No ☐ Yes
If YES, when and where did you travel?
____

11 Are you currently undertaking any form of regular exercise? ☐ No ☐ Yes
(If yes, briefly describe the type and amount (i.e. frequency, duration) of exercise you perform)

____

WORK

12 Are you, or have you ever been, involved in shift work? ☐ Yes ☐ No
If YES, when were you involved in shift work, and for how long?

____
_

13 Are you currently employed? ☐ Yes ☐ No
If YES, what is your current occupation?

____

14 How often do you work?

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

FIREFIGHTING HISTORY

15 Years of fire fighting experience (volunteer and/or salaried)? ________________

16 How long have you been a member of the CFS? ________

17 What training have you completed?
____
____

18 Approximate number of campaign deployments? ______________________

19 When were you last called for a job to which you responded/attended? __________________

HEALTH

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

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

22 *Have you ever had?*	Yes	No	Don't Know
Chest pain, chest discomfort, chest tightness or chest heaviness?	☐	☐	☐
Shortness of breath out of proportion to exercise undertaken?	☐	☐	☐
Sensations of abnormally fast and/or irregular heart beat?	☐	☐	☐
Episodes of fainting, collapse or loss of consciousness?	☐	☐	☐
Abnormal bleeding or bruising?	☐	☐	☐

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

____

____

____
____

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

☐ Yes ☐ No ☐ Don't Know

If YES, please elaborate:

---

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

☐ Yes ☐ No ☐ Don't Know

If YES, please elaborate:

____
____
____

25 Are you currently taking any medications? ☐ Yes ☐ No

If YES, please list the medications ____
_____
____
____
____

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

If YES, please list the allergies ____
____
____

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

☐ Yes ☐ No ☐ Don't Know

SLEEP

28 How many hours of sleep do you need to feel rested? ____________ hours

29 How satisfied are you with the amount of sleep you get?

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

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

☐ very poor ☐ poor ☐ fair ☐ good ☐ very good ☐ excellent

31 Have you ever been diagnosed with a sleeping problem? ☐ No ☐ Yes

If YES, please describe

____

____

____

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

____

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

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

33 Please answer the following in relation to sleep timing

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

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

  5:00 – 6:30 AM ☐

  6:30 – 7:45 AM ☐

  7:45 – 9:45 AM ☐

  9:45 – 11:00 AM ☐

  11:00 – 12 Noon ☐

  12 Noon – 5:00 AM ☐

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

  8:00 – 9:00 PM ☐

  9:00 – 10:15 PM ☐

  10:15 – 12:30 AM ☐

  12:30 – 1:45 AM ☐

  1:45 – 3:00 AM ☐

  3:00 AM – 8:00 PM ☐

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

  Not all dependent ☐

  Slightly dependent ☐

  Fairly dependent ☐

  Very dependent ☐

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

  Not all easy ☐

  Not very easy ☐

  Fairly easy ☐

  Very easy ☐

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

Not all alert ☐

Slightly alert ☐

Fairly alert ☐

Very alert ☐

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

  Not all hungry ☐

  Slightly hungry ☐

  Fairly hungry ☐

  Very hungry ☐

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

  Very tired ☐

  Fairly tired ☐

  Fairly refreshed ☐

  Very refreshed ☐

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

  Seldom or never later ☐

  Less than one hour later ☐

  1 – 2 hours later ☐

  More than two hours later ☐

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

  Would be in good form ☐

  Would be in reasonable form ☐

  Would find it difficult ☐

  Would find it very difficult ☐

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

  8:00 – 9:00 PM ☐

  9:00 – 10:15 PM ☐

  10:15 PM – 12:45 AM ☐

  12:45 – 2:00 AM ☐

  2:00 – 3:00 AM ☐

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

  8:00 AM – 10:00 AM ☐

  11:00 AM – 1:00 PM ☐

  3:00 PM – 5:00 PM ☐

  7:00 PM – 9:00 PM ☐

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

  Not at all tired ☐

  A little tired ☐

  Fairly tired ☐

  Very tired ☐

- For some reason you have gone to bed several hours later than usual, but there is no need to get up at any particular time the next morning. Which ONE of the following are you most likely to do?

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

  Will wake up at usual time and will doze thereafter ☐

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

  Will NOT wake up until later than usual ☐

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

  Would NOT go to bed until watch was over ☐

Would take a nap before and sleep after ☐

Would take a good sleep before and nap after ☐

Would sleep only before watch ☐

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

  8:00 AM – 10:00 AM ☐

  11:00 AM – 1:00 PM ☐

  3:00 PM – 5:00 PM ☐

  7:00 PM – 9:00 PM ☐

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

  Would be in good form ☐

  Would be in reasonable form ☐

  Would find it difficult ☐

  Would find it very difficult ☐

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

  5 hours starting between 4:00 AM and 8:00 AM ☐

  5 hours starting between 8:00 AM and 9:00 AM ☐

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

  5 hours starting between 2:00 PM and 5:00 PM ☐

  5 hours starting between 5:00 PM and 4:00 AM ☐

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

  5:00 – 8:00 AM ☐

  8:00 – 10:00 AM ☐

  10:00 AM – 5:00 PM ☐

5:00 – 10:00 PM ☐

10:00 PM – 5:00 AM ☐

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

  Definitely a "morning" type ☐

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

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

  Definitely an "evening" type ☐

34 Do you have any other condition or injury not previously mentioned that the researchers should be aware of (i.e. that would prevent you from undertaking your normal duties)? ☐ No ☐ Yes

If YES, please elaborate
____
____
____

Thank you for taking the time to fill in this questionnaire

I believe the information I have provided to be true and correct.
SIGNED:______________________________
DATE:_______________________

This project is funded by the Bushfire CRC
The CFS is in full support of this research

DEAKIN UNIVERSITY

Human Ethics Research

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

Memorandum

To: Dr Brad Aisbett
School of Exercise and Nutrition Sciences

B

cc:

From: Deakin University Human Research Ethics Committee (DUHREC)

Date: 06 October, 2010

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

Please quote this project number in all future communications

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

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

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

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

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

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

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

(d) you provide the Human Research Ethics Committee with a written "Annual Report" on each anniversary date of approval (for projects of greater than 12 months) and "Final Report" by no later than one (1) month after the approval expiry date; *(A copy of the reporting pro formas may be obtained from the Human Research Ethics Committee Secretary, Sue Evans please contact at the telephone or email given on the first page.)*

(e) you accept that the Human Research Ethics Committee reserves the right to conduct scheduled or random inspections to confirm that the project is being conducted in accordance to its approval. Inspections may include asking questions of the research team, inspecting all consent documents and records and being guided through any physical experiments associated with the project

(f) if the research project is discontinued, you advise the Committee in writing within five (5) working days of the discontinuation;

(g) A copy of the Statement of Findings is provided to the Human Research Ethics Committee when it is forwarded to participants.

Please note that failure to comply with the conditions of approval and the *National Statement on Ethical Conduct in Human Research* may result in withdrawal of approval for the project.

In the event that you require an extension of ethics approval for this project, please make written application in advance of the end-date of this approval. The research cannot continue beyond the end date of approval unless the Committee has granted an extension of ethics approval. Extensions of approval cannot be granted retrospectively. Should you need an extension but not apply for this before the end-date of the approval then a full new application for approval must be submitted to the Secretary for the Committee to consider.

The Human Research Ethics Committee is committed to supporting researchers in achieving positive research outcomes through sound ethical research projects. If you have issues where the Human Research Ethics Committee may be of assistance or have any queries in relation to this approval please do not hesitate to contact the Secretary, Sue Evans or myself.

Yours sincerely,

Signature Redacted by Library

Professor Phillip Ebrall
Chair, Human Research Ethics Committee

Cc: A/Prof Sally Ferguson, Dr Sarah Jay (CQUniversity researchers) Dr Luana Main, Dr Brad Aisbett (Deakin University co-researchers), Mr Alexander Wolkow (Deakin University student researcher) Project file

APPROVED

Secretary, Human Research Ethics Committee
Ph: 07 4923 2603
Fax: 07 4923 2600
Email: ethics@cqu.edu.au

CQUniversity
Bruce Highway
Rockhampton QLD 4702
AUSTRALIA
Tel +61 7 4930 9777
www.cquni.edu.au

Dr Sally Ferguson
C/- Centre for Sleep Research
University of South Australia
GPO Box 2471
Adelaide SA 5001

7 February 2012

Dear Dr Ferguson

HUMAN RESEARCH ETHICS COMMITTEE ETHICAL APPROVAL PROJECT: H12/01-016
AWAKE, SMOKY & HOT: WORKPLACE STRESSORS WHEN FIGHTING BUSHFIRES

The Human Research Ethics Committee is an approved institutional ethics committee constituted in accord with guidelines formulated by the National Health and Medical Research Council (NHMRC) and governed by policies and procedures consistent with principles as contained in publications such as the joint Universities Australia and NHMRC *Australian Code for the Responsible Conduct of Research.*

On 7 February 2012, the Chair of the Human Research Ethics Committee of CQUniversity considered this project, under the provisions of chapter 5.3 of the National Statement (minimising duplication of ethical review). The project has received prior approval from the Deakin University HREC (Protocol number 2010-170) in the name of Dr Brad Aisbett.

It is advised that CQUniversity HREC accepts this determination, and hereby extends full clearance as a CQUniversity project **(Project Number H12/01-016)** please quote this number in all dealings with the Committee. The period of ethics approval will be from 7 february 2012 to 31 August 2014.

The standard conditions of approval for this research project are that:

(a) you conduct the research project strictly in accordance with the proposal submitted and granted ethics approval, including any amendments required to be made to the proposal by the Human Research Ethics Committee;

(b) you advise the Human Research Ethics Committee (email ethics@cqu.edu.au) immediately if any complaints are made, or expressions of concern are raised, or any other issue in relation to the project which may warrant review of ethics approval of the project. *(A written report detailing the adverse occurrence or unforeseen event must be submitted to the Committee Chair within one working day after the event.)*

(c) you make submission to the Human Research Ethics Committee for approval of any proposed variations or modifications to the approved project before making any such changes;

Page 1 of 2

Central Queensland University CRICOS Provider Codes: QLD - 00219C, NSW - 01315F, VIC - 01624D

(d) you provide the Human Research Ethics Committee with a written "Annual Report" on each anniversary date of approval (for projects of greater than 12 months) and "Final Report" by no later than one (1) month after the approval expiry date; *(A copy of the reporting pro formas may be obtained from the Human Research Ethics Committee Secretary, Sue Evans please contact at the telephone or email given on the first page.)*

(e) you accept that the Human Research Ethics Committee reserves the right to conduct scheduled or random inspections to confirm that the project is being conducted in accordance to its approval. Inspections may include asking questions of the research team, inspecting all consent documents and records and being guided through any physical experiments associated with the project

(f) if the research project is discontinued, you advise the Committee in writing within five (5) working days of the discontinuation;

(g) A copy of the Statement of Findings is provided to the Human Research Ethics Committee when it is forwarded to participants.

Please note that failure to comply with the conditions of approval and the *National Statement on Ethical Conduct in Human Research* may result in withdrawal of approval for the project.

You are required to advise the Secretary in writing within five (5) working days if this project does not proceed for any reason. In the event that you require an extension of ethics approval for this project, please make written application in advance of the end-date of this approval. The research cannot continue beyond the end date of approval unless the Committee has granted an extension of ethics approval. Extensions of approval cannot be granted retrospectively. Should you need an extension but not apply for this before the end-date of the approval then a full new application for approval must be submitted to the Secretary for the Committee to consider.

The Human Research Ethics Committee wishes to support researchers in achieving positive research outcomes. If you have issues where the Human Research Ethics Committee may be of assistance or have any queries in relation to this approval please do not hesitate to contact the Secretary, Sue Evans or myself.

Yours sincerely,

Signature Redacted by Library

Professor Phillip Ebrall
Chair, Human Research Ethics Committee

Cc: Dr Brad Aisbett, Ms Katrina Onus, Ms Cara Lord (Partner investigators from Deakin University),
Dr Sarah Jay
Project file

APPROVED

Page 2 of 2

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

Instructions to the Borg-RPE-Scale®

During the work we want you to rate your perception of exertion, i.e. how heavy and strenuous the exercise feels to you and how tired you are. The perception of exertion is mainly felt as strain and fatigue in your muscles and as breathlessness or aches in the chest.

Use this scale from 6 to 20, where **6** means "No exertion at all" and **20** means "Maximal exertion."

9 Very light. As for a healthy person taking a short walk at his or her own pace.

13 Somewhat hard. It still feels OK to continue.

15 It is hard and tiring, but continuing is not terribly difficult.

17 Very hard. It is very strenuous. You can still go on, but you really have to push yourself and you are very tired.

19 An extremely strenuous level. For most people this is the most strenuous exercise they have ever experienced.

Try to appraise your feeling of exertion and fatigue as spontaneously and as honestly as possible, without thinking about what the actual physical load is. Try not to underestimate, nor to overestimate. It is your own feeling of effort and exertion that is important, not how it compares to other people's. Look at the scale and the expressions and then give a number. You can equally well use even as odd numbers.

Any questions?

BORG
PRODUCTS USA

Thermal Sensation Scale

0.0	Unbearably Cold
0.5	
1.0	Very Cold
1.5	
2.0	Cold
2.5	
3.0	Cool
3.5	
4.0	Comfortable
4.5	
5.0	Warm
5.5	
6.0	Hot
6.5	
7.0	Very Hot
7.5	
8.0	Unbearably Hot

Instructions: Rate you perception of thermal sensation using the rating scale above

CIRCUIT ORDER

TIME ↓	FF 1	FF 2	FF 3	FF 4	FF 5
0 – 5	LAT	BOH	LAT	CHA	RAKE
5 – 10	REST	LAT	BOH	LAT	CHA
10 – 15	HR	REST	LAT	BOH	LAT
15 – 20	LAT	HR	REST	LAT	BOH
20 – 25	BOH	LAT	HR	REST	LAT
25 – 30	LAT	BOH	LAT	HR	REST
30 – 35	RAKE	LAT	BOH	LAT	HR
35 – 40	CHA	RAKE	LAT	BOH	LAT
40 – 45	LAT	CHA	RAKE	LAT	BOH
45 – 50	BOH	LAT	CHA	RAKE	LAT
50 – 55	**STA**	**STA**	**STA**	**STA**	**STA**

LAT = Lateral hose repositioning

REST = Dedicated rest break

HR = Hose rolling

BOH = Blackout hose work

RAKE = Rakehoe work

CHA = Charged hose advance

STA = Static hose hold

RESEARCH IN ACTION

We need volunteer firefighters to be part of our project!

We are interested in how ***very hot*** environmental conditions (45°C) influence firefighters' **work performance** and **safety** when on the fire-ground.

In order to do this, we are looking for male volunteer wildland firefighters to simulate building a firebreak (using a rakehoe), and perform a low-intensity step test, in temperatures of 18°C and 45°C. Participants will simultaneously undergo a battery of physiological (e.g., heart rate and core temperature measurement) and cognitive (e.g., memory, attention) tests, to assess how safely they're able to perform the work.

Participants will be required to attend Deakin University on three occasions:

- One x 1 hour 'familiarisation' session
- One x 3 hour work simulation in 18°C
- One x 3 hour work simulation in 45°C

Ideally, all three sessions would be conducted within a two-week period

---

If you are interested in participating in the study or finding out more information, please contact

Brianna Larsen **E:** b.larsen@deakin.edu.au **PH:** 0418 503 791

OR

Dr Brad Aisbett **E:** brad.aisbett@deakin.edu.au **PH:** 03 9244 6474

This research is being funded and conducted by Deakin University

DEAKIN UNIVERSITY AUSTRALIA

PLAIN LANGUAGE STATEMENT AND CONSENT FORM

TO: Participant

Plain Language Statement

Date: 18/02/2014

Full Project Title: Firefighting in very hot conditions: performance, physiological, and cognitive responses

Principal Researchers: Dr Brad Aisbett & Prof Rod Snow (Deakin University)

Associate Researcher(s): Brianna Larsen (Deakin University)

You are invited to participate in the project 'Firefighting in very hot conditions: performance, physiological, and cognitive responses'

Purpose:

The aim of this study is to understand the effect of very hot ambient temperatures on firefighters' work performance, physiology, and cognition.

Methods:

Participation in this study will involve you performing a simulated fireground task in both a thermo-neutral (18°C) and a very hot (45°C) environment, at Deakin University (in a climate chamber). During the two trials, you will perform three hours of intermittent 'work', using a rakehoe to build a simulated firebreak, interspersed with a low-intensity stepping test. Prior to these two trials, you will also need to come into Deakin University (for approximately one hour) to be familiarised with all aspects of the protocol. Ideally, all of the three sessions (1 x familiarisation, 2 x experimental trials) would be conducted over a three week period, spaced one week apart.

Throughout the testing period, core temperature, skin temperature, and heart rate will be recorded. Core temperature will be measured using a disposable, ingestible tablet that will log to an external receiver. You may drink as much water throughout the three-hour protocol as you like. Any urine produced during the three-hours will be measured and analysed, to determine your hydration status. We will weigh you before and after you take part in the exercise to determine sweat loss. Every now and then, you will be asked to do some short tasks on the iPad to see how your concentration and memory are affected by working in hot conditions. Finally, after each work bout you will be asked to rate your perceived exertion (e.g., how hard you felt you were working) and thermal sensation (e.g., how hot you felt). As participation is strictly voluntary, you can withdraw from the study at any time without consequence.

Demands:

While it's important to make the conditions similar to what you experience when firefighting, we need to make sure that you stay safe. Hence, you will only be asked to work under these conditions for three hours.

Potential risks to participants:

You will be performing hard physical exercise (albeit for only short periods), which does carry some risk of musculoskeletal injury, heat stress, and sudden cardiac death. The risks are, however, very small. This is due, in part, to the medical screening questionnaire we will be using in the study. In order to make sure that people who complete the study will be safe, we will get all participants to fill out a medical questionnaire prior to participation, to make sure no one has an increased risk of injury or heat illness. We will ask questions about things such as previous injuries, previous instances of heat illness, medications being taken etc. to establish that all participants are considered safe to perform the protocol. People with current musculoskeletal injuries, or two (or more) risk factors for cardiovascular disease, will be asked to seek medical authorisation before commencing testing. In fact, **all participants are encouraged to consider a medical check before participating in the research.** There are some instances where, unfortunately, participants will be deemed to be 'high-risk' of injury or heat illness, and will be excluded from performing the protocol. If this is the case, researchers will thoroughly explain the screening process with participants, including why they were considered too high-risk to be included in the study. For those who are considered safe to perform the study, the likelihood of injury occurring is very low, as the protocol is based on "real" work practices which you perform routinely during bushfire supression.

Exposure to hot working conditions can, in some cases, lead to heat stress. However, the conditions are similar to those often faced during real fireground operations. As per fire agency guidelines, you will be provided with unlimited access to water to help avoid dehydration (and limit heat stress). All researchers are also First Aid qualified, and will be monitoring your health throughout the study, so will be ready to help in the case that you develop heat-related symptoms.

Expected benefits to wider community:

Research dedicated to understanding the impact that the working environment, namely high temperatures, has on firefighters and their work performance is fundamental if fire agencies are to implement policies to promote the safety of their crew. The proposed research will provide an evidence-base from which Australian firefighting agencies can make informed decisions around personnel performing fire suppression in very hot ambient environments.

Privacy and confidentiality:

Your privacy and confidentiality will be preserved through a number of measures. Firstly, your interest and participation in (or withdrawal from) the study will be kept confidential. You may, however, perform your testing alongside one other firefighter. Therefore, it is likely that one person will know your identity. We ask, however, that all participants do not disclose the identity of any other participant without explicit consent. We will re-iterate the need to gain consent for revealing the identity of another participant before testing commences. Secondly, your results and identity will be stored separately, such that the researchers will only refer to your data by a unique identifier code. Your data will be stored securely for a period of six years after the final publication of results, as per University guidelines. Thirdly, should you choose to withdraw from the research, any data collected prior to your withdrawal will not be included in the final analysis. Finally, your fire agency will have no record of your decision to participate in, or withdraw from, the proposed research.

Dissemination of the research results:

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

Research monitoring:

All research will be monitored by principal investigators Dr Brad Aisbett and Prof Rod Snow.

Payments to participants:

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

Sources of research funding:

The proposed research is funded by Deakin University.

Should you have any questions, please contact

Brianna Larsen
School of Exercise and Nutrition Sciences
Deakin University
Burwood VIC 3125
Phone: 0418 503 791
Email: b.larsen@deakin.edu.au

Complaints

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

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

Please quote project number 2014-040.

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DEAKIN UNIVERSITY AUSTRALIA

PLAIN LANGUAGE STATEMENT AND CONSENT FORM

TO: Participants

Consent Form

Date: 18/02/2014

Full Project Title: Firefighting in very hot conditions: performance, physiological, and cognitive responses

Reference Number: 2014-040.

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

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

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

The researcher has agreed not to reveal my identity or personal details, including through published material or oral presentations.

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

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

Should you wish to return your consent form, please send the forms to:

Brianna Larsen
School of Exercise and Nutrition Sciences
Deakin University
Burwood VIC 3125
Phone: 0418 503 791
Email: b.larsen@deakin.edu.au

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PLAIN LANGUAGE STATEMENT AND CONSENT FORM

TO: Participants

Revocation of Consent Form

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

Date: 18/02/2014

Full Project Title: Firefighting in very hot conditions: performance, physiological, and cognitive responses

Reference Number: 2014-040.

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

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

Signature ………………………………………………………………. Date ……………………

Please mail or fax this form to:

Brianna Larsen
School of Exercise and Nutrition Sciences
Deakin University
Burwood VIC 3125
Phone: 0418 503 791
Email: b.larsen@deakin.edu.au

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DEAKIN UNIVERSITY AUSTRALIA

MEDICAL SCREENING QUESTIONNAIRE

Name

1 What is your age?___________ years

2 What is your height? ___________ cm

3 What is your weight? ___________ kg

4 Do you consume caffeinated products (e.g., coffee, tea, cola, energy drinks)? Yes ☐ No ☐

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

5 Do you describe yourself as a:

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

☐ Occasional smoker (I do not smoke every day)

☐ Ex-smoker (I used to smoke but not anymore)

☐ Non-smoker (I have never smoked regularly)

6 How often do you drink alcohol?

☐ Never ☐ Less than once per week ☐ Once or twice per week

☐ Once every two days ☐ Daily

7 On a typical drinking occasion, how many drinks do you have? (One drink equals a glass of beer, a glass of wine or 30ml of liquor).

☐ None ☐ Less than 2 drinks ☐ 2-4 drinks ☐ 5-6 drinks

8 Have you travelled overseas in the last four weeks? ☐ No ☐ Yes
If YES, when and where did you travel?
____

9 Are you currently undertaking any form of regular exercise? ☐ No ☐ Yes
(If yes, briefly describe the type and amount (i.e. frequency, duration) of exercise you perform)

____

FIREFIGHTING HISTORY

10 Years of fire fighting experience (volunteer and/or salaried)? ___________________

11 How long have you been a member of your firefighting agency? _________

12 What training (if any) have you completed?
____
____

13 Approximate number of campaign deployments? __________________________

14 When were you last called for a job to which you responded/attended? ____________________

HEALTH

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

16 *Has anyone ever told you that you?*	Yes	No	Don't Know
Are overweight?	☐	☐	☐
Have high blood pressure?	☐	☐	☐
Have a heart murmur?	☐	☐	☐
You have asthma?	☐	☐	☐
You have diabetes?	☐	☐	☐

17 *Have you ever had?*	Yes	No	Don't Know
Chest pain, chest discomfort, chest tightness or chest heaviness?	☐	☐	☐
Shortness of breath out of proportion to exercise undertaken?	☐	☐	☐
Sensations of abnormally fast and/or irregular heart beat?	☐	☐	☐
Episodes of fainting, collapse or loss of consciousness?	☐	☐	☐
Abnormal bleeding or bruising?	☐	☐	☐

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

☐ Yes ☐ No ☐ Don't Know

If YES, please elaborate:

---

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

☐ Yes ☐ No ☐ Don't Know

If YES, please elaborate:

____
____
____

20 Are you currently taking any medications? ☐ Yes ☐ No

Some medications may increase your risk of dehydration (e.g., diuretics), so if you answered YES, please list all medications

____
____
____
____
____

21 Do you have any allergies (e.g. to any food, tapes or Band-Aids (adhesives), latex etc.)

If YES, please list the allergies

____
____
____

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

____
____
____
____

22 Will you be having a medical procedure or travelling by aeroplane in the next month?
☐ Yes ☐ No ☐ Don't Know

23 Is there any other information that you feel is relevant to taking part in the study? If so, please detail below

____
____
____
____

Thank you for taking the time to fill in this questionnaire

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

SIGNED:___________________________________ DATE:__________________________

Human Research Ethics

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

Memorandum

To: Dr Brad Aisbett
School of Exercise and Nutrition Sciences

B

cc: Miss Brianna Larsen

From: Deakin University Human Research Ethics Committee (DUHREC)

Date: 27 March 2014

Subject: 2014-040
Firefighting in very hot conditions: performance, physiological, and cognitive responses

Please quote this project number in all future communications

The application for this project was considered at the DU-HREC meeting held on 17/03/2014.

Approval has been given for Miss Brianna Larsen, under the supervision of Dr Brad Aisbett, School of Exercise and Nutrition Sciences, to undertake this project from 27/03/2014 to 27/03/2018.

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

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

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

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

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