Maximising the safety and performance of Australian urban firefighters working in the heat

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Doctor of Philosophy

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This thesis is dedicated to Amanda,

Lochie and Soph.

I couldn't have done this without you

Acknowledgements

First and foremost, the success of this project is underpinned by the massive effort expended by my primary supervisor Ben Rattray. Your relentless pursuit of perfection in my work has made it possible to present work at the standard that is required to play with the big boys. To take on something so far from your normal research, to put up with firefighters and take an interest in their world is to be commended. Without you, this would not have been possible and you will forever have my thanks.

To former chief officer ACT Fire & Rescue Paul Swain, sir you are a legend! You never questioned my motivations and to me, showed the world what a true leader looks like. This project was all about improving the safety of firefighters everywhere and you put your money where your mouth was by providing me not only the financial and logistical resources that I needed, but more importantly you put your faith in me and you will never know just how much that meant.

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Christos Argus, my kids still think you are a bit odd but I reckon you are a legend. To come on board with nothing other than a hunch that this would work, took some guts and every day I'm happy that you did. Your sense of humour and willingness to learn about the business of being a firefighter was nothing short of legendary.

Though not officially on my supervisory team, I cannot thank Matt Brearley enough. To continually provide me with advice and support goes well beyond what I could ever hope to have received. You consistently grounded me with your good humour and candid feedback and were never too busy to dumb it down for me. Practical experience in this field is short in supply and mate, you are one of the best.

Most of all, this project would not have happened without the support from my colleagues and mates from ACT Fire & Rescue. To keep putting your hands up to be cooked, frozen, poked and prodded showed the world just what a great bunch of people you are. Canberra doesn't realise how lucky it is to have you looking after them day after day, as you attack every problem with good humour and enthusiasm, just like this project.

Abstract

Australian urban firefighters work in hot environments, experiencing significant increases in core temperatures (T_c), which then leads to changes in immune and inflammatory function. These core temperatures can exceed recommended safe working limits and increase the risk of premature fatigue, leading to injury or fatality. The highest cause of line-of-duty injuries and fatalities in urban firefighters are cardiac events occurring during, or in the hours following, emergency responses. These cardiac events have been linked with increased thermal strain and immune and inflammatory function. The purpose of this thesis was, by simulating work tasks in a hot environment (~100 °C), to gain an appreciation of the thermal strain experienced by Australian professional urban firefighters. By comparing responses to working in the heat, this thesis then aimed to establish an understanding of how variations in individual physiology may impact on the risk of a cardiac event following work in the heat. This information, along with the evidence based post-incident cooling practices examined, can inform pre-conditioning practices for professional urban firefighters, along with changes to standard operating procedures to minimise thermal strain experienced during emergency responses in the heat.

The first two studies of this thesis aimed to gain an appreciation of the physical profile of a modern Australian urban firefighter and the impacts of design changes to their protective clothing. In study 1, significant and ongoing age-related declines in cardiovascular fitness ($p<0.05$), strength ($p=0.001$) and operational power testing

($p<0.001$) were detected. Also, age related changes to body composition including increasing body-fat and decreasing lean mass were observed. Although firefighters are recruited in relatively superior physical standards compared with the general population, in a fire service lacking ongoing health and fitness programs, Australian firefighters appear to be experiencing physical declines which may be exposing older firefighters to an unacceptable level of risk of injury when they respond to emergency events.

Study 2 then examined the impacts of an impermeable moisture barrier in modern structural firefighting personal protective clothing (PPC) in both extreme heat (~120 °C) and more temperate (~17 °C) conditions. In the temperate environment, tympanic temperatures (T_{tymp}) were moderately elevated (+0.3 °C) when wearing PPC containing the moisture barrier, possibly increasing the thermal strain on operators in conditions where nearly 95 % of firefighting responses occur *(Keelty, 2013).* In the hot environment, wearing the moisture barrier was associated with higher skin temperatures (T_{sk}) (+0.6 °C), air consumption (+2.9 $L.min^{-1}$) and change in body mass (+0.2 %). Acknowledging these differences, the remainder of studies were conducted with participants wearing the PPC containing the moisture barrier.

Studies 3, 4 and 5 then aimed to establish an understanding of the thermal strain experienced by Australian urban firefighters during simulated search and rescue tasks. All studies were conducted in a purpose built heat chamber (~100 °C) with study 3 and study 6 conducted in heavy smoke and darkness to accurately simulate conditions likely to be encountered during emergency responses. Study 3 demonstrated that in extreme

heat and low visibility, urban firefighters experience gastrointestinal temperatures (T_{gi}) (group mean 38.9 (0.7) °C, individual peak 41.0 °C) that exceed safe working limits of 38.5 °C for heat-acclimated, medically monitored workers *(ISO, 2004).* Increases in T_{gi} in this study were associated with a 12.7 (12.3) % reduction in grip strength (-5.9 kg, $p<0.01$), along with increased perceptions of effort ($p<0.01$) and thermal sensation ($p<0.01$). To minimise the possible confounding effects of reduced visibility from heavy smoke and darkness, studies 4 and 5 were conducted without smoke, and with a standardised work rate.

Studies 4 and 5 demonstrated significantly elevated levels of platelets, leukocytes, tumor necrosis factor-α (TNFα) and interleukin 6 (IL-6) (all $p<0.01$) following work in the heat, despite a decrease in lipopolysaccharides (LPS). While leukocytes, TNFα and IL-6 remained elevated after 1 hour of rest, platelets also remained elevated following 24 hours of rest ($p<0.01$). Any residual elevations in immune and inflammatory function following rest periods may be an issue when firefighters re-enter fire scenes or are redeployed. To determine whether pre-conditioning of firefighters, in the form of appropriate strength and conditioning programs, could be of assistance in reducing immune and inflammatory activity, study 5 used body composition (dual energy x-ray analysis; DXA) and maximal aerobic capacity ($VO_{2\ max}$) profiles. Participants were classified into low, moderate and high groups based on aerobic capacity, body-fat, lean mass and BMI. The study demonstrated that higher body fat was associated with higher resting levels of leukocytes, which then led to greater peak values. Higher peak values are likely relevant to the cardiac risk profile of firefighters who are overweight or obese with

elevated leukocytes being a predictor of thrombosis in otherwise healthy individuals *(Targer et al., 1996)*. Those firefighters with low absolute levels of lean mass may also be at increased risk with significantly elevated leukocyte counts observed compared with individuals with higher lean mass directly following work in the heat and after 1 and 24 hrs of rest ($p<0.01$, 0.02 and 0.05 respectively) despite similar pre-heat values. No changes in other variables were detected based on body composition or aerobic fitness.

Finally, study 6 aimed to validate cold-water immersion (CWI) (~15°C for 15 minutes to the umbilicus) and iced-slush ingestion (SLUSH) (7 $g.kg^{-1}.BW^{-1}$) as protocols to rapidly cool heat-affected firefighters. The majority of Australian fire service use only passive cooling methods, in the form of removing clothing and seeking shade, following work in the heat. Therefore, study 6 aimed to compare this practice with CWI and SLUSH. The study found that both CWI and SLUSH were effective at cooling firefighters to baseline T_c within 15 minutes (cooling rates 0.093 and 0.092 $°C.min^{-1}$ respectively), compared with a passive cooling protocol (0.058 $°C.min^{-1}$). Passive cooling alone resulted in T_{gi} still consistent with the lower limits recommended (*ISO, 2004)*. Thus, both CWI and SLUSH are far more effective tools and should be considered by fire services for post-incident cooling of heat-affected firefighters with studies 3 to 6 all demonstrating that T_{gi} of firefighters likely exceeds safe working limits *(ISO, 2004)* after two work bouts in hot environments.

Collectively, all studies in this thesis have demonstrated that Australian urban firefighters experience significant levels of thermal strain during work tasks in the heat. This thermal strain is then exposing them to elevated risks of a cardiac event through increased T_c,

heart rates, immune and inflammatory activity and reduced fitness, which is likely exacerbated by declining physical standards of firefighters as they age. Further, it is likely that the current practice of passive cooling may return firefighters to active duty with elevated T_c possibly increasing these risks on re-entry or redeployment. Thus, taking into account any possible logistical limitations, adopting cooling methods including CWI and SLUSH at fire scenes should be considered as effective tools for post-incident cooling of firefighters following work in the heat.

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List of peer-reviewed publications

Research output directly related to this thesis includes five papers that have been published in peer-reviewed journals or books with a further chapter in its final stage of review. The research output is listed below. A number of papers related to this thesis, and published during candidature are also listed.

Chapter Three

Walker A, Argus C, Driller M, Cooke J & Rattray B (2014). The ageing Australian Firefighter: An argument for age based recruitment and fitness standards for urban Fire Services. *Ergonomics 57(4): 612-621. DOI 10.1080/00140139.2014.887790. PubMed 24588283.*

Chapter Four

Walker A, Argus C, Driller M & Rattray B (2014). Physiological Responses to design adaptations in Firefighting PPC during simulated firefighting tasks. *Science of Sport, Exercise and Physical Activity in the Tropics; Sports and athletics preparation, performance and psychology. Chapter 11, pgs. 91-102. Nova Scientific Publishers, New York. ISBN 978-0-9873109-9-6.*

Chapter Five

Walker A, Argus C, Driller M & Rattray B (2015). Repeat work bouts increase thermal strain for Australian firefighters working in the heat. *International Journal of Occupational and Environmental Health. In Press (accepted 1st March, 2015). DOI: 10.1179/2049396715Y.0000000006. PubMed 25849044.*

Chapter Six

Walker A, Keene T, Argus C, Driller M, Guy J, Rattray B (2015). Immune and inflammatory responses of Australian firefighters after repeated exposures to the heat. *Ergonomics. In Press (accepted 4th May 2015). DOI:10.1080/00140139.2015.1051596. PubMed 26082313.*

Chapter Seven

Walker A, Keene T, Zanetti S, Driller M, Argus C, Rattray B. Body composition affects immune responses of Australian firefighters in the heat. *In Review*.

Chapter Eight

Walker A, Driller M, Brearley M, Argus C & 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, and Metabolism 39 (10): 1159-1166. DOI 10.1139/apnm-2014-0038. PubMed 25017114.*

Other papers published during candidature

Keene T, Brearley M, Bowen B & **Walker A** (2015). Accuracy of Tympanic Temperature Measurement in Firefighters Completing a Simulated Structural Firefighting Task. *Prehospital and Disaster Medicine 30 (5): 1-5. DOI:10.1017/S1049023X15005038.*.

Brearley, M & **Walker A**. (In Press). Water immersion for post incident cooling of firefighters; a review of practical fire ground cooling modalities. *Extreme Physiology and Medicine*. Accepted 16th September 2015.

List of peer-reviewed conference presentations

Walker A, Driller M, Argus C & Rattray B (2013). The effect of different recovery methods in lowering core temperatures following a simulated firefighting task. *Science of Sport, Exercise & Physical Activity in the Tropics conference. 28 - 30 November. Cairns, Australia.*

Walker A, Rattray B, Argus C & Driller M (2013). Physiological responses to design adaptations in PPC during simulated firefighting tasks. *Science of Sport, Exercise & Physical Activity in the Tropics conference. 28 - 30 November. Cairns, Australia.*

Walker A, Driller M, Argus C & Rattray B (2014). Does increasing age result in declining physical standards of firefighters? *6th Exercise and Sport Science Australia (ESSA) Conference: Research to Practice. 10-12 April. Adelaide, Australia.*

Walker A, Driller M, Argus C & Rattray B (2014). Ageing firefighters may impair the quality of emergency responses. *AFAC and Bushfire & Natural Hazards CRC Conference. 2 - 5 September. Wellington, New Zealand.*

Walker A, Driller M, Brearley M, Argus C, Rattray B (2014) Iced Slush Ingestion and Cold-water Immersion are effective at rapidly reducing core temperatures of urban firefighters post emergency response. *AFAC and Bushfire & Natural Hazards CRC Conference. 2 - 5 September. Wellington, New Zealand.*

Brearley M, **Walker A** (2014). Water Immersion Cooling of Firefighters - Forearms or multiple segments? *AFAC and Bushfire & Natural Hazards CRC Conference. 2 - 5 September. Wellington, New Zealand.*

Walker A, Keene T, Argus C, Driller M, Rattray B (2015). Fat or Fit: Does body composition or fitness affect immune and inflammatory changes of firefighters in the heat? *20th Annual Congress of the European College of Sport Science (ECSS). 24 – 27 June. Malmo, Sweden.*

Walker A, Keene T, Driller M, Argus C, Rattray B (2015). Immune responses of urban firefighters following work in the heat. *The 16th International Conference on Environmental Ergonomics (ICEE). 28 June – 3rd July. Portsmouth, United Kingdom.*

Walker A, Rattray B (2015). Perception and Reality; re-entry into fire scenes should be subject to physiological monitoring. *AFAC and Bushfire & Natural Hazards CRC Conference. 1 – 3 September. Adelaide, Australia*.

Statement of Candidate Contribution

This thesis comprises six research investigations which have been completed almost entirely by Anthony Walker (the candidate). The candidate designed the studies, coordinated and supervised all data collection, analysed the data and prepared all manuscripts. The contributions of all parties to each of the six studies are detailed below.

Study one: The ageing Australian Firefighter: An argument for age based recruitment and fitness standards for urban Fire Services.

- Mr Anthony Walker: lead role in study design, data collection, statistical analysis and first author on manuscript (80%)
- Dr Ben Rattray (primary supervisor): assisted with study design, data collection and manuscript revision (10%)
- Dr Christos Argus (supervisor): assisted with study design and manuscript revision (5%)
- Dr Matthew Driller (supervisor): assisted with study design and manuscript revision (2.5%)
- Dr Julie Cooke: assisted with data collection and manuscript revision (2.5%)

Study two: Physiological Responses to design adaptations in Firefighting PPC during simulated firefighting tasks.

- Mr Anthony Walker: lead role in study design, data collection, statistical analysis and first author on manuscript (80%)
- Dr Christos Argus (supervisor): assisted with study design, data collection and manuscript revision (10%)
- Dr Ben Rattray (primary supervisor): assisted with study design and manuscript revision (5%)
- Dr Matthew Driller (supervisor): assisted with study design and manuscript revision (5%)

Study three: Repeat work bouts increase thermal strain for Australian Firefighters working in the heat.

- Mr Anthony Walker: lead role in study design, data collection, statistical analysis and first author on manuscript (80%)
- Dr Ben Rattray (primary supervisor): assisted with study design, data collection and manuscript preparation (10%)
- Dr Christos Argus (supervisor): assisted with study design and manuscript preparation (5%)
- Dr Matthew Driller (supervisor): assisted with study design and manuscript preparation (5%)

Study four: Immune and inflammatory responses of Australian firefighters after repeated exposures to the heat

- Mr Anthony Walker: lead role in study design, data collection, statistical analysis and first author on manuscript (80%)
- Dr Ben Rattray (primary supervisor): assisted with study design and manuscript preparation (10%)
- Mr Toby Keene: assisted with data collection (2.5%)
- Mr Joshua Guy: assisted with haematology analysis (2.5%)
- Dr Christos Argus (supervisor): assisted with manuscript preparation (2.5%)
- Dr Matthew Driller (supervisor): assisted with manuscript preparation (2.5%)

Study five: Body composition affects immune responses of Australian firefighters in the heat.

- Mr Anthony Walker: lead role in study design, data collection, statistical analysis and first author on manuscript (80%)
- Dr Ben Rattray (primary supervisor): assisted with study design and manuscript preparation (10%)
- Mr Toby Keene: assisted with data collection and statistical analysis (2.5%)
- Ms Sara Zanetti: assisted with data collection (2.5%)
- Dr Christos Argus (supervisor): assisted with manuscript preparation (2.5%)
- Dr Matthew Driller (supervisor): assisted with manuscript preparation (2.5%)

Study six: Cold water immersion and iced slush ingestion are effective at cooling firefighters following a simulated search and rescue task in a hot environment.

- Mr Anthony Walker: lead role in study design, data collection, statistical analysis and first author on manuscript (80%)
- Dr Ben Rattray (primary supervisor): assisted with study design, data collection and manuscript preparation (10%)
- Dr Matthew Driller (supervisor): assisted with data collection and manuscript preparation (5%)
- Dr Matt Brearley: assisted with manuscript preparation (2.5%)
- Dr Christos Argus (supervisor): assisted with manuscript preparation (2.5%)