**Abstract**

*Objectives:* The aim of this study was to assess current perceptions of heat stress, fatigue and recovery practices during active duty in Australian firefighters.

*Design:* Prospective survey

*Methods:* 473 firefighters from Fire and Rescue New South Wales completed a two-part, 16-item survey. Questions included perceptions of the operational activities and body areas associated with the most heat stress, the most mentally and physically demanding activities, and levels of fatigue felt. Further questions focussed on the use and importance of recovery practices, effectiveness of currently used heat-mitigation strategies and additional cooling strategies for future use.

*Results:* Around a third of firefighters (62%) reported structural fire-fighting as the hottest operational activities experienced, followed by bushfire-fighting (51%) and rescue operations (38%). The top three responses for which body-parts get the hottest ranked as 'the head' (58%), 'the whole body' (54%) and 'the upper back' (40%), respectively. The majority of firefighters (~90%) stated they always or sometimes use the opportunity to recover at an incident, with the top three being 'sit in the shade' (93%), 'cold water ingestion (drinking)' (90%) and 'removing your helmet, flash hood and jacket' (89%). Firefighters reported higher usefulness for more easily deployed strategies compared to more advanced strategies. Limited age and gender differences were found, although location of active service differences were present.

*Conclusion:* These findings may inform future research, and translation to operational directives for recovery interventions; including exploration of protective gear and clothing, education, resources and provision of cooling methods, as well as recovery aid development.

## Introduction

Australian firefighters are exposed to numerous situations which can compromise their safety and health. For instance, during structural fire-fighting, they are required to perform critical physical tasks (e.g. stair climb, personnel rescue) in extreme heat whilst wearing heavily insulated and semi-permeable personal protective clothing[1]. Furthermore, career, on-call and volunteer firefighters must perform extensive suppression techniques to safeguard communities in hot and potentially catastrophic conditions, such as bushfires[2] that are reportedly increasing in frequency and intensity[3]. These prolonged and repetitive tasks in the heat typically elicit acute physiological and psychological fatigue, in turn compromising work performance, and increasing the risk of injury[4] and workplace accidents[5]. Of further concern, it's estimated ~75% of firefighters experience heat-related illness symptoms (headache, sudden muscle cramps, dizziness, nausea, vomiting, and fainting)[6]. Despite these risks, there is currently limited understanding of how firefighters perceive the challenging tasks they perform, the conditions they face, or the fatigue and recovery required to optimise performance and health during active duty.

Understanding the task demands and fatigue induced during fire-fighting duties can guide the development of both operational and policy directives to aid fire-fighters, though current knowledge in the Australian context is limited. Australia is typified by hot, dry and remote geographical areas with a variable and arid climate[3], and fire fighting under these conditions can increase thermal strain and the risk of heat illness[7]. Indeed, the number of heatwaves in major Australian cities has increased since 1950[8], and can exacerbate the risk of heat illness[7], in turn indirectly increasing risk of cardiovascular failure (e.g. sudden cardiac death accounts for almost half of all firefighter duty-related fatalities[9]). Separately, sustained physical work in the heat results in poorer cognitive functioning and decision making[10], although research in firefighters is limited. Despite these potentially life-threatening exposures, there is little known about the unique environmental and logistical challenges (e.g. increasing environmental threats such as bushfires, extensive shift work) faced by Australian firefighters. As an example, around ~60% of British firefighter instructors reported that specific training courses (compartment fire behaviour training with live fire scenarios) as the most physically straining task; which in turn guides policy and practice of safety limits for breathing apparatus use[11]. However, Australian firefighters are faced with a multitude of different conditions, terrains and duties compared to their European or American counterparts, which present such a unique set of demands[12]. Thus, focussed investigation into the demands of Australian firefighters in hot environments and the way they perceive fatigue is warranted.

Characterising the experiences of Australian firefighters is also essential to aid local fire agencies to optimise the design of recovery strategies to improve performance and reduce risk of workplace heat strain. For instance, one of the various operational procedures to optimise safety for firefighters in hot events is the implementation of cooling recovery or regeneration techniques, especially when repetitive bouts of fire-fighting activity are required. As an example, current guidelines in New South Wales, Australia (NSW) instruct that after the depletion of one to two breathing apparatus cylinders or 20-40 minutes of intense work, firefighters should rest and rehydrate, however these recommendations are due for review[13]. Previous research on cooling strategies to relieve heat strain have indicated that forearm/wrist cooling[14, 15], ice slushy ingestion[16] and cold water immersion[16] show small to moderate effectiveness in reducing core temperature and recovery of other physiological parameters from simulated fire-fighting activities (although data on physical and cognitive performance is limited). This evidence, and others[17], has led to various recommendations on best practice for cooling in these populations (e.g. immerse forearms and hands in water for 10-20 min[13]). Nonetheless, a survey by Bach[18] on first responders in the United States reported that 25% of all departments surveyed provided no cooling at all. To the authors' knowledge it remains unknown whether these outcomes reflect the perspective and operations of Australian firefighters or the heat management practice for its workers. Indeed, including perceptions of the end user are critical to effective implementation of occupational evidence-based practice outcomes such as usability, efficacy and uptake[19].

Therefore, the aim of this study was to gather current perceptions of heat stress, fatigue and recovery practices in Australian firefighters. To undertake this, a two-part survey was developed in conjunction with a state fire-fighting service which firstly investigated the demands of their firefighters in hot environments and their perceived fatigue, and secondly assessed their current habits, value and feasibility of recovery-cooling methods in the field across age, gender and location.

**Methods**

473 firefighters (mean±SD; 46 ± 11 years old, 417 M, 51 F, 5 other; 16.7 ± 10.6 years of service) from a NSW state fire-fighting agency (Fire and Rescue NSW (FRNSW)) fully completed a 16-item survey which was split into two-parts: 1) the characteristics of heat stress, including the perceived physical and cognitive demands and fatigue of firefighter in hot environments and 2) current practices, value and feasibility of recovery-cooling methods for firefighters in the field. Participants came from a range of different locations of active service (51%; career metropolitan, 25% on-call regional, 12% career regional, 8% on-call metropolitan and 4% operational support personnel) and firefighter ranks (25% senior firefighter, 20% station officers, 17% on-call deputy captain/captain, 8% qualified firefighter, 8% on-call <5 y service, 4% on-call firefighter 5-10 years' service, 4% leading firefighter, 4% on-call >15yrs service, 2% lead station officer, 2% on-call 10-15yrs service, 2% career firefighter not qualified, 2% inspector, <1%superintendent and chief superintendent).

The survey was co-designed by the research team and FRNSW to ascertain perceptions of the workforce on physical and cognitive demands faced during in extreme environments and how best to recover from these tasks performed. Initially, 25 questions were drafted by a panel including members of both the research team and FRNSW, before being refined and agreed upon at three subsequent meetings. This included a draft survey being piloted internally with members of the agency on the panel who were firefighters (*n*=5). Once finalised, the survey was distributed by FRNSW to active firefighter crews via email with an online link to the survey (RedCap). Via this online link, firefighters were provided information pertaining to the study and chose to provide consent to partake in the survey (or not). Data were stored on a secure webserver with a password protected database, accessible only by the researchers to protect participants' data identity. The survey was open for approximately eight weeks to maximise participation and was completed once only (full survey Appendix 1). All procedures were approved by the institutional Human Research Ethics Committee (ETH20-4578).

*Survey Part 1: Characteristics of heat stress, physical and cognitive demands and fatigue*

To understand operational demands, firefighters were first asked to list operational activities in their role that were associated with heat stress. This included identifying regions of the body that felt the hottest during operational duties (head, neck, upper back, arms and hands, lower back, upper leg, lower leg and feet and whole body). Firefighters were then asked to list the mentally demanding activities occurring within their role (i.e. those requiring a high degree of concentration and coordination) before ranking how mentally and physically fatigued they felt after average and very strenuous operational duties on a 1-10 Likert scale (0 = not fatigued at all, 10 = maximum fatigue).

*Survey Part 2: Current recovery practices*

In the second part of the survey, firefighters responded whether (given the opportunity) they engaged in recovery strategies following an incident (never, rarely, sometimes, and always). They were then asked which methods they currently used whilst on duty from nineteen available options from the participating agency Safe Operating Procedures[13]. Further, they rated how helpful certain cooling strategies were on a Likert scale 1-10 (0 = not helpful at all, 10 = extremely helpful). Appreciating the unpredictability of heat and hazardous situations, firefighters provided their best estimate of how long (in minutes) they felt they needed to recover/undertake recovery procedures/rest to fully recover after an incident (physically and mentally). Finally, firefighters were given the chance to express open answer responses on other cooling strategies that they might have personal experience with, and whether there were any additional cooling strategies or recovery aids the agency should consider for use.

Once collated, data were exported to Python 3.7 (Spyder version 4.0.1) and frequency counts, percentages, means and SD were calculated for closed response questions. In addition, gender, age and location groups were compared. Gender was split into male (417) and female (51) samples (five of the respondents did not identify as either). For age, respondents were binned into groups (<30 y, 30-39, 40-49, 50-59 and ≥60), whilst locations were classified according to their organisational location (Permanent Metropolitan, Permanent Regional, Retained Regionals, Retained Metropolitan and Operational Support Personnel). To conduct comparisons, a Mann Whitney U test (for gender) and

Kruskal-Wallis H-test one-way analysis of variance (for age and location) were used to determine whether significant differences were apparent between group responses to questions related to: mental and physical fatigue and heat, use and frequency of recovery, recovery methods utilised and helpfulness of methods. If differences were present, a post-hoc pairwise test for multiple comparisons of mean rank sums was used to confirm significance (Conover Imans test). Significance was accepted at $p<0.05$. Answers to open-ended questions were organized and subjected to inductive content analysis[20] per previous research[21, 22]. General dimensions were established and used to calculate percentages of responses in accordance with open-answer themes in Part 1. In Part 2, second order themes were established and then independently validated. All responses underwent peer debriefing to ensure a valid representation of the data had been obtained.

## Results

*Survey Part 1: Characteristics of heat stress, physical and cognitive demands and fatigue*

62% of firefighters reported structural fire-fighting as the *hottest operational activity* experienced by firefighter's, followed by bushfire-fighting (51%) and rescue operations (38%). Although not activities *per se*, 38% of respondents reported the fire-fighting uniform and protective clothing as a primary contributor to heat retention and 35% reported external heat sources to be a major contributor (e.g. fire, ambient temperature, sun-exposure in Australian summer) within the open-answer section. In turn, firefighter's outlined the top three responses for which body-parts get the hottest as 'the head' (58%), 'the whole body' (54%) and 'the upper back' (40%), respectively. In general, firefighters reported feeling physically and mentally fatigued from active duty (0 = not fatigued at all and 10 = maximum fatigued; 4.2 ± 2.4 mental fatigue and 4.9 ± 2.4 physical fatigue under average conditions, and 6.7 ± 2.2 mental fatigue and 7.6 ± 1.8 physical fatigue after strenuous duties). The most *mentally challenging tasks* were reported as 'rescue' (46% of respondents), followed by 'structural fire-fighting' (18%), 'bushfire-fighting' (11%) and 'hazmat incidents' and 'training drills' (both 8%). No significant between-group differences were apparent for any heat stress, physical and cognitive demands and fatigue responses for age or gender (all $p>0.05$). For location, significant differences were present in very strenuous conditions, where Permanent Metropolitans (7.7 ± 1.8) and Permanent Regionals (8.1 ± 1.3) reported higher physical fatigue than Retained Regionals (7.1 ± 1.6, both $p<0.01$). In addition, Permanent Metropolitans reported the whole-body to get significantly hotter compared to Retained Regionals ($p<0.01$).

*Survey Part 2: Current recovery practices*

Just over half of firefighter respondents (55%) stated they always use the opportunity to recover at an incident when available (34% stated sometimes, 9% rarely and 2% never). The *most commonly used* recovery practices are presented in Figure 1, with the top three being 'sit in the shade' (93% of respondents), 'cold water ingestion (drinking)' (90%) and 'removing your helmet, flash hood and jacket' (89%). No significant between-group differences were present for age or gender for use of recovery methods (all $p>0.05$). Compared to Permanent Regionals, more Permanent Metropolitans reported that they attended the rehabilitation area (75% ± 43 vs 51 ± 50; $p = 0.001$) and used cold towels (73% ± 26 vs 20 ± 40; $p = 0.01$). Operational Support Personnel reported to attend the rehabilitation area more than Permanent Regionals (90% ± 32 vs 51 ± 50; $p = 0.03$).

The recovery practices *deemed most helpful* (0 not helpful - 10 extremely helpful) are presented in Figure 2, with the top three most helpful strategies being 'removing your helmet, flash hood jacket, pants and boots' (8.1 ± 2.0), 'removing your helmet, flash hood and jacket' (7.7 ± 1.9) and 'cold water ingestion (drinking)' (7.5 ± 2.0), whilst Figure 3 depicts the comparisons between men and women, where women identified 'removing your helmet, flash hood and jacket' ($p = 0.03$) and 'cold water ingestion (drinking; $p<0.01$)' as significantly more helpful than men (Figure 3). Retained Regionals found sitting in the shade more helpful (7.4 ± 1.9) compared to Permanent Metropolitans (6.8 ± 2.0; $p = 0.03$) and Retained Metropolitan (6.5 ± 2.0; $p = 0.01$).

*** Insert figure one here ***

*** Insert figure two here ***

*** Insert figure three here ***

Firefighters self-reported needing 22 ± 13 minutes to fully recover (mentally and physically) from a bout of operational duties, with FF's aged <30 years tended to take less time to recover (16 ± 10 min) than FF aged 40-49 years (23 ± 14 min; $p = 0.046$). Finally, firefighters reported in open answer response format four primary themes for cooling strategies to be considered in future, including: 'improved gear and clothing', 'cooling ingestion', 'cooling exposure' and 'technical recovery aids' (Table 1).

*** Insert table one here ***

## Discussion

This study provides novel insight on the perceptions of heat stress, fatigue and recovery practices during active duty by Australian firefighters. The main findings were that firefighters consider structural fire-fighting as the hottest situations they face, followed by bushfire-fighting and rescue operations. When performing these activities, their fire-fighting uniform and protective clothing as well as external heat sources (e.g., solar radiation, fire) were the main contributors to heat stress. These sources of heat stress were perceived to most affect the head, whole body and the upper back regions. In the second part of our survey, the majority of firefighters reported using the opportunity to recover between operational duties at an incident. However, the most commonly used recovery strategies were passive in nature including sitting in the shade, drinking cold water and removing their helmet, flash hood and jacket; with limited active cooling exposures used. Limited age and gender differences were found, although perceptions for both heat stress and recovery practices differed according to certain locations of active service. Based on these insights, future operational interventions should consider improved protective clothing that minimises heat stress while maintaining appropriate protection. Furthermore, resources surrounding cooling methods and further recovery aid development, deployment and education should be considered.

### *Characteristics of heat stress, physical and cognitive demands and fatigue*

More than half of firefighters reported structural fire fighting and bushfire-fighting as the operational activities associated with the greatest heat stress. This is unsurprising given the air (upwards of 750 $^{o}$C) and helmet temperatures (190 $^{o}$C) experienced during fire suppression activities in residential structural fires[23]. In addition, maximum flame temperatures during bushfire scenarios can reach 300-1100 $^{o}$C[24]. Within these extreme environments, physically demanding tasks are performed which result in high rates of metabolic heat production[25]. These physical loads in such environmental conditions remain an ongoing operational concern given the risk of heat illness or injury[23]. For instance, more than two-thirds of fire department and HAZMAT operators reported heat stress/injury during recent work activities in the United States, along with commonly reported severe cases of heat illness and injury (i.e. medical attention, hospitalisation or death)[18]. As well as the conditions faced, firefighters in our study reported exacerbation of heat-induced fatigue from the personal protective clothing, likely because this clothing encapsulates the wearer, creating a hot-humid microclimate between the skin and clothing that impairs heat loss and augments thermal strain[26]. Such clothing can also increase metabolic heat production by restricting movement efficiency and increased carriage weight, and thus further contribute to continued rise in skin and core temperatures[27, 28]. The irony of this balancing act is well known, given personal protective clothing (PPC) provides a necessary physical barrier to mitigate the threats of the external environment, and yet may contribute to endogenous thermal load. Hence, continually seeking to optimise the design of PPC (balancing protection with heat stress mitigation) remains of high importance for firefighters[29], agencies[30] and industries alike (e.g. military[31]).

A first point of call for relieving heat stress would be to further understand firefighter perceptions of where they feel heat stress is most felt. When asked about which body-parts get the hottest during operational scenarios, firefighters ranked the head and upper back regions as primary areas of concern. These results were somewhat expected since these areas are likely closest and most directly facing external heat sources (i.e., solar radiation), incur additional load carriage (i.e. breathing apparatus) and will increase skin temperature more than other regions[32], likely leading to the perceived heat stress of that area. In addition, the head/face and upper back/neck are also thermally sensitive areas compared to other regions of the body and may be most noticed in such conditions[33]. It is also possible that these body areas are associated with issues surrounding mobility and discomfort of the protective gear itself, again highlighting the effect of PPC on firefighting functionality[29, 34]. Hence, instigating removal of clothing, and rest/recovery methods directed at these body areas where possible would appear a high priority to promote operational capacity and optimise safety[25].

The roll out of these recovery methods would likely be location dependant, where an understanding of resource allocation and differences between groups is pertinent. In our study, significant differences were present in very strenuous conditions, where permanent firefighters reported higher physical fatigue than retained. It is possible that permanent crews are subject to a continual exposure to physical demands in their role, especially in metropolitan areas where call out rates, and subsequent exposure, are higher compared to retained regional areas where staff work on an on-call basis. Alternatively, these results may simply represent the array of different environmental conditions these areas are exposed to (e.g. metropolitan – more structural incidents; regional – increased bushfire risk). In addition, those in permanent metropolitan groups reported the whole body to get significantly hotter compared to perceptions of retained regionals. This result may appear somewhat surprising given environmental temperatures are higher in regional areas[35], although this may concomitantly enhance thermal comfort and tolerance by eliciting greater thermoregulatory adaptation[36]. Another possibility is that there may be greater and/or more frequent periods of high metabolic heat generation in metropolitan areas due to the requirement to ascend stairs and/or haul equipment inside larger structures as aforementioned (e.g., high-rise apartments). Nonetheless, given the nuances that exist between locations and type of fire-fighting groups, it would appear prudent for Australian fire-fighting agencies to align specific standards/procedures for heat stress recovery for fire fighters which suit their personnel's' circumstances.

*Current recovery practices*

Most respondents in our study (~90%) stated they make use of recovery time following fire fighting in the heat if provided the opportunity. These results concur with previous research in the United States which found 91% of fire agency respondents utilised at least one form of cooling recovery strategy[18]. Of those who used the opportunity to recover post-incident in our study, the primary strategies included sitting in the shade, drinking cold water and removing their protective gear (helmet, flash hood, and jacket). Indeed, these strategies appear focussed on alleviating the aforementioned areas of heat stress (head and upper back), by virtue of rather "passive" and simple methods likely to be commonly available to fire agency employees (Figure 2) as based on operational recommendations. Whilst it is positive that firefighters appear aware of the importance of post-incident recovery, it is concerning that these strategies may be less than optimal for reducing core and body temperature based on the existing literature[16, 17]. For example, a review by Brearley and Walker[11] indicates overall evidence shows forearm immersion cooling rates as unacceptably slow for core body temperature (~0.01 to 0.05 °C $min^{-1}$).

Notwithstanding, outside of core temperature further research is required to ascertain the effects of these strategies on physiological and cognitive outcomes to enhance operational performance.

Given the predicted increased prevalence of bushfires in Australia[35] and potential resultant increased risk to operational safety, it is pertinent to identify more effective, yet practical cooling strategies to recovery from physical and mentally demanding tasks in the heat. Specifically, firefighters in our study expressed a desire for improved access to cooling ingestion (e.g. ice slushies) and exposure (e.g. ice packs), as well as further recovery aids (e.g. immersion cooling, fans; see Table 1). These results are supported by respondents' low use of these strategies, likely due to a lack of resourcing or availability to disperse these strategies state-wide (e.g. no fridges/ice machines on trucks). There is some evidence to indicate the efficacy of these suggested strategies (forearm/wrist cooling[14, 15], ice slushy ingestion[16] and cold water immersion[16]) in reducing core temperature, although results vary across environmental conditions, task exposure and experimental designs[17].

Interestingly, there is little known about how these advanced cooling strategies might impact firefighter physical or cognitive function, which in turn could impact performance and safety in repeated bouts of firefighter activity. There were calls for increased recovery resources from the open answer section in our study (Appendix 1), despite some reports of limitations in use. Such perceptions may relate to a lack of access to resources, awareness of their efficacy or limited stakeholder education[37]. Ideally, future research should target the identified strategies under various combinations and timings of duty, representing the needs of stakeholders and focusing education surrounding potential strategies for end users[18]. For instance, whilst cold water immersion may offer advanced cooling rates compared to other modalities (0.35 °C $min^{-1}$)[11], this strategy may incur several logistical constraints for continual use in the field. As another example, firefighters in our study self-reported needing ~22 minutes to fully recover (mentally and physically) from a bout of operational duties, with FFs aged <30 y tending to take less time to recover than those aged 40-49 y. Thus, agencies may need to consider worker age when determining future research or the implementation/timing of these strategies from a work:rest ratio perspective. It is recommended that FRNSW use these collective results to formulate evidence-based strategies for cooling specific to their employees and equipment resourcing.

Whilst no significant differences were apparent for any heat stress, physical and cognitive demands and fatigue responses for age or gender, women identified ‘removing your helmet, flash hood and jacket’ and ‘cold water ingestion’ as significantly more helpful than men. Although sex dependence of human thermoregulation encompassing mass-supported exercise is debated, it has previously been shown that sex differences in thermoeffector function are morphologically dependent, rather than sex dependent[38]. Finally, while we observed no significant gender-differences for any heat stress, physical and cognitive demands and fatigue responses, women identified ‘removing your helmet, flash hood and jacket’ and ‘cold water ingestion’ as significantly more helpful than men. Collectively, this indicates there is a potential for gender differences in the strategies deemed effective for coping with heat stress on duty. However, given the relatively small number of female respondents (~11%), we were unable to fully explore this possibility while considering the various secondary factors (e.g., aerobic fitness, body morphology) that impact the physiological response to occupational heat stress[39]. This represents an important area of further study, particularly given the growing number of female firefighters[40].

Indeed, while this study is the first to examine the perceptions of heat stress, fatigue and current recovery practices in Australian firefighters, it is not without limitations. There is a possibility of participant self-selection bias, as well as cross over regarding firefighter roles and ranks which could impact their perceptions; however, it was deemed a higher priority to garner a representation of the workforce as a whole. Further, these survey data are limited to a snapshot of current attitudes and behaviours at a moment in time, and could be influenced by numerous factors (e.g. recent experiences, workplace culture). For instance, although our results may help guide understanding of firefighter views on heat stress and recovery, they are limited to FRNSW. Australia is serviced by numerous agencies, where environmental conditions and job requirements can vary and may have nuances which impact their experiences.

## Conclusions

This is the first study to gather perceptions of heat stress, fatigue and current recovery practices in Australian firefighters. Firefighters reported structural fire-fighting as the hottest situations they face, followed by bushfire-fighting and rescue operations whilst they considered their fire-fighting uniform and protective clothing, and external heat sources to be the main contributors to heat stress. Most firefighters report the use of passive recovery strategies between operational duties at an incident, using methods such as sitting in the shade, drinking cold water and removing their helmet, flash hood and jacket, though more active cooling methods have limited use. Our findings could be used to guide future policy and operational interventions, which could consider improvements in protective gear and clothing and education and resource provision for cooling and recovery aid development.

## Practical Applications

- The most thermally stressful fire-fighting tasks reported here can inform further research into safe work practices and potentially identify heat mitigation strategies for these tasks.
- Relatedly, observations from this study provide the body regions that were perceived to be most affected by these sources of heat stress. This information may have important implications for clothing design and targeted cooling strategies to better protect these areas, whilst maximising comfort and performance.
- While the firefighters in our study appear to be aware of cooling interventions that are perhaps more effective for recovery, they are drawn to those that are more practical and easy to deploy when on the job (i.e., removal of clothing). Such information may help to design education around cooling interventions, as well as availability for these tools to be optimised on trucks or recovery vans/pods.

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**Figure 1.** Commonly used recovery practices by firefighters

**Figure 2.** The perceived usefullness of recovery practices for firefighters

**Figure 3**. The perceived usefullness of recovery practices across genders for firefighters

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