Repeat work bouts increase thermal strain for Australian firefighters working in the heat

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Background: Firefighters regularly re-enter fire scenes during long duration emergency events with limited rest between work bouts. It is unclear whether this practice is impacting on the safety of firefighters.

Objectives: To evaluate the effects of multiple work bouts on firefighter physiology, strength, and cognitive performance when working in the heat.

Methods: Seventy-seven urban firefighters completed two 20-minute simulated search and rescue tasks in a heat chamber ($105 \pm 5^\circ\text{C}$), separated by a 10-minute passive recovery. Core and skin temperature, rate of perceived exertion (RPE), thermal sensation (TS), grip strength, and cognitive changes between simulations were evaluated.

Results: Significant increases in core temperature and perceptual responses along with declines in strength were observed following the second simulation. No differences for other measures were observed.

Conclusions: A significant increase in thermal strain was observed when firefighters re-entered a hot working environment. We recommend that longer recovery periods or active cooling methods be employed prior to re-entry.

Keywords: Core temperature, Physiology, Recovery, Heat stress, Perception of effort, Firefighter safety

Introduction

When working to suppress structure fires, modern firefighters are exposed to extreme ambient temperatures and high levels of radiant heat flux^{1,2} leading to increased core temperatures^{3,4} and fatigue.⁵ To protect firefighters from the external environment and increase working time, they wear heavy impermeable protective clothing (PPC) and self-contained breathing apparatus (SCBA), which reduces the ability of operators to dissipate metabolic heat production⁶ and in turn, contributes to a greater risk of heat illness.⁷ Added to this strain, Australian urban firefighters are often tasked with re-entering a fire scene with minimal recovery time using only passive cooling methods, a situational condition not well reported in the literature.

Exacerbating the heat load from the operating environment, PPC creates an uncompensable environment, which slows core temperature regulation by disturbing the evaporation of sweat and decreasing the temperature gradient from core to skin.⁷ Due to a

requirement for firefighters to remain ready for emergency response during rest periods, it is likely that some level of PPC will remain donned during recovery, which will slow the natural cooling process provided by the sweat mechanism and thereby reduce rates of cooling. Any reduction in the ability of firefighters to cool during rest periods will likely impact on their ability to safely and effectively complete work tasks when re-entering fire scenes.⁸ However, testing using real world conditions and operational tempo is currently lacking.

Standards for firefighting operations in the United States of America, outlined by the National Fire Protection Association (NFPA), form the basis of fire ground recovery practices⁹ in that jurisdiction. Standard 1584 (NFPA, 2008) requires that a formal recovery sector be established following a second SCBA cylinder during fire suppression activities, as it is likely that core temperatures would exceed safe working limits of between 38.0°C and 38.5°C ¹⁰ at this point. However, no common policy for recovery has been established in Australian urban fire services, which may be resulting in firefighters re-entering hot environments with core temperatures in excess of safe working limits. Further, standardized cooling protocols are lacking across Australian fire services with

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many jurisdictions using only passive cooling methods including partial PPC removal, rehydration, and shade. This type of recovery is generally informal and levels of PPC removal and rehydration are generally self-selected by firefighters.

High core temperatures are a critical factor for fatigue during physical activity in uncompensable environments^{11,12} and are prevalent in firefighters working in hot environments.^{5,13,47} In a study comparing skin and core temperatures during moderate exercise in high ambient heat (40°C), it was reported that core temperature values greater than 40°C were a driving factor for fatigue of trained athletes independent of skin temperatures.¹¹ However, other studies have indicated that high skin temperatures, rather than core temperatures, in euhydrated subjects impairs submaximal aerobic performance.^{14,15} The disparity in views requires further examination, particularly in an Australian firefighting context, to guide policies for recovery and re-entry during long duration emergency responses.

The physical and dynamic nature of emergency response requires that firefighters demonstrate appropriate levels of strength to safely complete tasks such as moving hose lines, raising ladders, and rescuing casualties.^{16,17} Consequently, any declines in strength likely affect the ability of firefighters to safely complete work tasks. Links between heat exposure and declines in strength have been observed in athletic populations,^{18,19} and it is therefore intuitive to expect that as firefighters work in the heat, strength may be impaired. However, it is currently unclear whether heat-related reductions in strength are occurring in trained firefighters and, as a result, whether safety and operational effectiveness are being affected during long duration events.

Firefighters are required to quickly evaluate and respond to changes in the emergency environment during operational tasks. Thus, it is critical to the safety of firefighters that situational awareness and cognitive function be maintained. Extended exposure to heat has previously been linked with cognitive impairment in military^{20,21} and athletic settings²² and has been attributed to dehydration and increased core temperatures.¹ However, testing in firefighting populations has been generally confined to simple reaction time tests only.²³ Given that the working environment for firefighters is inherently dynamic and subject to rapid changes, investigation of cognitive changes, based on complex tasks conducted following realistic operating conditions is necessary.

Despite formal recovery guidelines in place in other jurisdictions (NFPA, 2008), currently, no standardized approaches to recovery exist across Australian fire services. Additionally, the implications of using only passive cooling methods to facilitate

core temperature reductions along with minimizing possible strength and cognitive declines are currently not well understood. Therefore, the present study aimed to characterize the thermal strain experienced by urban firefighters during a simulated search and rescue task when they are tasked with re-entering a fire scene after a brief recovery period using passive recovery protocols. A secondary aim was to establish whether NFPA 1584 is appropriate for use in the Australian context.

Methods

Participants

Seventy-seven male Australian professional urban firefighters volunteered to participate in the present study. Subject demographics and morphometrics are shown in Table 1. All participants were operationally active at the time of testing and represented all active ranks of the fire service. Testing was conducted in early autumn, and participants were partially heat acclimated following a summer bushfire season. Informed written consent was obtained from all participants prior to undertaking testing based on protocols approved by the University of Canberra Human Ethics Research Committee.

Participants undertook physical fitness profiling within a 2-week period prior to undertaking a simulated search and rescue task. Aerobic capacity was estimated using the Yo-Yo Intermittent Recovery Test Level 1 (YYRT1)²⁴ with participants dressed in athletic attire, and running on a flat bitumen surface. Body composition including body fat was measured using dual energy X-ray analysis (DEXA). Body mass index (BMI) was calculated²⁵ with height measured to the nearest 0.1 cm using a wall mounted stadiometer (Seca 222, Hamburg, Germany) and weight to the nearest 0.1 kg with electronic scales (Seca, Hamburg, Germany).

Simulated search and rescue task

Participants wore a full structural fire fighting PPC ensemble comprising boots (Haix Special Firefighter®, Haix, Lexington, KY, USA), wool socks, Nomex® pants (Stewart and Heaton, Padstow, NSW, Australia), over-pants and tunic (Stewart and Heaton, Padstow, NSW, Australia), cotton T-shirt, Nomex® flash hood

Table 1 Demographics and morphometrics of participants (n=77)

Age (years)	38.9 ± 9.0
Height (cm)	180.0 ± 10.0
Mass (kg)	84.3 ± 9.3
BMI (kg m ²)	25.8 ± 2.2
Estimated aerobic capacity (ml kg ⁻¹ min ⁻¹)	48.7 ± 6.0
Body fat (%)	20.1 ± 6.5

BMI: body mass index.

(Life liners Inc., Morristown, NJ, USA), structural fire fighting gloves (ESKA, Thalheim, Austria), and helmet (Pacific Helmets, Wanganui, New Zealand). Participants wore an open-circuit Scott Safety Contour 300 SCBA weighing 9.6 kg (Scott Safety Australia, Sydney, NSW, Australia). The combined weight of PPC and SCBA was ~ 22.0 kg.

Participants completed a simulated search and rescue task consisting of two 20-minute simulations in a purpose built heat chamber set at $105 \pm 5^\circ\text{C}$, separated by a 10-minute intermediate seated rest period ($19.3 \pm 2.7^\circ\text{C}$). During the simulations, participants were required to negotiate a multi-room facility (Fig. 1) containing a range of furniture configurations

that would likely be encountered at a typical house fire. Searching was conducted in darkness and smoke and required firefighters to locate a cache of plastic drums containing firefighting foam (20 kg) and return them individually to the starting location. Participants exited the chamber briefly to undertake core temperature and perceptual data measurement at each 5-minute interval after an initial 10-minute search. Timing clocks were stopped when participants were outside the chamber (< 20 seconds). Other variables including HR and skin temperatures were recorded and accessed via computer at the conclusion of testing. Participants were instructed to conduct their search using pre-established techniques that

Figure 1 Internal floor plan of heated cell. The cache of drums was located at the top right of the building and entry and exit occurred via the door in the top left. All internal doors were closed during the simulated search and rescue task, and searching was conducted in smoke and darkness

involved periods of crawling and climbing. Working in pairs, both members retrieved drums after completing a search pattern down either the left or right wall. The search pattern was alternated after the first 20-minute period.

During the intermediate rest period, participants removed their SCBA, jacket, gloves, and helmet, changed their SCBA cylinders, and consumed 600 ml of water (ambient temperature). Due to safety requirements requiring participants to wear SCBA in the high heat environment, they had no access to water during the simulations.

Core temperature monitoring

Core temperatures were measured using an ingestible thermometer and radio receiver (HQ Inc., FL, USA) swallowed at least 6 hours prior to testing to minimize the confounding influence of food or fluid on the pill.⁶ Ingestible thermometers are considered a valid tool for the measurement of core temperature with differences $<0.1^{\circ}\text{C}$ when compared with rectal temperatures^{26,27} and are a recommended method of temperature measurement for ambulatory, field-based measurements.²⁸ To control the effect of localized cooling from fluid ingestion, core temperature data were excluded from analysis when baseline temperatures were $\leq 35.5^{\circ}\text{C}$ or decreased by 2°C in any 5-minute period during testing.^{5,29} However, participants completed the simulated simulations with all other testing variables reported. Baseline core temperatures were measured with participants wearing PPC and SCBA, directly prior to entering the heat chamber for the first simulated search and rescue task.

Mean skin temperature (MST)

Skin temperatures were measured using Thermocron iButtons (Maxim Integrated products, Inc., Sunnyvale, CA, USA) based on protocols previously validated.³⁰ Sensors were secured with rigid strapping tape on the right side of the body at the following points; chest (T_C), placed on pectoralis major, forearm (T_A) placed on brachioradialis, thigh (T_T) placed at the midline of quadriceps femoris, and calf (T_L) placed at the midline of the gastrocnemius at the level of the largest circumference. Overall mean skin temperature (MST) was calculated by $(\text{MST}) = 0.3 * T_C + 0.3 * T_A + 0.2 * T_T + 0.2 * T_L$.³¹

Heart rate monitoring

Heart rate was continuously monitored during the simulated firefighting task with each participant wearing a Suunto Memory Belt and measured in beats per minute (bpm) (Suunto, Vantaa, Finland).

Perceptual measurements

During testing, a surrogate measure of work – Borg's rate of perceived exertion (RPE),³² was measured

using a scale of 6 (very, very light) to 20 (very, very hard). Participants were asked, "how hard are you working?" and responded by pointing to a number on a chart presented. Further, thermal sensation (TS)³³ was measured using a scale of 0.0 (unbearably cold) to 8.0 (unbearably hot). Participants were asked, "how do you feel?" and responded by pointing to a number on a chart presented. A short familiarization session occurred prior to testing for all participants.

Cognitive testing

All participants completed baseline cognitive testing prior to entering the heat chamber and then immediately following the second simulation. Participants wore PPC during testing; however, they removed their helmet, gloves, and SCBA mask. Testing was completed on portable laptop computers (CogState Inc., CT, USA) and involved colored playing cards appearing on the screen. Three tests were performed in sequence as follows: (1) speed of processing (detection task) – measuring variations in psychomotor function. Participants were asked, "Has the card turned over?" Response times were measured in milliseconds with a lower score indicating better performance; (2) visual attention (Identification task) – measuring variations in vigilance. Participants were asked, "Is the card red?" Lower scores indicated better performance; (3) working memory (one-back task) – measuring variations in attention. Participants were asked, "Is the previous card the same?" Results were measured as the proportion correct with a higher score indicating better performance.³⁴ To minimize learning effects between the first and second trials, all participants were fully briefed and completed a familiarization session prior to testing, with an instructor giving assistance as required.³⁵

Grip strength testing

Grip strength was assessed with participants seated, with their shoulder adducted and neutrally rotated using a 200 lb. Baseline[®] hydraulic hand dynamometer (Fabrication Enterprises Inc., NY, USA). The elbow was flexed at 90° with the forearm in a neutral position and the wrist between 0° and 30° of dorsiflexion.^{36,37} The arm was unsupported during testing, and all participants were tested on the right hand only.

Change in body mass

Participants were weighed immediately prior to the first simulation and directly following the second wearing only underwear (Charder MS 3200, Charder Electronic Co. Ltd., Guozhong, Taiwan). Participants used a towel to wipe all sweat from their bodies prior to being weighed. Overall changes in body mass were calculated taking into account water ingestion and any urine output.

Air consumption

Air consumption during each simulation was calculated based on the following formula; Air consumption (l min^{-1}) = Δ pressure (bar) * Total volume of cylinder (6.8 l) * compression factor at altitude 600 m (0.911) divided by wearing time (minutes). Cylinder pressure was measured in bar using the pressure gauge attached to the SCBA immediately after donning and directly prior to doffing the facemask. The difference in readings was used to calculate air consumption during the simulation.

Data Analysis

Data analyses were performed in SPSS ver. 20 (SPSS Inc., Chicago, IL, USA). Results are presented as mean $\pm$ SD. A repeated measures analysis of variance (ANOVA) was conducted to determine differences in core temperature, skin temperature, heart rate response, and cognitive variables at all time points. Rate of perceived exertion and TS were analyzed using a Friedman's two-way ANOVA. *Post hoc* tests were conducted with a Bonferroni adjustment to determine individual differences with the alpha level set at $P \leq 0.05$. To maximize clarity for practitioners in occupational settings, 95% confidence intervals (CI) were reported. Effect sizes (Cohen's *d*) were calculated between simulations for core temperature, skin temperature, heart rate response, and cognition and reported as being "small" 0.20–0.49, "moderate" 0.50–0.79, and "large" ≥ 0.80 .³⁸

Results

Core temperatures

Mean baseline core temperature of participants was $37.5 \pm 0.4^\circ\text{C}$ and rose significantly ($P < 0.001$) to $38.0 \pm 1.3^\circ\text{C}$ at the conclusion of the first simulation and $38.9 \pm 0.7^\circ\text{C}$ at the conclusion of testing (Fig. 2). Temperatures at the conclusion of the seated intermediate rest period were $38.3 \pm 0.5^\circ\text{C}$. Further, a large increase in core temperatures was detected at the

conclusion of the second simulation relative to the first ($+0.8^\circ\text{C}$, 95% CI 0.525–1.135, $P < 0.001$, $d = 0.822$). Thirty participants demonstrated core temperatures in excess of 39.0°C , with two participants exceeding 40.0°C (40.2°C and 41.0°C).

Three participants voluntarily withdrew from testing citing fatigue and dizziness, with peak core temperatures of 38.4°C , 39.1°C , and 39.7°C . All three participants withdrew following the 15-minute measurement during the second simulation.

Mean skin temperature

Results showed significant differences in MST during the testing period ($P < 0.001$) (Fig. 2) with large differences at the conclusion of simulation 1 and simulation 2 compared with the intermediate rest period observed (Simulation 1: $+5.8^\circ\text{C}$, 95% CI 5.1–6.4, $P < 0.001$, $d = 4.93$; Simulation 2: $+5.9^\circ\text{C}$, 95% CI 5.3–6.5, $P < 0.001$, $d = 4.79$). However, no significant differences in MST were detected at the conclusion of simulation 2 compared with simulation 1 (-0.1°C , 95% CI -0.4 to 0.2 , $d = 0.158$).

Heart rate response

A significant increase in heart rate response was detected overall ($P < 0.001$) (Fig. 2). Relative to the first simulation, *post hoc* analysis showed a moderate increase in heart rates at the conclusion of the second 20-minute simulation ($+15.1$ bpm, 95% CI 11.9–18.4, $P < 0.001$, $d = 0.775$).

Perceptual results

Rate of perceived exertion

A significant increase in RPE was detected during the testing period ($P < 0.001$) (Fig. 3) with *post hoc* analysis also showing a significant increase at the conclusion of the second 20-minute simulation compared with the first ($P < 0.005$). A significant decrease in RPE was observed following the intermediate rest period.

Figure 2 Mean $\pm$ SD core temperatures (A), skin temperatures (B), and heart rates (C) of participants during two simulated search and rescue tasks separated by a 10-minute passive rest period. Data were collected at 5-minute intervals after an initial 10-minute search was conducted. * Represents significance at $P < 0.05$ and ** $P < 0.01$.

Figure 3 Thermal sensation (TS) (A) and rate of perceived exertion (RPE) (B) of participants during two simulated search and rescue tasks taken at 5-minute time points after an initial 10-minute search was conducted. A 10-minute passive recovery was undertaken between search and rescue tasks. * Represents significance at $P < 0.05$ and ** $P < 0.01$.

Figure 4 Results of cognitive testing including speed of processing (A), visual attention (B), and working memory (C). * Represents a significant difference ($P < 0.01$) between scores pre- to post-simulated search and rescue task. Thermal sensation

A significant increase in TS was detected during the testing period ($P < 0.005$) (Fig. 3) with *post hoc* analysis also showing a significant increase at the conclusion of the second 20-minute simulation relative to the first ($P < 0.005$). A significant decrease in TS was observed following the intermediate rest period.

Cognitive testing

Speed of processing

Relative to the baseline score, no significant differences were detected for speed of processing at the conclusion of the second simulated search and rescue task, with only a trivial effect size detected Figure 4A (+0.01 ms, 95% CI −0.02 to 0.023, $P = 0.112$, $d = 0.15$).

Visual attention

Relative to the baseline score, the simulated search and rescue task produced significantly improved scores and a small effect size for visual attention of participants Figure 4B (−0.022 ms 95% CI, −0.32 to −0.012, $P < 0.01$, $d = 0.39$).

Working memory

No significant differences were detected between the results of working memory testing at the conclusion of the second simulated search and rescue task compared with the baseline score Figure 4C (+0.013 95% CI −0.011 to 0.037, $P = 0.289$, $d = 0.10$).

Grip strength

Relative to the first simulation, a significant decrease in grip strength was detected at the conclusion of the second 20-minute simulation (−5.9 kg, 95% CI 4.6–7.2, $P < 0.0001$, $d = 0.015$).

Change in body mass

Mean body mass change for all participants was $-1.52 \pm 0.01\%$ during the total testing period. Twelve participants exceeded 2% body mass change during the testing period.

Rate of air consumption

A significant increase in the rate of air consumption during the second 20-minute simulation was detected

compared with the first simulation ($+3.41 \text{ min}^{-1}$, 95% CI 0.2–4.4, $P=0.029$, $d=0.015$).

Discussion

The present study demonstrates a significant increase in the thermal strain of firefighters when tasked with completing multiple work bouts during a simulated search and rescue task in the heat. This study was conducted using protocols closely reflecting actual operating conditions and timing for an Australian fire service making our results unique in the literature, with previously published results based on studies completed in hot laboratories, or with participants not wearing PPC.^{8,39} Significant increases in core and skin temperatures, heart rate, and perceptual responses, along with a significant decrease in grip strength were observed across the duration of testing and also at the conclusion of a second simulation relative to the first. Further, this study indicates that, using only passive recovery methods during rest periods, firefighters likely re-enter fire scenes with core temperatures exceeding the recommended safe limits of between 38.0°C and 38.5°C.¹⁰

Core temperatures of participants rose rapidly during the first 20-minute simulated search and rescue task and, interestingly, continued to rise during the intermediate rest period prior to re-entering the hot environment for a second time (Fig. 2A). Temperatures continued to increase significantly during the second work simulation with mean temperatures of $38.9 \pm 0.7^\circ\text{C}$ recorded at the conclusion, a value approaching the limit of occupational safety.¹⁰ Thus, it appears that when using only passive cooling methods, rest and hydration alone was ineffective in ameliorating core temperature increases resulting from the initial exposure to the hot environment. The findings of the present study are likely replicated in real-world settings, and it appears that safety of firefighters may be compromised when re-entering fire scenes using only passive recovery methods between work bouts.

Research in military and firefighting settings has demonstrated the value of active cooling methodologies in delivering superior cooling rates compared with passive methods alone.^{5,40,41} Using active cooling methodologies, specifically cold-water immersion (CWI),⁴² it has been shown that core temperature rises can be attenuated through immediate cooling. Cold-water immersion also provides a precooling effect for subsequent work bouts.²⁹ Thus, active cooling methods may be effective in ameliorating the rising core temperatures in firefighters and thereby mitigate the risk of exertional heat stress⁴³ during emergency responses. Further, active cooling methods have been shown to partly ameliorate heat-related declines in strength⁵ and will likely improve the operational safety and effectiveness of firefighters when tasked with re-entering fire scenes.

NFPA 1584⁹ currently recommends that formal recovery sectors be instigated at the conclusion of a second SCBA cylinder. Results of the present study indicate that this recommendation is appropriate in the Australian context following repeat work bouts in the heat with mean core temperatures approaching 39.0°C following a second SCBA cylinder. Further, 30 participants exceeded this value at the conclusion of the testing period. Operational decisions at emergency incidents are integrally linked to the number of available firefighters and appliances. Therefore, to allow for shorter work intervals and increased rest periods, it would be prudent to increase the number of firefighters deployed to emergency incidents, particularly in the initial stages where workloads are likely to be high. Precooling of firefighters when they are in standby positions may also assist in mitigating likely core temperature increases²⁹ and should be investigated.

Despite an ongoing increase in core temperatures, removing PPC led to significant declines in skin temperature, RPE, and TS during the intermediate rest period (Fig. 2B/C and Fig. 3A/B). Thus, it appears that perceptions of well-being are closely related to skin rather than core temperatures. The apparent disconnect between perceptions of well-being and core temperature may highlight significant issues in the ongoing safety of firefighters with incident controllers generally relying on individual perceptions of well-being prior to their re-entry to fire scenes. The present study indicates that relying on individual sense of well-being to dictate re-entry to fire scenes, likely fails to account for the ongoing core temperature rises occurring when passive cooling alone is employed and, as a result better monitoring systems should be explored.

Changes in core temperature, perceptual data, cognition, and strength occurred despite relatively small changes in body mass, indicative of only mild dehydration. Studies into the effects of hydration have previously indicated a decline in physical¹⁴ and cognitive¹⁵ performance when body mass loss exceeds 2%. Changes in body mass of participants in the present study did not typically exceed the 2% threshold value indicating that the hydration strategy employed (600 ml of room temperature water) appears to be appropriate to minimize dehydration of firefighters when working in the heat.

The present study indicated no significant decrements to cognition as a result of working in the heat. Any impairment to cognitive function is highly relevant to the safety of firefighters operating in rapidly changing operating environments. Given previous links between dehydration and cognitive impairment,¹⁵ it appears that the hydration strategy applied in the present study may have played a role

in mitigating cognitive declines in participants in this study. However, though we found no significant negative impacts on cognition, the link between hydration and cognitive performance in urban firefighters still remains largely unclear and requires further investigation, possibly with standardized workloads and self-selected hydration strategies during rest periods.

The significant declines in grip strength observed in the present study replicate findings in a number of settings and are likely related to exposure to heat.^{18,19} Firefighters responding to emergency incidents in the heat are tasked with carrying various loads including hoses and tools requiring high levels of physical strength to ensure safe and effective operations.^{16,44} Thus, heat-related declines in strength observed in this study would likely be replicated in the field and may be leading to a decrease in the ability of firefighters to safely complete work tasks during long duration emergency events. Thus, it may be prudent to evaluate possible strength and conditioning programs in order to maximize strength, in conjunction with appropriate rehabilitation programs to maximize strength-related performance and safety of firefighters when working in the heat.

Previous research by Hostler *et al.*, using a similar timeframe, albeit conducted in a laboratory and without SCBA, saw no firefighters able to complete a 50-minute simulation⁸ despite mean core temperatures of participants not exceeding 38.2°C. The reported aerobic capacity of participants in the Hostler (2010) study, was $37.4 \pm 3.4 \text{ ml kg}^{-1} \text{ min}^{-1}$, a value well below the recommended standard of $42 \text{ ml kg}^{-1} \text{ min}^{-1}$ ^{45,46} and below those previously reported for Australian firefighters.¹⁶ In comparison, only three participants voluntarily withdrew during this study, perhaps due to higher mean predicted aerobic capacity of participants ($48.7 \pm 6.0 \text{ ml kg}^{-1} \text{ min}^{-1}$). Emergency responses of firefighters generally involve periods of high intensity work interspersed with relatively lower intensity as reflected in the design of the present study, when compared with Hostler (2010) who performed a constant workload. Compared with Hostler (2010), whose participants worked at a constant rate, the regular pauses in our study may have produced sufficient distraction to facilitate an extended work period. However, while noting the difference in work protocols, it is likely that differences in aerobic capacity are a factor in the ability of participants to work for sustained periods in the heat. However, the links between aerobic capacity and the ability of firefighters to work in the heat remain largely unclear and we recommend further study comparing individual responses, to determine appropriate standards of fitness for firefighters operating in hot environments.

The present study demonstrated increasing thermal strain in firefighters when they are tasked to re-enter fire scenes, particularly when only passive cooling protocols are employed. Further, reductions in skin temperatures and perceptual measures during rest periods, independent of significant increases in core temperatures, indicates that relying solely on individual perceptions of well-being may be insufficient to ensure the safety of firefighters when asked to re-enter fire scenes. In line with NFPA standard 1584, we recommend that active cooling protocols and monitoring systems be adopted by Australian fire services following a second SCBA, to ensure that increases in physiological strain in firefighters are addressed prior to re-entry or redeployment. Further, we recommend that the duration of rest periods be investigated to ensure a balance between operational necessity and the safety of individual firefighters during emergency responses.

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Contributors All the authors listed in the paper have played an active role in data collection as well as developing the paper.

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Conflicts of interest The authors confirm that no conflicts of interest exist for this study.

Ethics approval The current paper was conducted based on protocols approved by the University of Canberra Human Ethics Research Committee.

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