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NRC Research Press

ARTICLE

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

Anthony Walker, Matthew Driller, Matt Brearley, Christos Argus, and Ben Rattray

Abstract: Firefighters are exposed to hot environments, which results in elevated core temperatures. Rapidly reducing core temperatures will likely increase safety as firefighters are redeployed to subsequent operational tasks. This study investigated the effectiveness of cold-water immersion (CWI) and iced-slush ingestion (SLUSH) to cool firefighters post-incident. Seventy-four Australian firefighters (mean ± SD age: 38.9 ± 9.0 years) undertook a simulated search and rescue task in a heat chamber (105 ± 5 °C). Testing involved two 20-min work cycles separated by a 10-min rest period. Ambient temperature during recovery periods was 19.3 ± 2.7 °C. Participants were randomly assigned one of three 15-min cooling protocols: (*i*) CWI, 15 °C to umbilicus; (*ii*) SLUSH, 7 g·kg^{-1} body weight; or (*iii*) seated rest (CONT). Core temperature and strength were measured pre- and postsimulation and directly after cooling. Mean temperatures for all groups reached 38.9 ± 0.9 °C at the conclusion of the second work task. Both CWI and SLUSH delivered cooling rates in excess of CONT (0.093 and 0.092 compared with 0.058 °C·min^{-1}) and reduced temperatures to baseline measurements within the 15-min cooling period. Grip strength was not negatively impacted by either SLUSH or CONT. CWI and SLUSH provide evidence-based alternatives to passive recovery and forearm immersion protocols currently adopted by many fire services. To maximise the likelihood of adoption, we recommend SLUSH ingestion as a practical and effective cooling strategy for post-incident cooling of firefighters in temperate regions.

Key words: iced slush ingestion, cooling, cold water immersion, firefighter, core temperature, recovery.

Résumé : Les pompiers sont exposés à des environnements très chauds qui élèvent ainsi leur température centrale. En abaissant rapidement leur température centrale, on devrait accroître leur sécurité lors de la reprise subséquente des tâches opérationnelles. Cette étude se propose d'analyser l'efficacité de l'immersion en eau froide (« CWI ») et la consommation de glace concassée (« SLUSH ») pour refroidir les pompiers après un incident. Soixante-quatorze pompiers australiens âgés de 38,9 ± 9,0 ans (moyenne écart-type) participent à un exercice de recherche et de sauvetage dans une enceinte chaude (105 ± 5 °C). L'évaluation consiste en deux exercices d'une durée de 20 min intercalées de 10 min de repos. La température de l'air ambiant au cours des périodes de récupération est de 19,3 ± 2,7 °C. Les participants sont assignés au hasard à l'un des trois protocoles de refroidissement d'une durée de 15 min chacun : (*i*) CWI, 15 °C jusqu'au nombril; (*ii*) SLUSH, 7 g·kg^{-1} masse corporelle et (*iii*) repos assis (« CONT »). On mesure la température centrale et la force musculaire avant et après l'exercice de simulation et immédiatement après le refroidissement. La température moyenne des trois groupes atteint 38,9 ± 0,9 °C après le deuxième exercice. Dans les conditions CWI et SLUSH, le refroidissement est supérieur à CONT (0,093 et 0,092 comparativement à 0,058 °C·min^{-1}) et la température centrale revient aux valeurs de base durant les 15 min de la période de refroidissement. La force de préhension manuelle n'est pas diminuée dans les conditions SLUSH et CONT. CWI et SLUSH constituent des alternatives probantes à la récupération passive et à l'immersion des avant-bras, deux protocoles couramment utilisés par plusieurs services de lutte aux incendies. Pour maximiser la possibilité de l'adoption de cette mesure, nous recommandons la consommation de glace concassée à titre de mesure pratique et efficace pour refroidir les pompiers à la suite d'incidents en régions tempérées. [Traduit par la Rédaction]

Mots-clés : consommation de glace concassée, refroidissement, immersion en eau froide, pompier, température centrale, récupération.

Introduction

Firefighters are exposed to extreme temperatures when responding to emergency incidents, which requires them to wear highly specialised personal protective clothing (PPC) and self-contained breathing apparatus (SCBA). Firefighters wear PPC that comprises many layers, including a vapour barrier that actively reduces the dissipation of metabolic heat via impairment of natural sweating mechanisms (Katica et al. 2011; McEntire et al. 2013). When the body produces heat at a rate in excess of its ability to dissipate heat, as occurs when firefighters work in PPC, uncompensable heat loading occurs. Further, extreme high heat conditions encountered in the firefighting setting can exacerbate this uncompensable heat gain and contribute to elevated core temperatures (McLellan and Cheung 2000; Barr et al. 2010; Cheung et al. 2010). Core temperatures of firefighters during extended operational incidents may exceed the recommended occupational lim-

Received 5 February 2014. Accepted 24 April 2014.

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its of 38.0–38.5 °C (International Organisation for Standardisation (ISO) 2004; National Fire Protection Association (NFPA) 2008).

High core temperatures lead to reduced maximal muscle contraction (Nybo 2008), physical exhaustion, and impaired cognitive function (Faerevik and Reinertsen 2003; Bandelow et al. 2010). In occupational settings, core temperatures in excess of 39.0 °C (ISO 2004; NFPA 2008) are considered to be unsafe despite regular observations of these higher core temperatures in athletic and medical settings. In hot conditions, if untreated, core temperatures can remain elevated for a considerable time and likely leave the individual in a lethargic state with reduced work capacity. Firefighters are often redeployed following operational incidents and must respond in a timely fashion. Thus, the goal of post-incident cooling should be to rapidly return core temperatures to recommended ranges in addition to restoration of baseline strength (Sund-Levander et al. 2002; Stanley et al. 2010).

Commercially available products are marketed to fire services to facilitate post-incident cooling. These include misting fans (Selkirk et al. 2004; Brearley et al. 2011), hand and forearm immersion devices (McLellan and Selkirk 2006), and cooling vests (Katica et al. 2011; McEntire et al. 2013). However, these devices provide little benefit in reducing core temperatures in temperate recovery climates even after 20 min (Carter et al. 2007; Hostler et al. 2010*b*). The fire service in the present study is small and has limited operational resources to respond to emergency events. Hence, responding units operate with reduced support and as a result limited rest periods between work periods are common, particularly in the early stages of emergency events. As a result, cooling protocols in excess of 20 min are impractical for rapid cooling, as redeployment of firefighters can be time critical. However, it must be noted that all active cooling methods investigated were more effective than passive cooling alone.

Cold-water immersion (CWI) protocols are well established in athletic programs for postexercise cooling and have proven to be effective at reducing core temperatures (Casa et al. 2007*b*; Vaile et al. 2011; Siegel et al. 2012). CWI is considered to be the gold standard for cooling of heat-affected individuals and is particularly effective in reducing core temperatures in individuals with greater body mass, who must lose more heat to achieve similar reduction in core temperatures (Casa et al. 2007*b*). Positive cooling effects for CWI have been observed in a range of conditions, though the most effective core temperature reduction has been achieved by immersion in cool–cold water (2–20 °C) for durations between 9 and 18 min (Proulx et al. 2003; Versey et al. 2013). Because of high rates of body surface area exposure during CWI, a sustained drop in core temperature occurs as heat transfers from the core to the periphery (Gagnon et al. 2010). This phenomenon is referred to as afterdrop and occurs after CWI partly because of blood temperatures being exposed to the reduced temperatures of the peripheral limbs and superficial tissue (Proulx et al. 2003; Casa et al. 2007*b*). A risk of overcooling exists from CWI, hence conservative temperatures for ceasing cooling and a recommendation for medical monitoring of hyperthermic individuals during cooling has occurred (Casa et al. 2007*b*). However, regardless of widespread adoption in medical and athletic settings, little research into the efficacy of CWI as a post-incident cooling method has been undertaken for firefighters.

Ingestion of cold drinks (4 °C) and iced slush drinks (SLUSH) have been considered (Stanley et al. 2010), though not extensively tested in firefighting settings. Brearley et al. (2011) provided a single bolus of 7.5 g·kg^{-1} body weight (BW) of SLUSH, reporting inability of firefighters to consume the provided volume and only moderate cooling rates in hot, humid conditions (0.032 °C·min^{-1}). Regardless, SLUSH (1.25 g·kg^{-1} BW) has been shown to be effective in partially ameliorating heat-related declines in maximal voluntary muscle contraction and endurance capacity when exercising in the heat (Stanley et al. 2010; Siegel et al. 2012) and is more effective at reducing core temperatures than cold water alone (Siegel et al. 2010). To date, little study of the efficacy of SLUSH as a cooling modality for firefighters has occurred.

Table 1. Mean ± SD demographics and morphometrics of participants (n = 74).

Age (y)	38.9±9.0
Height (m)	1.8±0.1
Mass (kg)	84.3±9.3
Body mass index (kg·m^{-2})	25.8±2.2
Body fat (%)	19.9±6.5
Body surface area (m^2)	2.1±0.1
Estimated aerobic capacity (mL·min^{-1}·kg^{-1})	49.8±5.1

To date, little research has been conducted in Australian urban fire services operating in temperate regions to develop coordinated and effective post-incident cooling protocols. Rather, warm–hot laboratories (Kong et al. 2010; Williams et al. 2011) and to a lesser extent, tropical settings (Brearley et al. 2011) have been examined. Protocols for rapid cooling are necessary to facilitate safe and effective redeployment of firefighters. Thus, the aim of the current study was to evaluate the effectiveness of CWI and SLUSH following a simulated search and rescue task compared with passive cooling alone.

Materials and methods

Participants

Seventy-four male operational firefighters were recruited from an Australian fire service and volunteered to participate in the present study (Table 1). All participants were professional urban firefighters who were operationally active at the time of testing and represented all ranks within the fire service. Testing was conducted in early autumn during duty hours, and participants were partially heat acclimated after completing a summer bushfire season. Informed written consent was obtained from all participants prior to testing based on protocols approved by the University of Canberra Human Ethics Research Committee. T1

Prior to the simulated search and rescue task, participants undertook physical fitness testing. Aerobic fitness was estimated using the Yo-Yo Intermittent Recovery Test Level 1 (Bangsbo et al. 2008). Body composition analysis, including body fat percentage, was conducted using Dual Energy X-Ray Analysis (DEXA). Body surface area (BSA) was calculated as BSA = (height$^{0.725}$ × mass$^{0.425}$) × 0.007184, where height is in cm and mass is in kg (DuBois and DuBois 1915).

Design

Following the completion of a simulated search and rescue task, participants removed their PPC and were randomly allocated to 1 of 3 groups: CWI (n = 26), SLUSH ingestion (n = 23), or a passive control (CONT) (n = 25), with each lasting 15 min. Following DEXA scanning during physical testing, no differences in body composition, including body fat percentage, were detected between groups. Baseline core temperature and grip strength was assessed prior to the simulated search and rescue task, at its conclusion, and directly after the cooling protocol (Fig. 1). F1

Simulated search and rescue task

To maximise the validity of testing by replicating operational conditions for this fire service, and following protocols previously validated (Hostler et al. 2010*a*; Kong et al. 2010), participants completed two 20-min simulated search and rescue tasks in a purpose-built heat chamber set at 105 ± 5 °C. Search and rescue tasks were separated by a 10-min seated rest period outside the heat chamber (Fig. 1). During the intermediate rest period (19.3 ± 2.7 °C), participants removed their jackets and changed breathing apparatus cylinders as per normal standard operating procedures for Australian fire services. Humidity was not measured during testing; however, average humidity for March in Canberra is 38% (1500 hours) (Australian Bureau of Meteorology 2014). Participants were required

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Fig. 1. Visual representation of timeline for testing. Core temperatures were assessed directly on exiting the heat chamber and at the conclusion of the cooling protocol.

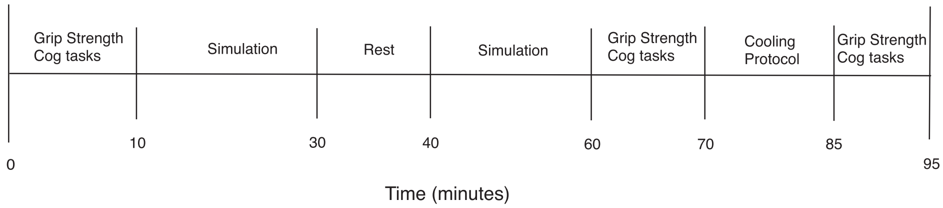

Fig. 2. Floor plan of heat chamber used for testing. Participants entered the chamber via the door in the top left. The cache of drums was located in the room at the top right of the chamber.

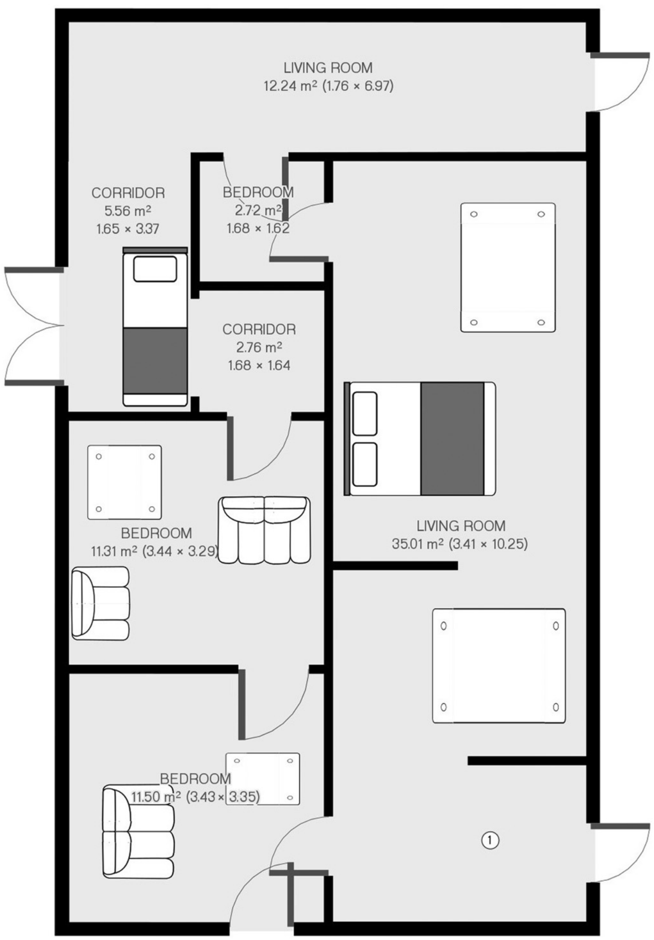

Table 2. Mean ± SD profiles of cooling groups for estimated aerobic capacity, body mass index (BMI), body fat percentage, and body surface area (BSA).

	Estimated aerobic capacity ($mL \cdot min^{-1} \cdot kg^{-1}$)	BMI ($kg \cdot m^2$)	Body fat (%)	BSA (m^2)
Cold water immersion	51.9±5.7	25.5±1.8	17.9±0.7	2.0±0.1
Iced slush drink ingestion	48.7±3.8	25.9±2.1	20.1±0.07	2.0±0.1
Control	58.6±4.8	25.7±2.3	21.7±0.5	2.1±0.1

to negotiate a multi-room facility containing a range of furniture configurations in order to simulate a search and rescue task at a
F2 typical house fire (Fig. 2). To minimise possible effects of hydration status, prior to entry, all participants consumed 600 mL of water provided from sealed bottles stored in the shade at ambient temperatures (19.3 ± 2.7 °C).

Searching was conducted in darkness and smoke and required firefighters to locate a cache of foam drums (weight 20 kg) and return them individually to the starting location. Participants were instructed to conduct their search using pre-established techniques, which involved periods of crawling and climbing. During the simulation, a surrogate measure of work, rate of perceived exertion (RPE) (Borg 1974), was measured at 5-min intervals 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. All participants completed a familiarisation session prior to undertaking testing to maximise the validity of their responses.

Participants completed testing while wearing a full structural firefighting PPC ensemble comprising boots (Haix Special Firefighter, Haix, USA), woollen socks, Nomex pants (Stewart and Heaton, Brisbane, Australia), over-pants and tunic (Stewart and Heaton), cotton T-shirt, Nomex flash hood (Life Liners Inc., Morristown, N.J., USA), gloves (ESKA, Thalheim, Austria), and helmet (Pacific Helmets, New Zealand). All protective clothing complied with Australian Standard AS/NZS 4967:2009. Participants wore an open-circuit Scott Safety Contour 300 SCBA weighing 9.6 kg (Scott Safety Australia, Sydney, NSW). The combined weight of PPC and SCBA was 22.0 kg. During the intermediate rest period, participants removed their SCBA, jacket, gloves and helmet and consumed 600 mL of water provided in sealed bottles stored in the shade at ambient temperatures (19.3 ± 2.7 °C). To simulate operational safety considerations, boots were not removed during the intermediate rest period. Participants worked in pairs, as per the Australian Capital Territory (ACT) Fire and Rescue standard operating procedures, with both members tasked with retrieving drums following each search pattern.

Cooling protocol

At the conclusion of the second simulated search and rescue task, participants were randomly assigned to 1 of 3 cooling protocols: CWI, SLUSH ingestion, or CONT (Table 2). No differences T2
were detected between groups for estimated aerobic capacity, body fat, or BSA (p = 0.055, 0.115, and 0.129, respectively). Following standard operating procedures for post-incident recovery for the present fire service, all groups had access to ad libitum water from sealed bottles stored in the shade at ambient temperatures (19.3 ± 2.7 °C). Thus, water was cool but not cold. Time from completion of the simulated search and rescue task to the beginning of the cooling protocol was 10 min, which simulates the time taken to recondition SCBA and operational appliances at operational incidents. All cooling protocols lasted for 15 min.

CWI

Participants were immersed in cold water (~15 °C) to the umbilicus with arms out for 15 min in the shade (19.3 ± 2.7 °C). This protocol for cooling has been previously validated in sporting settings (Brophy-Williams et al. 2011) and was chosen to minimise possible confounding effects because of localised cooling on the

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grip strength of participants. Participants were partially submerged in a purpose-built cooling pool located in the shade with temperatures controlled by a portable chilling unit (iCool Australia, Miami, Queensland, Australia). Water was not agitated and participants wore only shorts during the immersion period. Participants were given access to ad libitum water (ambient temperature) during the cooling period, which was not recorded.

SLUSH ingestion

Participants removed their PPC and boots and were in a seated position in the shade (19.3 ± 2.7 °C). All participants consumed 7 g·kg^{-1} BW (Ihsan et al. 2010) of crushed ice slush drink (~−1 °C) (Caress 1, CAB S.p.A, Italy), which contained a dissolved hypotonic solution (150 mOsmol·L^{-1}) (Aqualyte, Point Health Pty Ltd., Australia). Participants were given access to ad libitum water (ambient temperature) during the cooling period, which was not recorded.

CONT

Participants removed their PPC and boots and undertook a passive seated cooling protocol in a shaded area (19.3 ± 2.7 °C). Participants were given access to ad libitum water (ambient temperature) during the cooling period, which was not recorded.

Core temperature monitoring

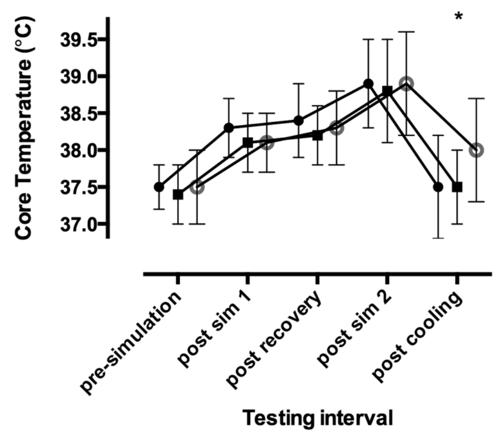
Core temperatures were monitored via an ingestible thermometer and radio receiver (HQ Inc., Fla., USA) that was swallowed at least 6 h prior to testing to minimise the confounding influence of food or fluid on the pill (Hostler et al. 2010*b*). Ingestible thermometers are considered a valid tool for the measurement of core temperature with differences <0.1 °C when compared with rectal temperatures (Gant et al. 2006; Casa et al. 2007*a*). Further, because of the relative ease of use, they are a recommended method of temperature assessment for ambulatory, field-based measurements (Byrne and Lim 2007). To control for the effect of localised cooling from ice or fluid ingestion, participants were excluded from core temperature analysis when baseline temperatures were ≤35.5 °C or decreased by 2 °C in any 5-min period during testing (Brearley et al. 2011). The exclusion criteria saw 1 participant from the CWI group and 7 from the SLUSH group removed. The number of remaining participants for data analysis of core temperatures was CONT (n = 25), SLUSH (n = 16), and CWI (n = 25). However, all participants were included in the of strength analysis. The authors acknowledge that a localised cooling effect as a result of the iced SLUSH on the pills may have occurred in some cases because of slow intestinal movement, which likely explains the number of subjects removed from the SLUSH group. However, we believe that the stringent cutoffs and removal of data meeting the exclusion criteria (Lee 2011) adds to the validity of measurement. The nature of the testing protocol, particularly given the high heat combined with participants wearing multiple layers of clothing, made ingestible pills the most appropriate core-temperature monitoring protocol for the present study.

Cooling rates (°C·min^{-1}) were calculated and reported for each cooling method based on the following formula: cooling rate = (postcooling temperature − postsimulation temperature)/time (15 min).

Grip strength testing

Grip strength was assessed directly prior to participants entering the heated chamber and directly on exiting the chamber, with participants seated and the shoulder adducted and neutrally rotated using a 200-lb. Baseline hydraulic hand dynamometer (Fabrication Enterprises Inc., New York, N.Y., USA). The elbow was flexed at 90° with the forearm in a neutral position and the wrist between 0° and 30° of dorsiflexion. The arm was unsupported during testing and scores were assessed on 1 trial on the right hand only as per protocols previously validated (Richards 1997; Nicolay and Walker 2005).

Fig. 3. Mean ± SD core temperatures of participants. Cold-water immersion protocol (filled circle); iced slush beverage protocol (filled square); and passive control protocol (open circle). *, Significant difference between interventions postcooling. Significant differences were detected between all adjacent time points; however, no differences occurred between groups at any time during the simulation (sim).



Statistical analysis

Statistical analyses were performed in IMB SPSS version 20 (IBM Corp., Armonk, N.Y., USA). Data are presented as means ± SD. A mixed-methods ANOVA was used to identify differences between 2 time points (presimulation to postsimulation and postsimulation to postrecovery) and to identify differences between recovery groups (SLUSH, CWI, and CONT). Significance was accepted at $p \leq 0.05$. Tukey's post hoc analysis was performed and 95% confidence intervals (CIs) were reported. Effect sizes (η^2) were calculated and reported as being “small” ≤0.009, “medium” 0.010–0.059, “large” 0.060–0.138, and “very large” ≥0.139 (Cohen 1988). To account for differences that were observed in grip strength between groups postsimulated search and rescue task, an analysis of covariance (ANCOVA) was conducted with the pre- to postsimulation change score in strength used as a covariant. Post hoc analysis was performed with a Bonferroni adjustment.

Results

RPE

A significant increase in perceived effort was detected over the testing cycle with mean RPE increasing from 12.0 ± 1.4 (fairly light/somewhat hard) for the first 10 min to 16.5 ± 2.5 (very hard) at the conclusion of the second simulation (p = 0.012, η^2 = 0.067). No differences were detected between cooling groups during the 2 simulations (p = 0.506, η^2 = 0.021).

Core temperatures

No significant differences in core temperatures were detected between groups prior to or at any time point during the 2 simulations (Fig. 3). Mean core temperatures for all groups presimulation was 37.5 ± 0.4 °C and were significantly higher at the conclusion of both the first and second simulated search and rescue tasks (simulation 1: + 0.7 ± 0.3 °C, 95% CI 0.7 to 0.8, p < 0.01, simulation 2: + 1.4 ± 0.5 °C, 95% CI 1.3 to 1.5, p < 0.01). Individual maximum core temperature measurements saw 28 participants in excess of 39.0 °C and 2 above 40 °C. Interestingly, overall mean core temperatures continued to significantly increase for all groups during the intermediate rest period (+0.1 ± 0.2 °C, 95% CI 0.1 to 0.2, p < 0.01) with no differences between groups detected. F3

A significant difference between cooling methods was detected postcooling (p = 0.016). Relative to the passive CONT, SLUSH (−0.5 °C 95% CI −0.9 to −0.2) and CWI (−0.5 °C, 95% CI −1.0 to 0.0) both produced significantly lower core temperatures postcooling

Table 3. Mean ± SD results of core temperature analysis during a search and rescue simulation and following cooling interventions.

	Core Temperature measurement (°C)						
	Presimulation	Postsimulation 1	Postrest	Postsimulation 2	Postcooling	Δ Temperature postsimulation to postcooling	Cooling rates (°C·min⁻¹)
CWI	37.5±0.3	38.3±0.4	38.4±0.5	38.9±0.6	37.5±0.7	1.4±1.1	0.093±0.071
SLUSH	37.4±0.4	38.1±0.4	38.2±0.4	38.8±0.7	37.5±0.5	1.3±0.6	0.092±0.038
CONT	37.5±0.5	38.1±0.4	38.3±0.5	38.9±0.7	38.0±0.7	0.9±0.6	0.058±0.039

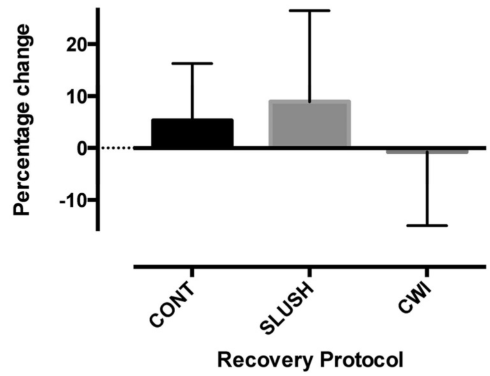
Note: CONT, cold water immersion; SLUSH, iced slush drink ingestion; CONT, control.

T3 ($p = 0.036$ and $p = 0.038$, respectively) (Table 3). No differences were observed between SLUSH and CWI.

Grip strength

Mean grip strength for all groups presimulation was 46.3 ± 7.7 kg (CONT 48.8 ± 7.6 kg, SLUSH 43.3 ± 8.4 kg and CWI 46.4 ± 6.4 kg, $p = 0.254$) and was significantly lower following the simulated search and rescue task (–5.9 ± 5.7 kg, 95% CI –4.6 to –7.2, $p < 0.01$). ANOVA results showed no significant differences within groups ($p = 0.255$, $\eta^2 = 0.038$) for pre- to postsimulation changes
F4 (Fig. 4). However, a significant difference was detected between groups ($p = 0.025$, $\eta^2 = 0.100$). After adjustment for the differences in grip strength between groups following the second simulated search and rescue task, ANCOVA analysis showed that there was a significant overall difference and a large effect size between cooling methods postsimulation to postrecovery ($p = 0.05$, $\eta^2 = 0.09$). However, post hoc analysis showed no significant differences between individual cooling methods. SLUSH resulted in the greatest magnitude in grip strength recovery although this was not significant (Fig. 4).

Fig. 4. Percentage change in grip strength pre- to postrecovery (mean ± SD). Postcooling grip strength was assessed after an ANCOVA was conducted using the pre-/post-Δ score as a covariant (–5.932). CWI, cold-water immersion protocol; CONT, passive control protocol; SLUSH, iced slush beverage protocol.



Discussion

The present study replicated the conditions experienced during structural fires (Eglin et al. 2004; Eglin 2007) and were among the most realistic simulations of standard operating procedures used by an Australian fire service. Current passive cooling methods (CONT) used post-incident may be insufficient to rapidly reduce core temperatures of firefighters compared with CWI (~15 °C) and SLUSH (7 g·kg⁻¹ BW), which were both significantly more effective in reducing core temperatures of firefighters after a 15-min cooling period (Fig. 3). CWI and SLUSH were not significantly different in cooling rates directly after the cooling intervention; however, an afterdrop in core temperatures was likely to have occurred following CWI, thereby increasing its overall effectiveness as a cooling modality. Given the significant reductions in core temperatures and high cooling rates observed, we recommend that CWI and SLUSH be considered as effective methods of rapidly cooling firefighters post-incident.

A key finding of the present study was that 7 g·kg⁻¹ BW of SLUSH is an effective protocol to rapidly cool firefighters post-incident in temperate climates, delivering a significant reduction in core temperatures. Mean core temperature reduction over the 15-min cooling period from SLUSH in the present study was 0.092 °C·min⁻¹ compared with 0.032 °C·min⁻¹ previously reported for SLUSH (Stanley et al. 2010; Brearley et al. 2011). Cooling rates may be partly explained by the volume of SLUSH ingested with our study using 7 g·kg⁻¹ BW compared with 14 g·kg⁻¹ BW for Stanley et al (2010). However, it is more likely that differences in the reported cooling rates is influenced by the duration of testing with cooling conducted over 15 min in the present study compared with 75 min for Stanley et al. (2010). They also did not report core temperature drops at equivalent time points to the present study; however, it is likely that cooling rates may be similar. Cooling rates are faster when core temperatures are higher at the beginning of cooling and subsequently slow as the body moves to defend against hypothermia (Proulx et al. 2003). Also, previous research has indicated that the cooling rates may be linked to differences in thermal gradients between core and skin temperatures as a result of ambient temperatures (Siegel et al. 2012). The study by Brearley et al. (2011) was conducted in the tropics where ambient temperatures and humidity were higher than the temperate conditions experienced in the present study. This may also explain some of the differences in cooling rates observed for SLUSH, particularly given that body mass was similar in both studies (86.7 ± 9.7 kg compared with 84.3 ± 9.3 kg in the present study).

Difficulty consuming higher volumes of SLUSH has been observed previously with sphenopalatine ganglioneuralgia (brain freeze) reported (Siegel et al. 2010). Reports of brain freeze are consistent with Brearley et al. (2011), who reported an inability of firefighters to consume 7.5 g·kg⁻¹ BW prior to melting in a tropical climate, which likely reduced the cooling rates observed for SLUSH (0.032 °C·min⁻¹). While ingestion issues were not evident in the present study, it is likely that smaller volumes of SLUSH would result in greater compliance from participants and increase the likelihood of adoption within fire services. Though 7 g·kg⁻¹ BW was shown to be effective in the present study (0.092 °C·min⁻¹), volumes as low as 1.25 g·kg⁻¹ BW can reduce core temperatures (Siegel et al. 2010). We recommend further study to establish the most appropriate rate of ingestion, which is still effective in rapidly cooling core temperatures of firefighters and maximises the likelihood of compliance. The fire service in the present study has a provision to provide welfare in the form of food and drink at incidents exceeding 2 h in duration (ACTF&R 2012). This occurs in most Australian fire services and requires logistical support in the form of fridges, freezers, and microwaves. Given that many Australian fire services provide a welfare capability post-incident (Fig. 5), the addition of equipment to make SLUSH should not be F5
onerous.

When conducting CWI of hyperthermic individuals, there is a risk of cardiovascular problems arising from potential overcooling after removal from cold water (Proulx et al. 2003). However,

Fig. 5. Australian Capital Territory Fire and Rescue Platform on Demand (POD) welfare system deployed to long duration operational incidents. (A) External view, (B) internal view.

cardiovascular problems are generally not prevalent in young, healthy individuals and many firefighters demonstrate these characteristics (Casa et al. 2005). To minimise risks from overcooling, we concur with the recommendations of Casa et al. (2005) in ensuring that individuals exhibiting symptoms of heat strain be monitored by medical personnel. In the present fire service, long-duration firefighting operations are conducted with onsite medical support in the form of paramedics. Thus the presence of medical support actively ameliorates the risk of overcooling post-CWI and to assist firefighters to safely operate with core temperatures in excess of 38.5 °C (ISO 2004; NFPA 2008).

The use of forearm immersion is a rehabilitation practice well established in a number of fire services throughout the United States and Australia. Cooling rates for forearm-immersion studies range from 0.013 °C·min^{-1} (Barr et al. 2011) to 0.054 °C·min^{-1} (Hostler et al. 2010*b*). The present study compares favourably to the study of Hostler et al. (2010*b*), achieving higher cooling rates of 0.093 °C·min^{-1} by immersion of the lower body in 15 °C water, despite use of similar water temperature (~15 °C) and body composition less conducive to cooling (17.9% ± 6.9% body fat for CWI in the present study compared with 14.7% ± 7.0%). The higher rates of cooling observed in our study reinforce the value of immersing large body surface areas, with potential to achieve cooling rates up to 0.35 °C·min^{-1} for whole-body immersion in water temperatures lower than those used in the present study (Proulx et al. 2003).

The efficacy of CWI for post-incident cooling may be questioned on the basis of the logistics to establish water cooling facilities. However, temperatures of reticulated water supplies in temperate settings are likely to be relatively cool, removing the need for ice or cooling systems and increasing the operational validity of CWI as a cooling method. Where cold water is not available, cooling rates for temperate water supplies have also been shown to be effective at reducing core temperatures (Taylor et al. 2008; Brearley et al. 2011). The high cooling rates reported for CWI increase the speed at which firefighters can be returned to operational duty. When used as a tool to allow for firefighters to re-enter fire scenes, there is a chance that should skin and clothing not be sufficiently dry, steam burns may occur. However, this risk appears to also exist when firefighters re-enter fire scenes wearing clothing soaked with sweat. Firefighting PPC in Australia complies with design standards (AS/NZS 4967:2009) that require high levels of resistance to radiant heat and the presence of a moisture barrier to prevent the ingress of steam (Standards Australia 2009). Thus, the design adaptations resulting from AS/NZS 4967:2009 significantly reduces the risk of burns when compared with more contemporary PPC.

The present study demonstrated a significant decline in grip strength for all groups during the simulated search and rescue task. Strength declines are likely related to the heat load similar to what has been observed in athletic populations (Nybo 2008; Peiffer et al. 2009). Allowing for differences in strength between groups postsimulation, the present study indicated that CONT and SLUSH had no negative impacts on grip strength directly postcooling, though this may not be the case for CWI (Fig. 4). Strength declines post-CWI were not significant, though previously it has been observed that lowering muscle temperatures leads to a reduction in peripheral contractile ability (Douris et al. 2003; Peiffer et al. 2009). An increase in strength post-CWI has been observed when measured at later time points than the present study (Vaile et al. 2008) and it has subsequently been recommended that CWI not be used for recovery in athletic settings, when high-intensity exercise occurs within 45 min of immersion (Halson 2011; Versey et al. 2013). However, in a firefighting setting it is likely that peak strength is less relevant than reducing core temperatures to improving the operational safety of firefighters, particularly given that firefighting tasks, including hose handling and search and rescue, generally require sustained rather than peak efforts.

It is also possible that donning PPC post-CWI may partially ameliorate any strength declines because of warming from PPC and reduced radiant heat loss during preparation and briefing prior to firefighters re-entering a fire scene. Testing of firefighter physical competency during simulated rescue tasks has shown that strength may not be as relevant to successfully completing rescue tasks as aerobic fitness (von Heimburg et al. 2006), thereby mitigating any negative effects observed postcooling. However, this is unclear and requires further study. Ingestion of carbohydrates, as was delivered during SLUSH ingestion, may have impacted on the speed of strength recovery compared with CWI. Therefore, it is unclear whether providing participants in the CWI group with carbohydrates during cooling may mitigate the continued strength declines observed in the present study and we recommend further investigation. On-scene rehabilitation coordinators will need to evaluate any possible negative impacts on strength when compared with core-temperature reduction and likely precooling effects of CWI.

Conclusion

The present study demonstrated that compared with CWI and SLUSH, passive cooling methods likely return firefighters to operational duty in a hyperthermic state and are therefore inappropriate for post-incident cooling. Because of the effectiveness of CWI and SLUSH in rapidly reducing core temperatures, both methods would be advantageous in rapidly reducing core temperatures of firefighters postoperational incident. Addressing high core temperatures during emergency responses should be seen as fundamental to ensuring the safety of firefighters. Because of the perceived logistical constraints of CWI, and to maximise the likelihood of adoption of active cooling methods within fire services, we recommend that SLUSH ingestion is a practical and effective cooling strategy for firefighters operating in temperate regions postoperational incident.

Conflicts of interest statement

No conflicts of interest exist for this study.

Acknowledgements

The authors in this study would like to acknowledge the ACT Fire and Rescue service for providing funding to undertake this study as well as providing on-shift resources including firefighters, operational appliances, and their heat-testing facility. We would also like to thank the 74 firefighters and officers who volunteered to participate.

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