Heat Stress Management in Firefighting

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Heat Stress Report- CFA 2011

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Background-

Heat stress has been shown to be one of the top three leading causes of injury during bush fire suppression [1]. It is also becoming an increased mechanism of injury during structural fire fighting. Structural protective clothing (PPC) provides considerable protection from the external environment during fire suppression. However, current structural PPC is heavy, multilayered and contains a moisture barrier that traps air, creating a microclimate between the skin and clothing [4]. Heat gain in firefighters is both intrinsic and extrinsic, meaning produced by the individual during physical exertion and gained from exposure to a hot environment [2, 3]. During normal exercise core temperature rises but is controlled through thermoregulation. The body cools through the evaporation of sweat from the skin, the higher the body temperature the more sweating occurs. When wearing PPC firefighters lose the ability to dissipate body heat by the sweating process [3].

The body's natural thermoregulation process is restricted due to limited water vapour permeability, increased metabolic load and insulative properties of the structural PPC. Add extreme environmental conditions and increased physical exertion, a firefighter is vulnerable to enhanced thermal strain [5]. The human body will tolerate a core temperature increase of only 3ºC before heat stroke could occur. Heat stroke is caused by the failure of sweating to cool the body. As the surroundings become hotter, all methods of heat elimination - radiation, conduction and convection become ineffective, the fire fighter gains heat from these mechanisms. In high ambient temperatures, evaporation of sweat is the main means of heat dissipation. The effectiveness of sweat evaporation from the skin is hindered when wearing PPC and when humidity and ambient air temperature is high. In extremely hot and/or humid conditions, the fire fighter will gain heat from the environment, and be unable to shed heat through the evaporation process.

For the safety of fire fighters, it is important to keep cardiovascular and thermoregulatory strain below critical levels while working in PPC. Under high ambient temperature, the body may experience exhaustion, mental confusion, disorientation, loss of consciousness, heart attack and in extreme cases death. A number of rehabilitation procedures exist within the fire services to decrease incidence of heat stress, such as crew rotation, fluid replacement, education about signs of heat illness and passive cooling (opening of PPC, sitting in shaded area). Although these current practices help to relieve heat stress, the National Fire Protection Association Rehabilitation Standard (NFPA 1584) outlines that active cooling methods shall be developed into standard operating procedures. Active cooling is the process of using external methods or devices (e.g. hand and forearm immersion, misting fans, ice vest) to reduce elevated core temperature[6]. Currently there are no rehabilitation standards within Australia fire services.

Previous studies have proven that active cooling; particularly hand and lower arm immersion may be the most effective method in reducing core temperature [7, 8, 9]. The hands and forearms act as an effective heat exchange between cool water when core temperature is high as there is a significant increase in vasodilation leading to increase peripheral blood flow [10]. Recently it has been shown that combining two active methods- ice vests with hand/forearm immersion provides no additional benefit compared to hand/forearm immersion alone [7]. Given the reported benefits of hand and lower arm immersion alone, this method was trialled as a practical cooling strategy. The purpose of the current trial was therefore to investigate the effectiveness of 20-minute hand and lower arm immersion in water to alleviate increase to fire fighters core temperature. The fire fighters are required to enter a heated building while wearing structural PPC and Breathing Apparatus (BA). A 20-minute recovery period was selected to meet the NFPA 1584 rehabilitation standards.

Over the past two years CFA's OH&S department in conjunction with Deakin University have conducted a number of heat stress trials. These trials aimed to assess increases in fire fighters core temperature following simulated fire fighting tasks while wearing structural PPC. 130 volunteer fire fighters participated in these trials conducted at Mt Hotham, Echuca, Lara and Penshurst. No heat stress trials have been conducted using bushfire PPC at this stage. Recommendations for the rehabilitation of fire fighters after wearing structural PPC have been made based on the trial's findings.

Methodology

Subjects

. Participants were recruited following an expression of interest in the trial by their regional Health & Safety advisor. Seventeen volunteer firefighters (16 male, 1 female) were recruited for this rehabilitation trial. These participants are representative of both the volunteer and career firefighters in fitness, health and body mass. One participant was excluded from statistical analysis as core temperature tablet was found to be inactive after ingestion. Inclusion criteria was current active members of the CFA, accredited BA trained, without cardiovascular or gastrointestinal conditions and not undertaking a magnetic resonance imaging within three days post trial as these are contraindications for the CorTemp tablets. Comparative data is taken from pervious trials at Echuca and Mt Hotham, where no cooling was applied, 16 subjects have been allocated to 'control group'.

Experimental Design

Prior to the testing, subjects met researchers from 1100-1300 on the day of the trial. Once informed consent was provided, each subject swallowed a CorTemp Core Body Temperature Sensor (HQ Inc, FL). The tablet was ingested at least six hours prior to the trial to ensure it was partially digested and in the lower intestines. CorTemp data receiver/logger was used to measure core temperature and heart rate. Phillips MP2 Cardiac monitor (diagnostic level) was the unit chosen for monitoring Blood Pressure. Subjects returned at 1800 to the Penshurst Training Ground where they were fitted with remaining equipment (see Equipment section below). All participants were checked for data transfer prior to commencement of trial. Prior to entering the pre-heated smoke filled training building, participants donned their current structural PPC and BA. To represent a structural fire the temperature range of 90 -124ºC and 50-60% relative humidity was chosen for the trial. Under the supervision of the structural instructor, subjects performed common structural firefighting activities, including search and rescue in the training building. Subjects divided into groups of 4-5 and performed tasks for 20-22 minutes using one BA cylinder each. Upon exited the building physiological measurement of Heart Rate (Hr), Tympanic temperature (Tt), Core temperature (Tc), Thermal sensation (St), and Blood Pressure (Bp) was measured, this was marked as 0 minutes. Participants were allocated to a KoreKooler Rehab Chair, which contain plastic bags filled with water in the armrests (Image 1-appendix). After the removal of jacket the hands and forearms were submerged in tap water approximately 10-12°C for 20 minutes (Rehabilitation group n=21). Physiological measurements where recorded every 5 minutes during the recovery.

Physiological Measures and Equipment

Subjects were fitted with a HR monitor (Polar RSD 800sd Polar Electro Oy, Finland) worn around the chest, during the exercise and recovery period. Tt was measured from subjects left ear by the same researcher to ensure consistent collection technique using the Braun Thermoscan Pro 4000 tympanic thermometer (Braun, UK).

Tc was recorded using the radio receiver (HQ Inc, FL) which received measurements from the ingested pill. Blood pressure measurements were taken using MP2 monitors. Subjects reported on St using the Young et al. 1987 Thermal Sensation scale every 5 minutes during recovery.

Findings-

Changes to core temperature- control trial vs. rehabilitation trial

- Core temperature reductions between 0.1 -2.9ºC are evident in the rehabilitation group compared to a range of -0.12-0.69ºC in the control group within 20 minutes.
- The largest reduction during the control trial in Tc was 0.69ºC for subject 3 (Figure 1b).
- Control trial found Tc remained constant between 37.5°C and 38°C with small changes 0.6±0.6ºC fall between 0 and 15 minutes post exercise (Figure 1b). No significant change in Tc across any of the recovery time points during control trial.
- Figure 1a shows that 15 of the 16 subjects undertaking the rehabilitation trial had decreases in Tc from 0 minutes to 20 minutes. An average fall in Tc of 1.5± 1.4ºC between 0 and 15 minutes post exercise was seen.
- Figure 1a shows large decreases of 1.2ºC, 2.4ºC and 2.9ºC in Tc from 0 minute to 20 minute for subjects 7, 10 and 16 respectively.
- Tc in the rehabilitation trial are cooler than then control trial by 0.8 ± 1.1°C, 1.4 ± 0.9°C, 1.3 ± 1.2°C, 1.5 ± 1.3°C at 0, 5-6, 9-10, and 15 minutes post-exercise.
- Although measuring time points between the trials are slightly different the rehabilitation trial (Figure 1a) indicates greater declines in Tc within 20 minutes compared with control trial (Figure 1b)

***Figure 1a** Individual changes in core temperature at time points during rehabilitation trial*

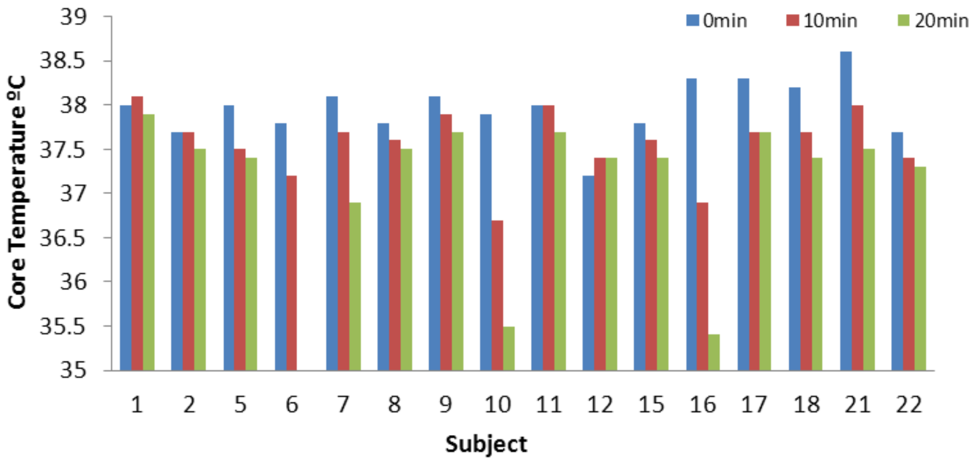
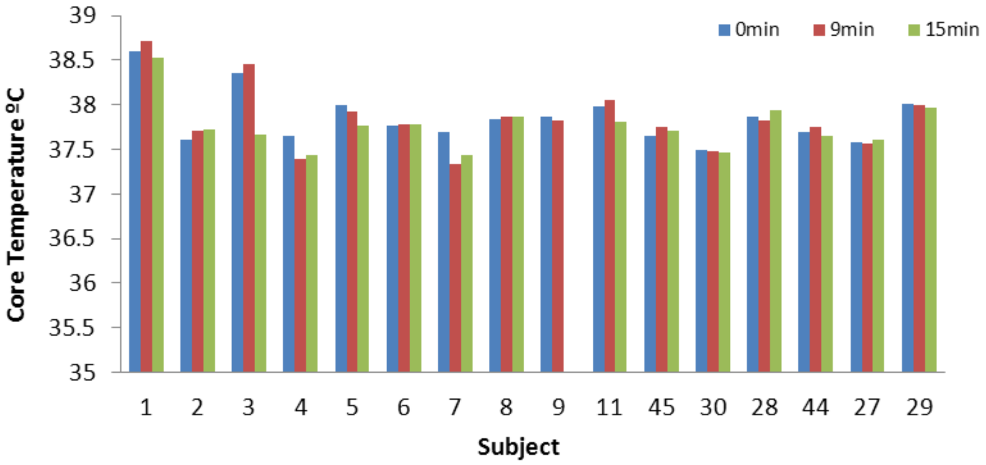


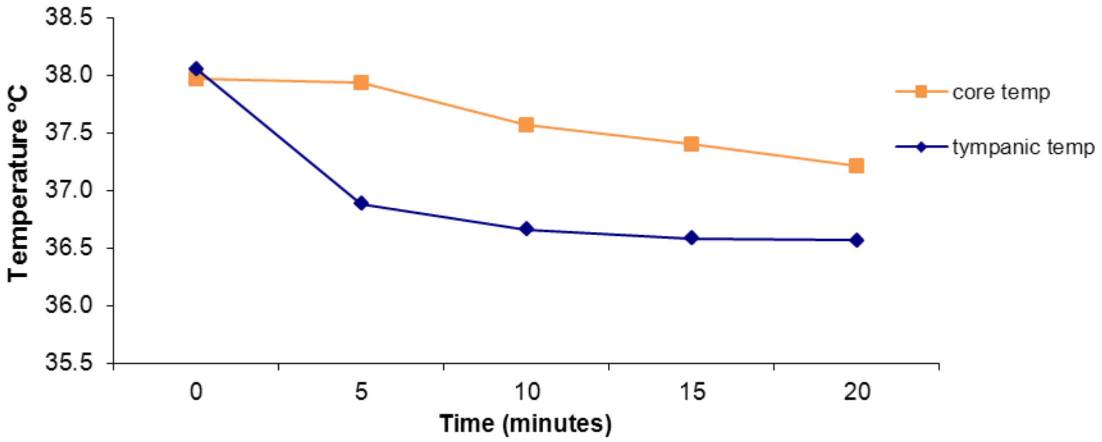
Figure 1b *Individual changes in core temperature at time points during control trial*



Relationship between Core and Tympanic temperature

- Figure 2 demonstrates that Tc remained consistently higher than Tt during all corresponding time points.
- The greatest difference 37.9-36.7º C (-1.2) between Tc and Tt can be seen at the 5 minute point.
- The differences between Tc and Tt are 1.2ºC, 0.9ºC, 0.8ºC and 0.6ºC at 5, 10, 15 and 20 minutes respectively.
- The variance between tympanic temperature and core temperature seen in this trial confirms current research, which warns tympanic temperature devices cannot accurately predict Tc [18, 19, 20].

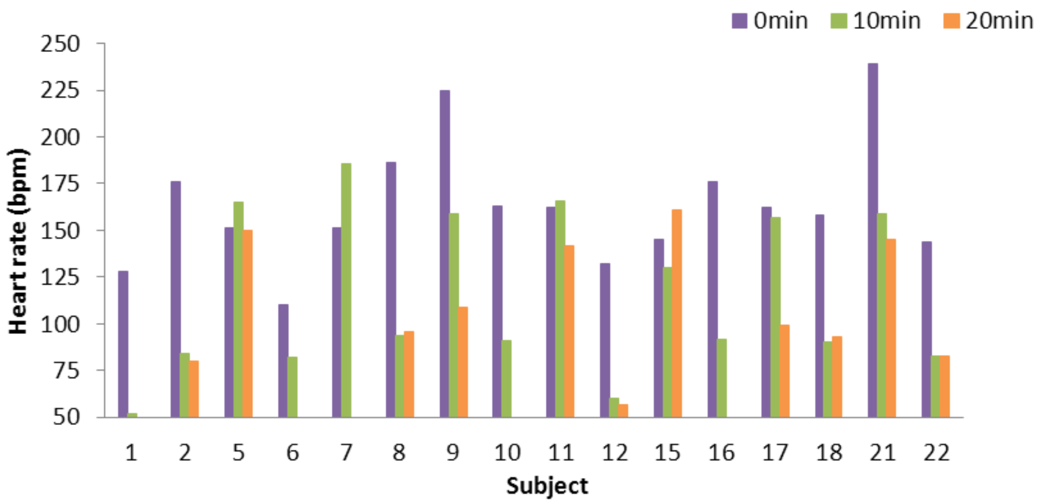
Figure 2 *Average tympanic and core temperature at time points during rehabilitation trial*



Changes to Heart Rate during hand and lower arm immersion

- At 0 minutes post exercise all subjects had heart rates greater than 110bpm, with the maximum being at 239 bpm for a 19 year old male.
- At 5 minutes, seven of the 16 subjects had heart rates greater than 100. At 15 minutes post exercise 6 subjects had heart rates greater than 100 bpm.
- Figure 3 demonstrates the decline in heart rate during hand and lower arm immersion, the greatest decline can be seen in subjects 2 and 8 with a decrease of 92bpm after 10 minutes post exercise.

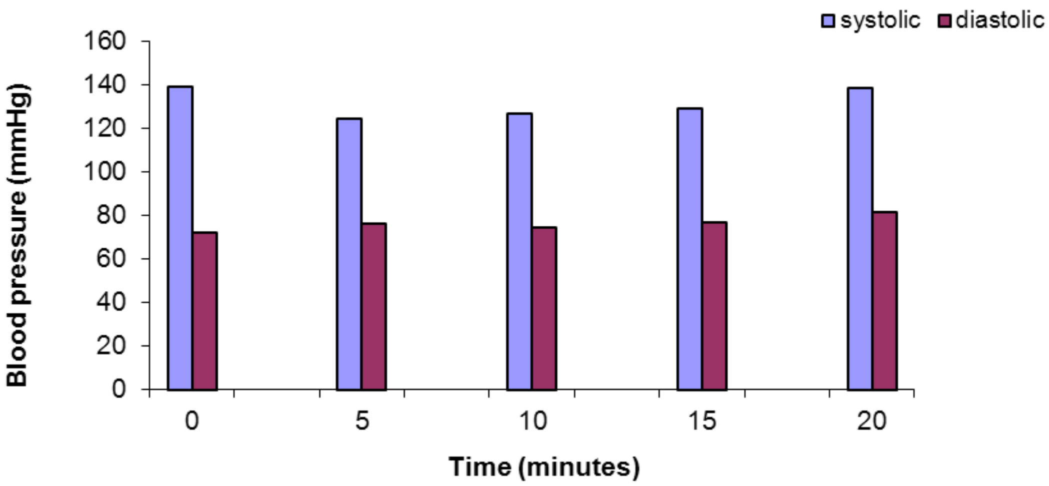
Figure 3 *Individual changes in heart rate at time points during rehabilitation trial*



Blood pressure changes during hand and lower arm immersion

- Figure 4 shows minimal variance in blood pressure during the 20-minute recovery period.
- Current NFPA 1584 recommends that following 20-minute recovery firefighters should have systolic pressures below 160mmHg and diastolic pressure below 100mmHg.
- Of the 16 subjects in the rehabilitation trial, one subject had a blood pressure of 177/123 at 20 minutes.

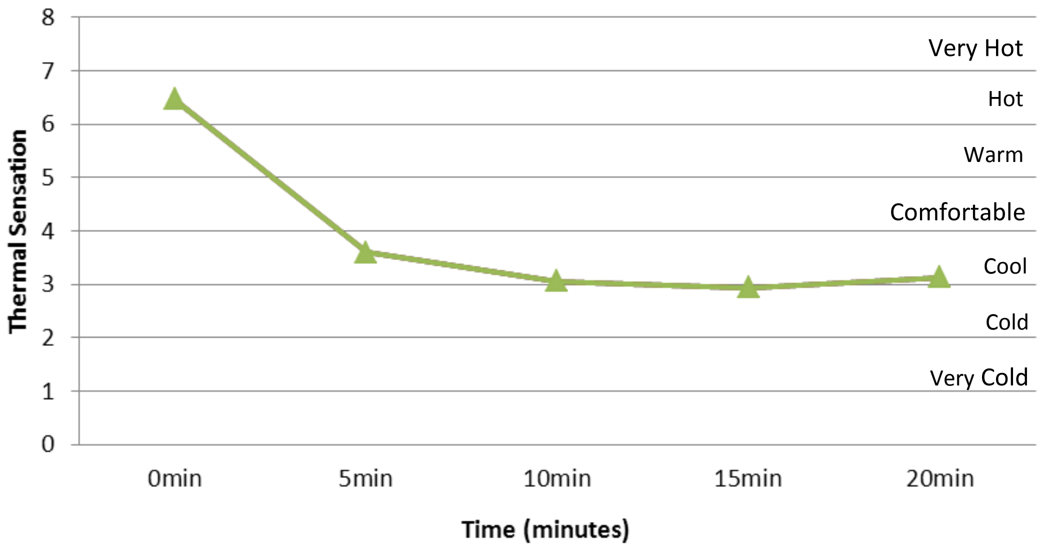
Figure 4 *Average blood pressures at time points during rehabilitation trial*



Perception of thermal sensation during hand and lower arm immersion

- Figure 5 indicates the changes to perceived thermal sensation during the 20-minute cooling period.
- Following the training exercise thermal sensation was perceived as warm to hot for all subjects.
- When compared with figure 2 it can be noted that as core temperature decreases, perceived thermal sensation also decreases.
- After 20 minutes of hand and lower arm immersion, on average subjects felt cool to comfortable.

***Figure 5** Average perception of thermal sensation at time points during rehabilitation trial*



Discussion

Although structural PPC is necessary for fire fighter safety, the current PPC that includes a moisture barrier creates an increased challenge to thermoregulation [10]. The purpose of the present trial was to examine the effectiveness of hand and lower arm water immersion in reducing the physiological strain on fire fighters after working in a hot, humid environment. A hot environmental condition of 90 -124ºC and 50-60% relative humidity was chosen to represent a structural fire environment. The effectiveness of passive cooling compared to active cooling using hand and lower arm immersion was also examined.

How does hand and lower arm immersion work?

All mammals have specific regions of the body's surface designed for dissipating excess heat from the core to the environment. In humans some of these areas are found in the soles of feet and palms of hands. When Tc is elevated vasoconstriction of the extremities significantly decreases [11]. During heat stress, vasodilation of arteriovenous anastomoses can increase blood flow to these regions by up to 1300% [7]. Figure 6a & b indicate the redistribution of blood flow when the body is placed under physical strain. Immersing the hands and lower arms in water reduces the temperature of the blood located at the surface, this cool blood returns to the core, reducing the central blood supply temperature [11]. Heat from the hands and forearms dissipates to the cooler water through convective heat transfer [8]. The cool blood returns to the core through the superficial veins thereby reducing core body temperature [7]. This cooling process is dependent on water temperature, core-to-surface temperature gradient and peripheral blood flow [8]. A number of studies have shown the optimal water temperature to be approximately 10ºC for forearm and/ or hand immersion [8, 11]. House et al. (1997) investigated the effectiveness of hand immersion in water at 10ºC, 20ºC and 30ºC and found Tc reductions within 10-minutes was more effective in colder water [11]. This temperature allows for a suitable core-to-water thermal gradient, aiding quick heat dissipation. At higher water temperatures ~20ºC both hands and forearms should be immersed to increase the surface area for heat dissipation [8].

Research from the Orange County Fire Authority (OCFA) and Toronto Fire Service found that forearm and hand immersion proved the most effective method to cool fire fighters following heat exposure [12,13]. The present trial with CFA volunteers has been able to repeat this. Figure *2* shows the decline in core temperature when comparing 0 minutes to 20 minutes during hand and lower arm immersion. OCFA 2007 Final Report on post-incident rehabilitation confirms the use of wet towels or cooling chairs to reduce Tc [13]. The study found both methods are similarly effective at reducing Tc.

Figure 6a- *Change to blood flow during cool and hot conditions*

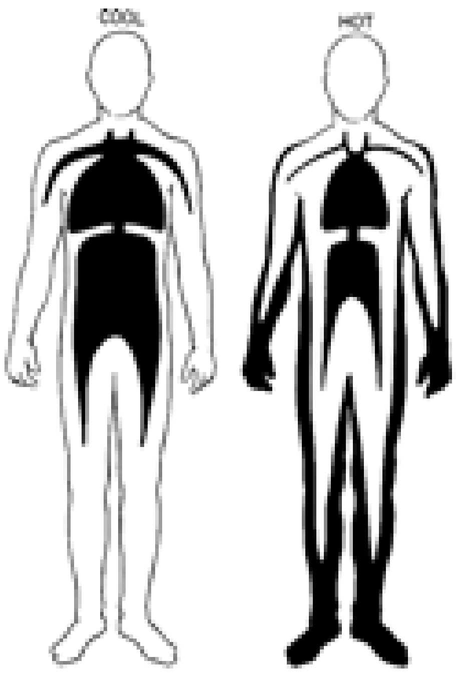
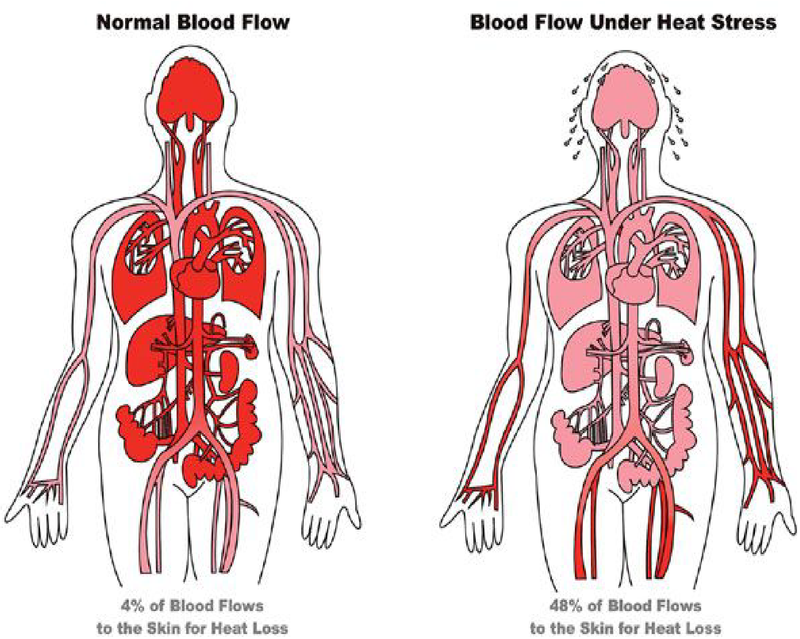


Figure 6b- *Redistribution of blood flow during heat stress*



Why hand and forearm immersion is preferred over others cooling methods?

Conventional cooling methods such as misting fans, ice packs or pouring cold water over the body are typically applied to the skin's surface. Although these methods make one "feel" cooler, they are commonly ineffective at cooling the body's core. A number of these methods have been compared to cold water immersion, using either the hands, forearms, or a combination and found this to be superior to conventional cooling methods. During surface cooling vasoconstriction of the peripheral blood vessels can occur and cause a reverse reaction. The body’s natural heat dissipation mechanisms will shut down and heat will remain within the core. Two common cooling techniques include passive cooling which uses shade and natural air flow, and ice vest for pre and post cooling, commonly used to cool athletes.

Passive cooling-

Studies of passive cooling techniques such as, opening ones jacket and resting in a shaded area has shown benefits when the environment is at a moderate temperature (~22-24ºC) [14]. Hostler et al. (2010) found no clear advantage when comparing active cooling devices to passive cooling in a moderate temperature environment (~24C). This environment allows the body to cool through the process of sweating and convection where heat from the body is transferred to the colder surroundings [15]. However these natural cooling techniques are limited when the environment is hot (~35ºC, 50% relative humidity) [15]. When a fire fighter is experiencing hyperthermia and the surrounding environment is hot the use of passive cooling alone will not allow sufficient heat dissipation. In a previous study in the heat (35ºC, 50% relative humidity) firefighters wearing protective clothing performed intermittent work for 50 minutes followed by 20 minutes of passive or active cooling [10]. The study found forearm submersion blunted the rise in core temperature and extended work time compared with passive cooling [10]. Another study found that adding the forearm with hand immersion produced a lower core temperature than passive cooling and hand immersion alone [8]. This is due to a greater surface area for heat exchange when using both the hand and forearm.

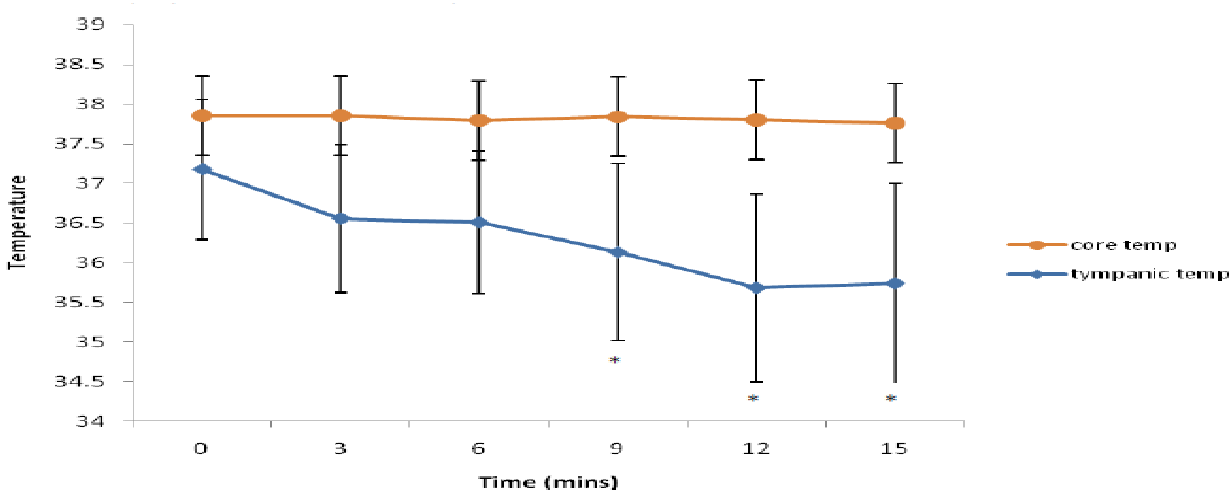
Ice vests-

Wearing ice vests has been proposed as an effective active cooling method for firefighters in some studies [16, 17]. The use of ice vests in the sports industry is common to pre-cool athletes and reduces core temperature before activity. Using ice vest for fire fighters may not be viable as we cannot predict when a crew will turn out to an emergency and there is relatively short preparation time prior to heat exposure [7].A major limitation of using ice vest during recovery is the extensive time required for this cooling method to be effective. This time is depended on a conductive pathway being established between the surface, subcutaneous fat and underlying muscle of the individual. This conductive pathway may take up to 60-minutes in individuals with skinfold thickness between 31 and 40mm [7]. Some studies have reported that using ice vests has induced vasoconstriction, initially increasing Tc, thereby reducing heat loss. Ice vest may only be effective with firefighters who are not redeployed and have sufficient recovery time [7].

Using Tympanic temperature to estimate Core temperature- Is this the best method?

Monitoring heat increases in fire fighters is a health and safety priority as heat stress can severely impair physical and mental performance of firefighters. Currently ambulance officers and medical personnel use external measuring devices such as tympanic measurements (eardrum) to predict Tc of firefighters. Tt measuring devices can accurately predict Tc in laboratory or controlled settings (GP clinic) as these are stable environments; however, Tt readings in uncontrollable environments are commonly below that of Tc [13, 18, 19, 20]. Uncontrollable environmental factors such as airflow, including wind and ambient temperature, along with physiological changes when exercising such as localised cooling to the ear canal can affect the accuracy of Tt measurements. A study by Lord et al. (2010) required volunteer fire fighters to stimulate firefighting duties within a smoked filled building for approximately 30 minutes; upon exit Tt readings were taken when passively recovering in outside temperature of 6ºC and 0ºC in Echuca and Mt Hotham respectively. The results found no consistent relationship between Tt and Tc post-simulation at any time point, and found that Tt is significantly lower than Tc after 6 minutes post-training (Figure 7)[18]. Another study to evaluate cooling methods involving Northern Territory structural firefighters, reported Tt averaged 1.3ºC below gastrointestinal temperature [20]. Fire fighters face extreme environmental conditions and physical loads, therefore using Tt devices to predict Tc is of little worth. While Tt devices are easily implemented on the fire ground, using this method to gain accurate Tc is not viable. Medical personnel need to exercise caution when using tympanic temperature devices to measure fire fighters true internal temperature [19, 20].

Figure 7 *Tympanic vs Core temperature at time points during Control trial*



Values are mean ± standard deviation.*P < 0.05

Source- Lord et al. 2010, p.12

Summary and Recommendations

Based on current research, and the present study it can be concluded that hand and lower arm immersion during a 20-minute recovery period following exposure to a hot environment, while wearing structural PPC is an effective cooling strategy to stimulate heat dissipation. This cooling strategy may be the only viable option in comparison to passive cooling methods and the use of ice vests alone. Hand and lower arm immersion decrease core temperature during the 20-minute recovery period and aiding heat transfer from the body. This active cooling modality will help to reduce heat strain associated with wearing structural PPC.

Key recommendations for the management of heat stress

- Hand and lower arm immersion is a practical cooling strategy as firefighters can remove their jacket during rest periods easily immerse the hands and forearms in cool/cold water.
- Cool/cold water is readily available at the fire ground.
- 10ºC is the optimal water temperature for heat dissipation when using hand and/ or lower arm immersion technique [8,10.]
- This method works extremely well in hot environments (35C, 50% relative humidity), or when an individual has suffered heat stress (hyperthermia).
- Hand and lower arm immersion should also be used during bushfire suppression when the body's natural cooling technique (evaporation) is limited in a hot environment.
- Northern Territory Fire and Rescue Service recommend establishing a rehabilitation areas for prolonged incidents (>1hr or require 2+ BA cylinder changes) that demand strenuous work tasks[20].
- Educate fire fighters in prevention, recognition and management of heat related illness and planning for incidents on extreme days. Refer to Heat stress chart and Rehabilitation recommendations (Appendix).
- Extended firefighting incidents should consider increasing number of personnel available and allow for longer or more frequent recovery time.
- Further education of fire fighters to improve pre-incident hydration status. Fire fighters should recognise that adequate hydration helps to prolong work time and reduce incidence of heat illness.
- Education of fire fighters to maintain a good level of fitness.
- Education of Incident Controllers and Crew Leaders in Rehabilitation requirements.

Rehabilitation area should:

- Be at a safe distance away from direct heat
- Provide shade
- Provide cool water and electrolyte to hydrate fire fighters
- Provide the opportunity for hand and lower arm immersion (examples- immersion in water buckets, use of cool chairs)
- Providing a fan within the rehabilitation area will enhance evaporative cooling
- Establishment of rehabilitation areas requires medical surveillance (Ambulance VIC or Health Support Team)
- Monitor workers who are at risk of heat stress- extra caution with structural PPC and HAZMAT incidents where extra Protective Equipment (PE) such as gas suits may be required.

Whilst this trial has given guidance for structural fire fighting rehabilitation, further research trials will assist in validating methods to minimise heat stress in both structural and bushfire environments.

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