Appendix 10

Fire Instructor Pre-cooling Strategies Research

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March 2014

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Background

Training for new recruits to the fire service requires exposure to severe heat on successive days throughout a two week training programme. This protocol induces a significant degree of heat and physical stress on the trainees and the instructors (Barr et al., 2010, Williams-Bell et al., 2010). Previous work (Smith et al., 2005) has identified short term changes in immune function using basic inflammatory markers pre, post and after 90 minutes recovery from live fire-fighting drills. Huang et al (2010) found increases in pro-inflammatory cytokines and decreases in lymphocytes after one severe heat exposure in fire fighters. Webb et al (2011) showed correlation between markers of immune and vascular function after controlled heat exposures in fire fighters Authors concluded that elevations in cortisol and interleukin-6 and associated vascular markers support the suggestion that fire fighters are at greater risk of a cardiovascular event as a result of repeated physiological stress.

Increases in ambient temperature lead to numerous physiological changes. The ability of the body to transfer heat by radiation and conduction is reduced, resulting in the body relying on evaporation of water, from sweat and the respiratory tract, to maintain thermoregulation (Maughan, 2010). In humid environments uncompensable heat stress situations can arise, where evaporation is limited as the air is already saturated with water (Cheung et al., 2000). This can lead to dehydration and a rise in core temperature (Tc). Furthermore, the cardiovascular system is limited in its ability to meet the dual demand of blood supply to working muscles and supply to the skin to maintain thermoregulation. Gonzalez-Alonso et al., (2008) conclude that it is the rise in Tc and brain temperature that limits exercise in the heat, not fatigue caused by limited perfusion. Studies agree that increased Tc is the critical limiting factor of performance in hot and humid environments, with exhaustion coinciding with a Tc of between 39.7-40.3^{0}C (Nielsen et al., 1993; Gonzalez-Alonso et al., 1999; Maughan, 2010). Lowering the initial Tc before a heat exposure through pre cooling methods, could expand the margin between initial Tc and exercise limiting Tc, therefore increasing heat storage capacity(Marino, 2002; Jones et al., 2012), and decreasing Tc at the end of live fire exercises.

Ice vests are based on jackets or vests, and have sections to be packed with ice or that are filled with liquid that once frozen turns to ice. Forty-three Australian athletes at the Atlanta Olympic Games 1996 wore ice jackets and reported on evaluation forms how they felt it affected their performance. All of the athletes believed that the ice jackets had had a positive contribution to performance (Martin et al., 1998 [online]). This form of evidence is very subjective and may not have been matched by actual improvements in performance, as this was not noted. On the other hand, Arngrimsson et al. (2004) conducted a cross over study on seventeen runners who wore the same ice vests as those used by the Australian athletes, during a 38 minute warm up, before running 5km in 32^0C with 50% humidity. Run time was significantly improved by 13 seconds and Tc was significantly lower by 0.21 $\pm 0.20^0$C before the 5km run, when wearing an ice vest rather than a T-shirt control. The study was conducted on nine men and eight women, showing that ice vest pre-cooling may be beneficial to both genders. Bogerd et al., (2010) carried out a more recent repeated-measures study on eight males in 29^0C and 80% humidity , and found that cycling time to exhaustion was significantly increased by 07:46 ± 05.45 minutes ($P<0.05$), and mean skin temperature significantly decreased by 2.7 ± 0.78^0C, compared to a T-shirt control. The ability to use ice vests during immediately before heat exposure makes them a practical pre cooling method. However, little changes in Tc have been noted during ice vests pre-cooling (Bogerd et al., 2010; Arngrimsson et al., 2004), suggesting that a pre-cooling method which does lower Tc could show further improvements of performance in hot environments.

Ice slurry consumption is an alternative pre-cooling method, which may lower Tc further than ice vests and be as effective as the commonly used water immersion technique (Siegel et al., 2012). Ingested ice requires $334kJ.kg^{-1}$ of energy for the enthalpy of fusion, therefore removing heat from the body to change ice into water (Tate et al., 2008). An early investigation into the use of ice slurries reported that intravenous cooling of swine using slurries was more effective at lowering brain temperature than chilled saline, and concluded that ice slurries could be a successful pre-cooling method (Vanden Hoek et al., 2004). Siegel et al. (2010) studied run time to exhaustion of 10 males and discovered a 9.5 ± 3.6 minute, 19% ± 6%, significant ($P<0.05$) increase in mean run time following $7.5g.kg^{-1}$BM ice slurry consumption versus a cold water control. Furthermore, Tc was reported to have significantly decreased by 0.66 ± 0.14^0C ($P<0.05$), a larger decrease than previously mentioned following ice vest cooling. Despite this, ice slurries may not be practical for all athletes, as sphenopalatine ganglioneuralgia (brain freeze) was experienced by 3 of the 10 participants, which would be an inconvenient discomfort.

In opposition Ihsan et al. (2010) reported no experiences of sphenopalatine ganglioneuralgia after investigating the effect of 6.8g.kg^{-1}BM ice slurry consumption compared to tap water control on 40km cycling time trials in 7 males, in 30^{0}C heat with 75% humidity. Ice slurry ingestion was stated to have caused a 6.5% increase in time trail completion and lowered Tc by 1.1 ± 0.59^{0}C compared to control. In addition, Yeo et al. (2012) conducted a field based study around a 400m track to replicate an outdoor 10km run, involving 12 (8 males and 4 female) participants. 8g.kg^{-1}BM slurry consumption compared to cold water, significantly improved average run time by 15 ± 39s (0.6±1.4%) and Tc was significantly reduced by 0.4°C ($P<0.05$). However, despite the study using a counterbalanced design, all participants ran en mass around the track, meaning that the difference between ice slurry and cold water ingestion may have been larger, as participants could have attempted to keep pace with their faster group members. Alternatively, Stanley et al., (2010) reported no significant improvement in cycling time trial performance when comparing ice slurry to cold water consumption, 29.47 ± 2.07 minutes for ice slurry versus 29.98 ± 3.07 minutes for cold water ($P>0.05$). These findings may be due to the 75 minute warm up performed before slurry consumption, which increased Tc before the start of the time trial; this is dissimilar to the protocol of Ihsan et al. (2010) who used a 10 minute warm up following ice slurry consumption. Furthermore, Stanley et al. (2010) provided their participants with 1L of ice slurry regardless of their body mass, a greater and less individual specific amount than used by both Ishan et al. (2010) and Seigel et al. (2010). However, because individuals previously exercised for 75 minutes, 1L may not have been enough in this instance to sufficiently pre-cool participants. Overall, it can be suggested that ice slurry consumption of between 6.8g.kg^{-1}BM and 8g.kg^{-1}BM may be an effective pre cooling method, as it may significantly lower Tc and has been shown to minimise the decrease of performance caused by hot humid environments. Furthermore, ice slurries are easily accessible, as they can be made in advance, transported without difficulty, and consumed whilst doing other activities. To add to this, they can be made from varying liquids depends on the desire and taste of the individual – from sports drinks, to high carbohydrate drinks, or simply water.

In conclusion, pre-cooling the body can reduce the levels of physiological strain often seen in hot humid environments. Pre-cooling works by decreasing core temperature, therefore increasing the body's heat storage capacity. It may also work without decreasing core temperature, by decreasing skin temperature, therefore giving individuals the perception of decreased thermal strain. There are various methods of pre-cooling that could be used by instructors, all of which have shown some benefit. However some methods may not be as practically applicable. Arm submersion may occupy more of an instructor's time before a wear, and would not be able to be complete simultaneously to other tasks. Both ice vests and ice slurries are more feasible alternatives which can be used whilst preparing for a wear. Ice slurries possibly offer a larger decrease in core temperature, due to the heat lost for the enthalpy of fusion. Research is needed to identify if pre-cooling methods are effective for instructors to use prior to live fire exercises, and also to identify which method causes the greatest decrease in end Tc, whilst being logistically applicable for instructors to use.

Purpose

The purpose of this project is to evaluate the use of pre-cooling methods prior to severe heat exposure in fire service instructors.

Research Questions

1. Quantify time course of core temperature cooling rate with each pre-cooling strategy.
2. Quantify the physiological responses to heat exposure.
3. Evaluate the physiological and perceptual benefit of pre-cooling prior to heat exposure.
4. Identify the most effective pre-cooling method.
5. Identify the most time efficient method of pre-cooling.

Outcomes

- Identify an appropriate pre-cooling strategy for fire instructors and fire fighters, based on effective and time efficient cooling to reduce subsequent increases in physiological strain, perceived fatigue and thermal discomfort, and inflammation.

Planning & Method

Participants

Eight physically active male University of Brighton students will be recruited to participate in the study. The protocol and any risks involved will be fully explained to all participants, who will then be required to give written informed consent and complete a medical questionnaire.
Participants may be excluded from the study if:

- answers given on the medical questionnaire reveal any medical reason for subjects not to take part, such as: fainting episodes, cardiac problems, hypertensive, etc.,
- they are unclear about the test protocol and risks involved,
- they have suffered from heat illness or injury within the last six months,
- they have been involved in heat acclimation in the previous month.

Experimental Design

The study will be a randomised cross-over design testing four different types of pre-cooling method: Ice Slurry (IS), Phase Change Ice Vest (IV), Radial cooling (RC), No cooling [Control (C)]. All participants will complete the protocol after all cooling methods, and will be randomly assigned to a testing order. Participants will dress in full fire instructor's ensemble and rucksack to replicate breathing apparatus, along with compression undergarments (Odlo, UK). They will rest for 10 minutes at an ambient temperature (19°C, 40%Rh). Following this, participants will enter a heat chamber where they will complete 45 minutes of intermittent exercise, involving alternating every 5 minutes between rest and exercise on the treadmill at $4km.h^{-1}$ and 1% gradient. This protocol has been chosen based on anecdotal evidence from Fire Instructors and unpublished data from the University of Brighton about the average wear time and exercise involved. Previous research shows mean fire exposure temperatures between $41^{0}C$ and $66^{0}C$ (Smith & Petruzzello, 1998; Optimal Performance Limited, 2005), that cause mean core temperatures of $39.1^{0}C$ to $39.8^{0}C$ (Smith et al, 1997; Optimal Performance Limited, 2005). This study will use a heat chamber set at $50^{0}C$ and 0% humidity.

Cooling Methods

Cooling will be completed over the 10 mins prior to heat exposure. RC will require participants to sit will both arms (up to the elbow) in cold tap water (14°C) for 10 mins. IS trials will require the participant to consume 500ml of ice slurry 10mins prior to the heat trial. The IV trial will require participants to wear a phase change ice vest on top of compression garments and under the BA fire kit from 10mins prior to heat, the ice vest will remain on during the trial. The control condition will have no cooling methods applied.

Schematic

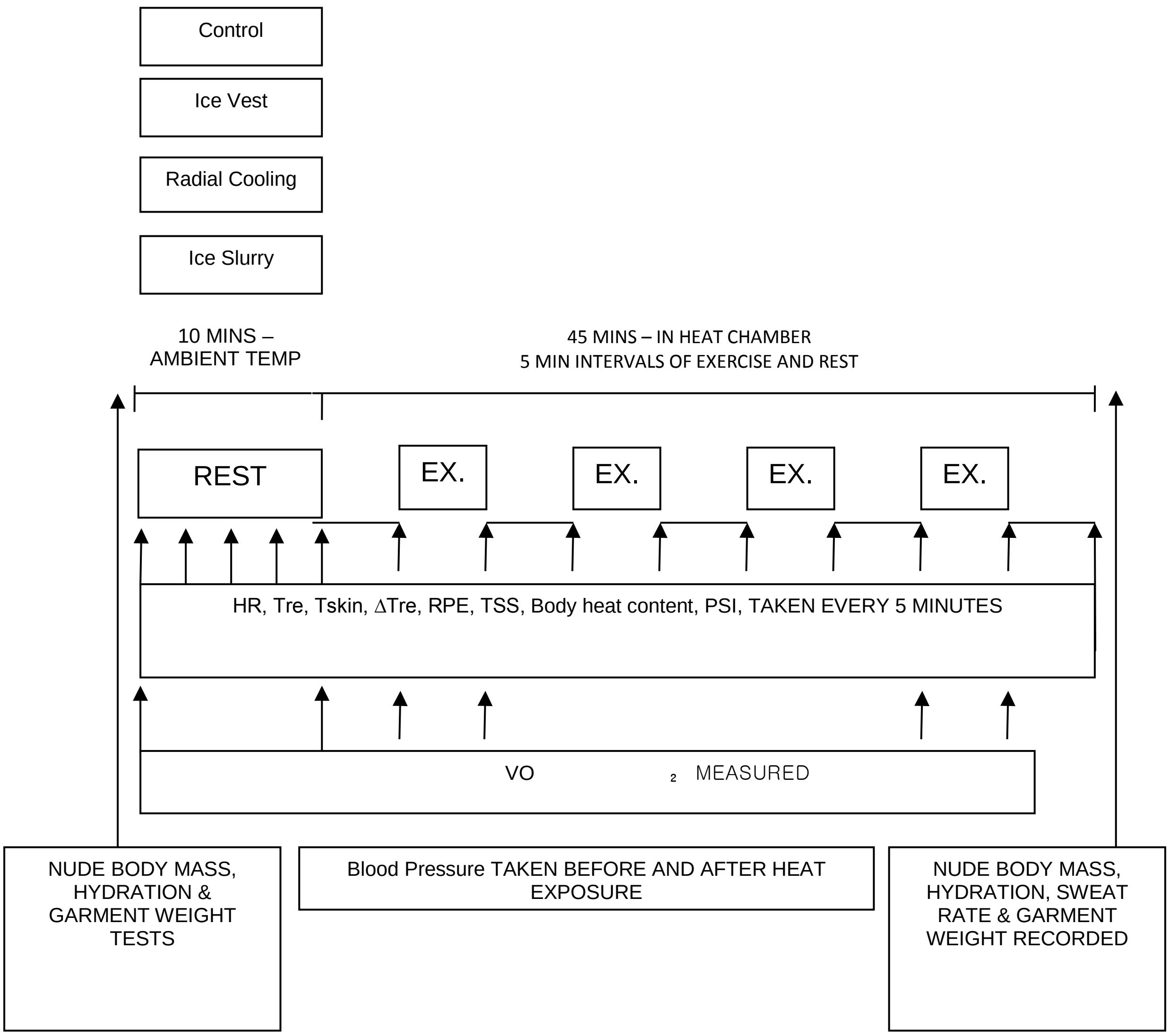

Figure 3: Schematic of experimental design

Measures

Physiological

Before and after all testing nude body mass and hydration status will be recorded. Hydration status will be established based on urine colour (U_{col}), osmolarity (U_{osm}), and specific gravity (U_{spg}). Participants must be hydrated before being allowed to take part in testing: U_{col} must be 3 or less (Armstrong, 2000), U_{osm} must be lower than 400mOsmol.kg^{-1}, and U_{spg} must be lower than 1.020. If participants do not arrive in a euhydrated state, then additional fluid must be consumed until their hydration status is satisfactory. Participants will then be required to rest for 10 minutes in ambient temperatures (19°C, 40%Rh), during which time the cooling trial will commence. During this cooling period physiological measures will be taken every 2 mins. After the resting period physiological measures will be taken every 5 minutes throughout the intermittent exercise. The physiological measures include heart rate (HR) (b.min^{-1}), established from a heart rate monitor (Polar FT1, Polar electro, Kempele,Finald); core temperature (Tre), recorded by rectal probe positioned 10cm past the anal sphincter, skin temperature from four locations, chest, triceps, quadriceps and calf, and blood pressure, measured using an automatic sphygmomameter, which will be positioned underneath the clothing before testing begins. Oxygen uptake (VO_2) will also be measured, using douglas bags, after rest and at the beginning and end of the first and last exercise block - from which RER and energy expenditure will be determined. Percentage change in Tre will also be calculated. From the collected data, mean skin temperature (Tskin) will be determined based on:

Tskin (°C) =0.3(Tchest+Tupper arm) + 0.2(Tupper leg + Tlower leg) (Ramanathan, 1964).

Body heat content will be also calculated using the equation:

Body Heat Content (kcal) = body temperature(°C) x body mass (kg) x 0.83.

Physiological strain index (PSI) will also be determined using the equation recommended by Moran (1998) and Tikuisis (2002):

$$PSI = 5(T_{re}t - T_{re0}) \times (39.5 - T_{re0})^{-1} + 5(HRt - HR_0) \times (180 - HR_0)^{-1}$$

where $T_{re}t$ and HR*t* are simultaneous assessments taken at any time during the exposure, and T_{re0} and HR_0 represent baseline states. Sweat rate will also be established based on:

Sweat rate = (Body mass pre – Body mass post) / Time (minutes).

At the end of the exercise protocol, participant's undergarments will be weighed, to distinguish which undergarment retains the least amount of moisture – as used by Roberts el at (2007).

Blood Measures

Blood will be taken from the anti-cubital fossa using a 20ml syringe pre and post exposure, while the participant is half lying. Blood will be spun in a centrifuge at 2000rpm for 10 minutes at 4°C in four EDTA tubes, placed into ten microvettes and put into ice slurry during transit and then stored at -86°C for later analysis. Interleukin-6 is an inflammatory marker, released to stimulate the immune response. These blood measures will be analysed at the biochemical laboratories at the University of Brighton using enzyme-linked immunosorbent assay plates (ELISA).

Psychological

Two psychological measures will be taken at the end of the resting period and every 5 minutes during the intermittent exercise in the heat: thermal sensation (TSS) and Borg's rating of perceived exertion (RPE).

Controllable Variables

- Participants must arrive in a hydrated state determined by measures mentioned previously. If they do not then they will be required to consume fluid until hydration is achieved. This is to help prevent the occurrence of any heat illness, and prevent the accentuate cardiovascular strain and plasma volume and VO_2 reductions which are associated with dehydration (Cheuvront et al, 2010).
- All testing will be conducted at the same time of day for each participant, to exclude the effect of circadian rhythms, which affect core

temperature, skin temperature (Reilly & Brooks, 1986) and heart rate (Guo & Stein, 2003), therefore impacting on physiological strain.

- Participants will be required to refrain from consuming caffeine 12 hours before participating in any testing session. Caffeine needs to be controlled as it has been shown to increase mean arterial blood pressure and heart rate during exercise in the heat (Stebbins et al, 2001). It has also been reported that it decreases RPE (Doherty & Smith, 2005).
- Consumption of foods should be kept the same for the 12 hours before each testing session. This is to prevent the consumption of different types and amounts of fuel from impacting on the amount of energy available to the individual during testing. No alcohol should be consumed in the 24 hours prior to testing. Individuals must also not consume food within the hour before testing begins.
- Physical activity should also be avoided for 24 hours before testing protocol, to prevent any muscle damage and energy depletion.

Statistical Analysis

Standard statistical analysis procedures will be followed to ensure objectivity and reliability. Data will be checked for normality and sphericity and will be adjusted using the Huynh-Feldt method. Pearson's product moment correlation coefficient will used to determine correlation between selected variables. Two-way repeated measures ANOVA will be used to compare between conditions, over time. All data will be analysed using a standard statistical package (SPSS version 16).

Resourcing

Consumables

Item	Quantity	Cost (£)
Blood Extraction Consumables		30
Lab Consumables		50
Interleukin-6 Assay	1	250
Rectal Thermistors	24	84
		Total Cost inc VAT: £414

Staffing

Staff	Time (hours)
Dr Alan Richardson	10
Miss Emily Watkins (Research Officer)	100
	Total: £1200

GRAND TOTAL: £1641

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