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The effect of hand cooling on intermittent exercise performance whilst wearing a bomb disposal suit

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The effect of hand cooling on intermittent exercise performance whilst wearing a bomb disposal suit

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Abstract

Introduction: Individuals, who are required to wear personal protective clothing (PPC), are more susceptible to suffer from heat strain. This is due to the clothing impeding heat exchange through sweat evaporation to the surrounding environment therefore causing core temperature (T_{core}) to increase (Holmér 1995). The continued rise in T_{core} and inability to lose heat creates a micro-environment within the PPC results in the individual suffering from uncompensable heat stress (UHS). The submersion of the hands or feet in cool water has been shown to improve exercise tolerance by reducing UHS whilst wearing PPC (Livingstone *et al.* 1989; 1995). Hand cooling has been found to be effective at reducing core temperature however; the effectiveness at different levels of core temperatures due to different durations or of exercise while wearing PPC has not been reported.

Aim: The primary aim of this study was to determine the effectiveness of hand cooling at different durations of exercise whilst wearing a bomb disposal suit.

A secondary aim was to determine whether having periods of 'mid' cooling during exercise is effective at reducing heat strain in comparison to having no cooling periods.

Methods: Eight healthy, males (mean age = 21.6 ± 1.5 years, mean body mass = 79.8 ± 12.6 kg) volunteered for this study. The test protocol required the participants to perform stepping exercise at 12 steps$\cdot$min^{-1} for 15 minute intervals. During each trial subjects undertook either one, two or three 15 minute bouts of exercise. Each bout was separated by a 15 minute rest period. At the end of each trial a 30 minute rest period was undertaken where cooling was applied. A further trial was undertaken where three 15 minute bouts were undertaken with cooling applied after each bout. During each rest period participants remained in the full Explosive Ordinance

Disposal (EOD) ensemble. During hand cooling the participants immersed both hands up to the wrist in 15 litres of water at an initial temperature of 10^oC. T_{core} (rectal, aural), skin temperature (Arm, Back, Chest, Thigh, Hand and Finger), Heart rate (HR), Blood lactate (Bla), RPE and TS were measured continuously with VO_2 being measured during the last minute of each bout of exercise. Heat extraction from the hands was calculated during each immersion period. Data were expressed as mean and standard deviation and analysed by analysis of variance with repeated measures (trial × time) on both factors. Where significance was achieved ($P<0.05$) Tukey post-hoc comparisons were undertaken.

Results: There was no significant interaction for rectal temperature (T_{rec}) between any of the trials ($p>0.05$), although there was a significant main effect for trial (15 MIN vs. 45 MIN and 45 MIN vs. MID-COOLING ($p<0.05$). There was no significant interaction for aural temperature (T_{aur}) ($p>0.05$), although there was a significant main effects for time and trial (15 MIN vs. 45 MIN and 45 MIN vs. MID-COOLING) ($p<0.05$). A significant interaction was observed for hand skin temperature between 45 MIN vs. MID-COOLING trials ($p<0.05$). There were no significant differences for heat flow ($P>0.05$).

Discussion: Significant main effects were found between trials for T_{rec} and T_{aur}, although there was no significant interaction. The reduction in T_{core} during cooling periods was not as much as has been previously reported, however this may be a result of T_{rec} and T_{hand} not being above thresholds required for hand cooling to be effective (Allsopp and Poole 1991 and Greenfield 1963). The use of MID-COOLING may not reduce T_{core} greatly, however it is maintained at lower levels and therefore may be a more relevant structure for work : rest in the field as it would irradiate the need to continually monitor T_{core} which is not always possible.

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1.0 Introduction

The normal functioning of body systems are heavily dependent on an individuals core body temperature (T_{core}) remaining between 36.5 to 38.5^{o}C (Moran and Mendal 2002). This is achieved through a variety of thermoregulatory responses which try to maintain body temperature of around 37^{o}C (Cheung *et al.* 2000) although T_{core} often fluctuates slightly throughout the day due to circadian rhythms (Kurz 2008). Slight rises or falls in T_{core} can cause a decreased functioning of body systems with T_{core} as low as 33.5^{o}C or as high as 41.5^{o}C can causing thermal injury or even death (Moran and Mendal 2002).

T_{core} is mainly dependent on the amount of heat produced from metabolic activity. However, environmental factors such as temperature and humidity also have an influence. In order to meet the metabolic demands, metabolic processes require a variety of nutrients and oxygen (Havenith 1999). At rest, metabolic activity is relatively low therefore demands placed on the thermoregulatory system are low. However during exercise metabolic activity increases to meet the energy demands required to perform the exercise (Havenith 1999). As exercise is relatively inefficient with only 25% of energy produced being used for human movement, the majority of the remaining energy is stored as heat (Marsh and Sleivert 1999). The accumulation of heat during exercise has been considered to be the main limiting factor in performance particularly in endurance exercise in hot environments (Gonzalez-Alonso *et al.* 1999) with studies indicating that once a T_{core} of ~39^{o}C is achieved exercise performance is limited due to the onset of fatigue (Quod *et al.* 2006).

Although exercise and environmental conditions can contribute to the onset of hyperthermia, the choice of clothing worn also influences the thermoregulatory response. Certain clothing setups and materials can have an advantageous effect on thermoregulation however, some; particularly those used in personal protective clothing (PPC), impede heat loss (Giesbrecht *et al.* 2007). The clothing worn and materials used in PPC are often heavy, thick and treated in order to make them impermeable to hazardous substances (Allsopp and Poole 1991). Although effective at protecting the individual from physical dangers, PPC acts as a barrier and prevents the ability to lose heat through evaporation therefore exposing individuals to Uncompensable heat stress (UHS) (Montain *et al.* 1994).

In order to prevent UHS cooling methods have been suggested to help delay the onset of hyperthermia. Methods used to reduce T_{core} have included; whole body water immersion (Yeargin *et al.* 2006), ice vest cooling (Ückert and Joch 2007) and part body cooling e.g. hands and feet (Livingstone *et al.* 1989, 1995). For those required to wear PPC the use of hand and foot cooling is the most practical and its effectiveness has been investigated (Allsopp and Poole 1991, House *et al.* 1997, Livingstone *et al.* 1989 and 1995). Hand cooling has been found to be effective at reducing T_{core} however; its effectiveness after different durations or intensities of exercise while wearing PPC has not been reported. Therefore this study was devised to exercise individuals in PPC to reach different levels of T_{core} after differing durations of exercise to determine the effectiveness of hand cooling.

The following literature review focuses on thermoregulatory responses during exercise in normal and hot conditions, PPC, physiological responses to wearing PPC during exercise and the methods used to reduce increases in T_{core} during exercise.

2.0 Literature Review

2.1. Control of Body Temperature

Although internal body temperature is referred to as being the 'core' this does not describe its anatomical location (Livingstone *et al.* 1983). This is due to there being no one single, internal location that shows an average internal body temperature. Instead, body temperature is controlled by the thermoregulatory centre within the hypothalamus which receives internal temperature information from a number of sites (Byrne and Lim, 2007). This centre is made up of the preoptic posterior and the preoptic anterior hypothalamus, which are responsible for heat production and heat dissipation respectively (Mekjavic and Eiken 2006). The control of body temperature is achieved through the coordination of these centres to maintain T_{core} within safe parameters (Gleeson 1998; Wendt *et al.* 2007). Rather than a 'set point' of T_{core} there is an 'interthreshold zone' in which body temperature can fluctuate without causing a thermoregulatory response (Mekjavic and Eiken 2006). The hypothalamus receives afferent information on body temperature by measuring blood temperature circulating through it and also from thermoreceptors located all over the body (Gleeson 1998). The thermoafferent information is collated together and depending on body temperature, there is an excitatory and an inhibitory stimulus to either one of the preoptic centres. In cool conditions there is a balanced response which causes even sensations of warmth and cold, resulting in thermal comfort (Mekjavic and Eiken 2006).

The physiological responses associated with changes in body temperature occur through vasomotor control via the sympathetic nervous system (SNS). With high T_{core}

the anterior hypothalamus will be stimulated causing the vasodilation of blood vessels to allow a greater flow of blood to the skin (Kenny and Johnson 1992). This response allows the transfer of heat from the body to the surrounding environment. If T_{core} continues to rise sweating threshold is reached resulting in heat loss through the evaporation of sweat (Gleeson 1998). In times of low body temperature this results in the opposite response with the posterior hypothalamus causing a vasoconstriction of blood vessels and ultimately shivering (Mekjavic and Eiken 2006).

Although the thermoregulatory centre aims to maintain T_{core} within this 'intertheshold zone' it is rarely possible. Thermal and non-thermal factors such as exercise and environmental conditions have a profound influence on the control of body temperature by either increasing or decreasing T_{core} to such a level that a thermoregulatory response is necessary.

2.2 Temperature regulation during exercise

During exercise the ability to maintain T_{core} is more difficult, as heat production is dependent on exercise intensity (Mitchell *et al.* 2001). In a cool environment at the start of continuous exercise there is a balance between heat loss and gain therefore T_{core} plateaus. The imbalance occurs when heat gain is greater than heat loss, resulting in T_{core} to rise. The circulatory system must meet both the metabolic needs of muscles along with thermoregulatory needs of the body (Fogarty *et al.* 2004). An increase in heat production from the skeletal muscles causes a greater need for heat removal predominantly via the blood (Gleeson 1998).

There are four heat exchange pathways used in the thermoregulatory response to dissipate heat whilst exercising, these are conduction, convection, radiation and evaporation (Havenith 1999). The main pathway for heat removal during exercise is the evaporation of sweat. All these pathways work on the same principle of heat transferring along a thermal gradient, from a higher to a lower temperature. Heat loss through conduction is relatively small during exercise in comparison to other pathways, with only around 3% of total heat loss occurring via this pathway (Wendt *et al.* 2007). Conduction is the transfer of heat from two objects in direct contact. For example if the skin were to come into contact with another object of a lower temperature heat would be transferred from the skin to the object. Convection has a more active role in heat removal. As air flows around the skin it is typically cooler, the thermal gradient results in the warm molecules being replaced by cooler ones at the skins surface. The heat from the skin is therefore transferred to the surrounding air (Havenith 1999). Thirdly heat also leaves the body through electro-magnetic radiation. This pathway allows heat to be removed from the body when there is a difference between environmental temperature and skin temperature. Heat is transferred through radiation waves to objects within the surrounding environment. Unlike conduction the individual does not need to be in direct contact with the object (Havenith 1999). Finally the forth heat exchange pathway is the evaporation of sweat from the skin and respiratory tract (Fortney and Vroman 1985). At rest the evaporation of sweat accounts for around 25% of heat lost, however during exercise evaporation has been found to increase 10-fold and is the main mechanism of heat loss during exercise (Fortney and Vroman 1985; Hargreaves 2008). The increase in sweating causes a reduction in blood volume, reducing stroke volume (SV), causing heart rate (HR) to increase which effects cardiac output (Q) (Gonzalez-Alonso *et al.*

1999). With dehydration reducing blood volume, HR is unable to compensate indefinitely and maintain Q, this ultimately results in performance levels decreasing.

During exercise the body is in competition with itself to maintain metabolic and thermoregulatory needs (Kenny and Johnson 1992). Due to the inefficiency of the muscular force reactions the increase in muscular activity during exercise causes an increase in the amount of heat produced (Gleeson 1998). Only a small amount of the heat produced in the active muscles is lost through the overlying skin (Gleeson 1998), with the majority of the heat being transported to the 'core' by venous blood (Fortney and Vroman 1985). The changes in muscular heat production is detected by the thermoreceptors within the skin which send afferent information back to the hypothalamus, changes to T_{core} are measured by the hypothalamus directly as it detects the rise in blood temperature passing through it. The increase in T_{core} causes the anterior hypothalamus to initiate the appropriate thermoregulatory response to remove heat (Mekjavic and Eiken 2006).

The main response is an increase in skin blood flow (SkBF) (Fortney and Vroman 1985). During the very early stages of exercise there is a vasoconstriction of peripheral blood vessels, particular those in the fingers, hands and forearms (Kenny and Johnson 1992). Therefore at the start of exercise the majority of heat produced is stored causing T_{core} to increase (Kenny and Johnson 1992). This response is associated with the sympathetic vasoconstrictor response which is typically associated with exercise. As T_{core} continues to rise, the vasoconstrictor effect is overridden and the peripheral blood vessels vasodilate to increase SkBF (Fortney and Vroman 1985).

2.2.i Cardiovascular Responses

The required increase in SkBF to dissipate heat coupled with the increase in blood flow to exercising muscles results in the vasomotor reflex cutaneous vasodilation (Wendt *et al.* 2007). This response involves the redistribution of blood flow away from inactive skeletal muscles and inactive tissues (e.g. digestive tract, gut) to meet the increased metabolic demands of active skeletal muscles whilst maintaining thermoregulatory demands to lose heat (Wendt *et al.* 2007). This response is due to the sympathetic vasoconstrictor response which is typically associated with exercise as it allows for the maintenance of Q whilst increasing blood pressure. The redistribution of blood flow from inactive tissues to active tissues has been shown by Ahlborg *et al.* (1986). Ahlborg *et al.* (1986) found that during rest leg blood flow was 0.44 $l\cdot min^{-1}$ with hepatic blood flow being 1.77 $l\cdot min^{-1}$. However during leg exercise blood flow changed considerably, blood flow to the legs increased to 2.96 $l\cdot min^{-1}$ and hepatic blood flow decreased to 1.19 $l\cdot min^{-1}$. These cardiovascular responses are required to maintain Q. During exercise the evaporation of sweat reduces blood volume, therefore causing SV to decrease. For Q to be maintained HR increases therefore the amount of blood flow can be maintained. The change in blood flow to active tissues causes’ blood pressure (BP) to increase due to the increased amount of blood being transported to the these tissues. The increase in cutaneous vasodilation also increases the amount of heat transported from the core to the body surface to help to reduce T_{core}. The changes in SkBF along with increases in skin temperature are detected by the anterior hypothalamus due to the thermoafferent information being sent through sensory nerves.

2.2.ii Sweating Responses

To further aid heat loss when sweat threshold is reached the anterior hypothalamus initiates the sudomotor reflex response to stimulate the eccrine glands in the skin to start secreting sweat (Figure 2.1) (Fortney and Vroman 1985). The evaporation of sweat on the skin surface causes a cooling effect (Gleeson 1998). Sweat secretion is an active 2 stage process and involves the secretion and re-absorption of sodium ions. The active transport of sodium ions into the secretory coil also results in the passive transport of water following them. The fluid is then transported into the sweat gland duct as the sodium ions are actively reabsorbed. As sweat rate increases the less amount of sodium ions are reabsorbed (Fortney and Vroman 1985).

If exercise continues at the same intensity, T_{core} will continue to rise, and be coupled with an increase in sweat rate, however this cannot continue indefinitely with the loss of fluid causes not only a reduction in Q but also causing dehydration. The fluid lost from sweating is from the blood plasma, during times of high sweat rates this causes blood volume to decrease. The reduction in blood volume causes SV to decrease as the water produced from the catabolism of carbohydrates is not sufficient to maintain water losses (Gleeson 1998). Research has shown that a reduction of around 2% in body mass through sweating can cause a reduction in performance (Maughan and Shirreffs 2004).

Figure 2.1: Thermoregulatory control and response during exercise in the heat (Gleeson 1998)

Throughout the duration of exercise there is an imbalance in the amount of heat produced and dissipated, resulting in an elevated T_{core}. This imbalance is due to the early vasoconstriction of peripheral blood vessels within the skin and resulting increase in T_{core} (Gleeson 1998). The aim of the thermoregulatory response during exercise is to try and maintain T_{core} within the 'interthreshold zone'. As has been stated heat production is dependent on exercise intensity, however the environmental conditions also have an influence on the functioning and efficiency of the thermoregulatory response.

2.3 Thermoregulatory response to exercise in the heat

Along with exercise intensity, the environment can also affect the rate of heat removal or heat gain in the body (Havenith 1999). The thermoregulatory response when exercising in the heat is similar to that in ambient conditions, although the degree of response is much greater.

The main limiting factor for endurance performance is the attainment of high T_{core} when exercising in hot environments (Gonzalez-Alonso *et al.*1999). When exercising in a hot environment the thermal gradient between the skin and surrounding air will be reduced or reversed, therefore resulting in a reduced rate of heat loss or conversely heat gain (Wendt *et al.* 2007). The time to fatigue is reduced due to the attainment of critically high T_{core} earlier in exercise and also the inability to sustain Q (Hargreaves 2008). When exercising at high intensities heat stress is accelerated due to a reduction in SV, Q, muscle blood flow and O_2 delivery, therefore reducing maximal oxygen uptake ($\dot{V}O_{2max}$) (Hargreaves 2008). In circumstances when environmental temperature is greater than skin temperature, an individual starts gaining heat instead of losing it, therefore putting them at a greater risk of hyperthermia (Havenith 1999). Air humidity can also influence the rate of heat loss during exercise. Typically moisture concentration on the skin surface is greater than in the environment thus allowing sweat to evaporate and therefore reduce body temperature. However, there may be situations when this gradient is reversed with the moisture levels being higher in the environment than on the skin (Wendt *et al.* 2007). When an individual is subjected to this type of environment it is very stressful and should only be exposed to it for a short period of time (Havenith 1999).

Exercise intensity and environment can influence thermoregulation by increasing T_{core} and preventing heat dissipation. As eluded to earlier environments where temperature and humidity are high can cause heat gain rather than loss. This response can also be influenced by the type of clothing worn, in particular, those required to where Personal Protective Clothing (PPC).

2.4 Clothing and its influence on thermoregulation

As noted above, exercise intensity and environmental conditions have a large impact on body temperature regulation. However clothing has also been found to influence the ability to lose heat from the body to the environment (Pascoe *et al.* 1994).

Clothing typically acts as a barrier between the skin and the surrounding environment, creating an insulating layer (Gavin 2003). The layer hinders or even prevents the evaporation of sweat from the skin, causing skin temperature, and therefore T_{core}, to increase (Pascoe *et al.* 1994). Greater increases in T_{core} whilst wearing certain clothing elicit similar physiological responses that occur whilst exercising in the heat, although fatigue occurs at much lower exercise intensities. When designing and developing clothing the requirements of the garment need to be considered, whether these are protective or performance aiding. The ideal clothing should be able to interact with the surrounding environment, allowing heat storage in cold environments or loss in hot environments so that work capacity is not affected (Pascoe *et al.* 1994).

2.4.i Protective Clothing in Work

PPC are garments worn to completely separate the individual from the surrounding environment, therefore the ability of the clothing to interact with the environment is compromised for protection. Wearing protective clothing is a requirement in a number of professions (Young *et al.* 1987). Fire fighters, military personal (NBC) and industrial workers are all required to wear some form of PPC (Giesbrecht *et al.* 2007).

The standard set up for protective clothing consists of trousers, a jacket, protective boots, protective chest plate, a helmet and gloves (Bomalaski *et al.* 1995). The ideal

PPC should allow T_{core} to remain within safe limits by allowing skin temperature to be maintained and allow sweating to prevent discomfort (Parsons 1988). However having these characteristics for PPC is rather contradictory particularly for those who are required to work with hazardous liquids or gases as the PPC protects the user from coming into contact with them. PPC often has high insulative properties which consist of several thick layers making them bulky and heavy, whilst also being treated with fire retardant (Giesbrecht *et al.* 2007). Fabrics treated with these finishes can be uncomfortable to wear, as they are impermeable to water, resulting in perspiration being trapped against the skin. The impermeable nature of the materials used to make the protective clothing prevents heat dissipation through convection, conduction, radiation and in particular evaporation (Allsopp and Poole 1991; Fogarty *et al.* 2004), however this is seen as a necessary compromise in order for the clothing to achieve the protection needed (Cheung *et al.* 2000). The inability to lose heat to the surrounding environment and the weight of the clothing increases the thermal and physiological strain put on the individuals (Levine *et al.* 2001).

The amount of surface area PPC covers also limits the ability of the individual to lose heat. Typically the only areas that can be exposed whilst wearing PPC are the face and occasionally the hands, however this is only when the mask covering the face is lifted off and when not wearing gloves. The wearing of helmets although does not cover a large surface area, prevents evaporative heat loss from one of the main body areas in which this occurs. Although the head only accounts for a relatively small section of total body surface area, between 30 to 40% of the body’s heat is lost from the head (Rasch *et al.* 1991).

2.4.ii Physiological responses whilst wearing PPC

When wearing PPC the thermoregulatory response is similar to the response whilst exercising in the heat. The same thermal responses occur with T_{core} increasing resulting in SkBF increasing and resulting in an increase in sweat rate to lose heat through evaporation (Gleeson 1998). The heat produced whilst wearing the PPC is unable to evaporate through the clothing. As a result a micro-environment is formed between the skin and clothing (Montain *et al.* 1994). At first, body temperature is maintained as some evaporative heat loss can occur into the micro-environment. However as heat production continues to increase the evaporative capacity of the environment cannot meet the evaporative heat loss demands (Cheung and McLellan 1998). Therefore the body begins to store heat as it cannot be lost to the environment, causing body temperature to increase and resulting in Uncompensable Heat Strain (UHS) (Montain *et al.* 1994).

Wearing PPC also causes greater cardiovascular strain on individuals, similar to those witnessed when exercising in the heat. The inability to maintain Q is due to the reduction in SV and the increase in HR being unable to compensate for this. These cardiovascular responses occur due to the impermeable nature and weight of the clothing.

Personnel required to wear PPC are highly susceptible to UHS, especially those who frequently work in high environmental temperatures (Selkirk *et al.* 2004; Allsopp and Poole 1991). The impermeable nature of PPC has resulted in a number of interventions being developed to reduce increases in T_{core} through a range of cooling techniques.

2.5 Cooling techniques

Whilst wearing PPC the natural thermoregulatory response alone is often not sufficient to cope with the increase in heat gain, due to UHS. To aid body temperature regulation a number of cooling methods have been developed. The method used is often dependent on the type, duration and intensity of exercise or work being performed whilst also dependent on the environmental conditions. Furthermore the types of cooling can vary in a number of ways through duration, timing, temperature of the coolant and also the part of the body cooled. The methods of reducing hyperthermia and UHS include whole-body / part-body cooling (Yeargin *et al.* 2006; Livingstone *et al.* 1989, 1995), heat acclimatisation (Cheung and McLellan 1998), rehydration (Wendt *et al.* 2007) and hyperhydration (Marino 2002). Although many of these cooling techniques are effective at reducing T_{core}, many of them are not appropriate or practical for individuals required to wear PPC and who are working in an industrial environment. Rather than maintaining T_{core} and preventing it from reaching critical levels, many of these cooling techniques are not implemented until the end of exercise or, if critical T_{core} is reached, ~39^{o}C including whole-body immersion and rehydration. Also many of the cooling techniques require the removal of clothing and access to area's of the body which are covered by the PPC, making them impractical e.g. whole-body immersion, ice vest – torso cooling. The use of hand and foot cooling for those required to wear PPC have been found to be the most effective. This method of cooling requires the individual to submerge just their hands or feet in water, therefore eradicating the problems associated with removing a large amount of the PPC.

2.5.i Hand and foot cooling

To combat the impracticalities associated with whole body cooling a number of studies have examined cooling different areas of the body to try and reduce overall heat strain, in particular the hands and feet. Hand and foot cooling is effective at reducing T_{core} due to the high concentration of blood vessels in these areas (House *et al.* 1997; Grahn *et al.* 2005). Within the extremities there are arteriovenous anastomoses (AVAs) which are found in the palms of the hands and soles of the feet (Grahn *et al.* 2005) these control blood flow through these areas. These small interconnecting blood vessels, which are smaller than the veins and arteries allow blood to bypass the capillary beds (House *et al.* 1997). The responses of the AVAs are controlled by the hypothalamus and therefore are influenced by skin and T_{core} (House *et al.* 1997). When T_{core} rises, the vessels in the hands or feet dilate allowing heat to be dissipated to the surrounding environment (House *et al.* 1997). When the hands or feet are placed in cool water the vessels within them remain dilated and allow for heat transfer to the water, therefore cooling the blood circulating through them (House *et al.* 1997). Once the blood has been cooled it is transported directly to the core by a series of superficial veins resulting in T_{core} being reduced or maintained (Allsopp and Poole 1991).

There have been a number of studies that have examined the effectiveness of hand cooling when exercising or when wearing PPC, with the majority supporting the use of this method. Grahn *et al.* (2005) studied hand cooling during endurance exercise and found that it prolonged performance, with cooling being more effective towards the latter stages of exercise than the beginning. Within this study Grahn *et al.* (2005) combined hand cooling with the application of subatmospheric pressure to the hand.

Altering the pressure surrounding the hand further improved heat removal and endurance performance. A greater amount of heat removal was achieved due to an increase in blood flow to the hand therefore there was more blood to extract heat from (Grahn *et al.* 2005). The research by Grahn *et al.* (2005) is supported by Hsu *et al.* (2005) who also found hand cooling to be effective at reducing T_{core} and improving aerobic performance although a negative pressure was not applied to the hand.

The use of hand cooling has also been studied in intermittent exercise (Price *et al.* 2007; Yeargin *et al.* 2006). Price *et al.* (2007) studied the effect on hand cooling on intermittent performance, suggested that although hand cooling was effective, the degree of success was dependent on T_{core} prior to cooling (Price *et al.* 2007).

2.5.ii Hand cooling and PPC

The use of hand cooling for individuals who wear PPC whilst working is considered the most appropriate cooling method as it can be easily incorporated into the required work and rest periods and overcomes the issues of impracticality associated with whole-body cooling (Selkirk *et al.* 2004). Several studies have investigated the effects of hand and feet cooling on T_{core}, a summary of these are provided in Table 2.1. Livingstone *et al.* (1989) examined the effects of hand cooling on heat tolerance whilst wearing PPC and found that it was effective at reducing core body temperature and therefore increased the ability of subjects to remain in a hot environment. These findings were supported by Allsopp and Poole (1991), who also found that individuals wearing NBC had a reduction in T_{core} and therefore heat strain when subjected to hand cooling.

Allsopp and Poole (1991) also compared the cooling potential of water at 25^{o}C and 10^{o}C. They found that both water temperatures were effective at reducing heat strain in comparison to no hand cooling. However, 10^{o}C water allowed for 120 Watts of heat loss, whereas the 25^{o}C water allowed only 70 Watts. These findings are supported by several other studies, House *et al.* (1997) compared water temperatures of 30, 20 and 10^{o}C and found similar results. In this study participants were required to immerse both the hands and forearms. Although all temperatures were effective at reducing core temperature, water at 20^{o}C and 10^{o}C were significantly more effective at reducing core temperature than at 30^{o}C. House *et al.* (1997) also noted that at cooler water temperatures the initial rate of cooling was greater. However, after around 30 min of cooling the T_{core} for 20^{o}C and 10^{o}C were similar.

Giesbrecht *et al.* (2007) studied hyperthermic fire-fighters who immersed both their hands and forearms in 10^{o}C and 20^{o}C water. In this study hand cooling alone was also compared with immersing both the hands and forearms. Giesbrecht *et al.* (2007) found that when the subjects immersed only their hands in 20^{o}C water T_{core} did not reduce, contradicting the findings of Livingstone *et al.* (1989). However hand cooling alone was found to be effective using 10^{o}C water. When the forearms were also immersed T_{core} was reduced to a greater extent in both 20^{o}C and 10^{o}C water. The greatest amount of cooling occurred with 10^{o}C water supporting the findings of House *et al.* (1997). The results from these studies support the principles that the greater the thermal gradient and the greater the surface area exposed the greater amount of heat loss achieved.

It would not be unreasonable to suggest using freezing water (0^oC) to achieve the fastest and greatest amount of heat loss (House 2003). The use of 0^oC water has been shown to be even more effective at reducing core temperature than 10^oC water (House 2003), however several issues about the practically of using this water temperature and even this method needs to be considered. A positive aspect is that water temperature could be more easily regulated as the ice will melt at a much slower rate in the water when at 0^oC. This would eradicate the need for continually monitoring water temperature through a thermometer, something which is required when using a water temperature of 10^oC (House *et al.* 2003). Although the use of iced water may be more practical, there would be a greater chance of the blood flow to and from the hands being restricted due to the vasoconstriction of blood vessels (House *et al.* 2003). The reduction in blood flow would reduce cooling capacity as the majority of the blood would remain in the core of the body therefore the amount of heat removed through the skin to the water would be reduced (House *et al.* 2003). Another issue to consider is the comfort of the participants whilst being subjected to cooling. Placing the hands in 'iced' water maybe extremely uncomfortable for the participants to do, which may prevent them from keeping their hands in the water for a prolonged period of time. In the present study a warmer water temperature of 10^oC was used as it would be more comfortable for the participants to keep their hands in for long periods of time whilst also having a cooling effect of T_{core}.

A possible issue associated with hand cooling is its effectiveness at reducing T_{core} when as part of the PPC individuals are required to wear gloves. The wearing of rubber gloves whilst wearing NBC is a typical requirement, which could therefore impede the rate of heat removal from the hands. Khomenok *et al.* (2008) found that wearing rubber gloves during hand cooling has a minimal effect on the efficiency of hand cooling, a finding further supported by Allsopp and Poole (1991) and House *et al.* (2003) who both found hand cooling to be effective at reducing T_{core} whilst wearing gloves. Although House *et al.* (1997) acknowledged that wearing gloves reduced the efficiency of hand cooling, it was suggested that wearing gloves may be necessary to prevent skin temperature from falling too low resulting in the vasoconstriction of blood vessels.

In the present study, participants wore an Explosive Ordinance Disposal suit, typically associated with bomb disposal. Individuals within this profession rarely wear gloves as they require the dexterity in their fingers, which can be impeded wearing gloves. Therefore in the present study participants did not wear gloves during trials and were glove-less during cooling periods.

2.5.iii Foot cooling and PPC

The use of the hands for cooling in some circumstances may not be appropriate particularly for those working within bomb disposal as exposing them to cold water my effect their dexterity and therefore affect their ability to perform in their job (Livingstone *et al.* 1995). Livingstone *et al.* (1995) tried to determine whether cooling the feet could be used to reduce core body temperature. Along with a water bath, a pair of cooling socks was also tested. In this study both the water bath and cooling socks managed to reduce core temperature with similar values for heat extraction to that observed for the hands (~100W). To find that the socks were also effective at removing heat can help with the practical application of these being used in the field.

Although the cooling socks are effective the equipment associated with this method is rather cumbersome. Therefore of the cooling methods hand immersion is more frequently used as they are more accessible than the feet and do not require the removal of any clothing. Heat extraction from the hands and feet has been found to be effective due to the high density of capillaries in both the hands and feet, this allows for the quick transfer of heat and also transport of the cooled blood directly to the heart therefore reducing T_{core} (Livingstone *et al.* 1995).

Table 2.1 Summary of hand and foot cooling studies.

(*TM = Treadmill, HC = Hand cooling, FC = Foot cooling, H&FC = Hand and forearm cooling, NC = No Cooling, IV = Ice vest, RN = Royal Naval, NBC = Nuclear Biological Clothing*)

Author	**Subjects**	**Mode of Activity**	**Cooling Method**	**Main Outcome**
Livingstone *et al.* (1989)	n = 5, Male, Military personnel, chemical protective clothing	TM, walked at 4.5km·h^{-1} for various durations.	HC at 10, 15, 20, 25, 30^{o}C	Cooling occurred at all temps, greatest cooling at lower water temps.
Allsopp and Poole (1991)	n = 6, 24-37yrs, NBC clothing	Stepping at 20 steps·min^{-1} until T_{aur} 37.5, 38.0 and 38.5^{o}C	HC at 25 or 10^{o}C and NC	The cooler the water the greater the reduction in T_{core}. Immersion during rest periods prolongs overall work time.
Livingstone *et al.* (1995)	n = 6, Military personnel	TM, walked at various speeds and durations.	FC 10, 15, 20, 25, 30^{o}C and Cooling socks	Greater decreases occurring at lower water temps. Cooling socks also effective, with greater cooling occurring during latter stages of exercise.
House *et al.* (1997)	n = 4, Male, 21-32yrs	Stepping at 12 steps·min^{-1}, RN fire fighting clothing until T_{aur} reached 38.5^{o}C	HC 10, 20, 30^{o}C and NC	Greater cooling rate occurred at lower water temps. Vasoconstriction did not occur within the hands in any of the trials.

Table 2.1 continued

House *et al.* (2003)	n = 10, Male, Military personnel	Stepping at 12 steps·min^{-1}, RN NBC clothing, for 3 hrs (10 min work : 5 min rest)	HC, 10, 0^{o}C, with and without IV.	Greatest reduction occurred with IV and HC 0^{o}C. Vasoconstriction of blood vessels can be possible.
Giesbrecht *et al.* (2007)	n = 6, Male	Stepping for 20 min bouts at 20 steps·min^{-1}	HC, H&FC 20 and 10^{o}C	Greatest cooling occurred with hands and forearms at 10^{o}C water. With 20^{o}C water forearms should also be immersed with hands to be effective

Cooling overall body temperature by immersing the hands or feet seems to be effective and consistent, however the time at which cooling should occur needs to be addressed.

When considering the data from these studies it is evident that cooling the extremities is an effective method of reducing T_{core}, with cooling the hands being the most frequently used. These studies have shown that when a greater surface area is subjected to cooling, the rate at which T_{core} falls is greater. When comparing hand cooling with hand and forearm cooling, the reduction in heat strain and cooling rate has been much faster when hands and forearms have been cooled. Using the hands and forearm's for cooling is not always practical for those required to wear PPC as it would be difficult to expose them. The rate of cooling has also been suggested to be greater at higher T_{core} due to a greater drive for SkBF and a greater thermal gradient from the hands to the water. Varying water temperatures has also been compared with colder water temperatures being the most effective at reducing core temperature due to a greater thermal gradient. Although studies have examined varying water temperatures and their effectiveness at reducing T_{core}, none have studied the effect of hand cooling on T_{core} after exercising for different durations of exercise.

2.6. Aim

The primary aim of this study was to determine the effectiveness of hand cooling at different durations of exercise whilst wearing a bomb disposal suit.

A secondary aim was to determine whether having periods of ‘mid’ cooling during exercise is effective at reducing heat strain in comparison to having no cooling periods.

2.7. Hypothesis

Null Hypothesis 1: There will not be a difference in heat loss at different durations of exercise.

Alternative Hypothesis 1: At higher core temperatures, hand cooling will cause a greater reduction in heat strain compared to lower core temperatures.

Null Hypothesis 2: Periods of mid-cooling will have no effect on core temperature during exercise.

Alternative Hypothesis 2: Hand cooling in between exercise bouts will significantly reduce core temperature and thermal strain compared to having no cooling periods.

3.0 Methods

3.1 Participants

Eight healthy men aged 21.6 years ± 1.5 years and a body mass 79.8 kg ± 12.6 kg volunteered to participate in this study. Seven were rugby league players; one was a football player and one a gymnast. A consent form informing each participant of the purpose, possible risks and benefits of participating was completed by each volunteer. All procedures were approved by Coventry University Ethics Committee.

3.2 Experimental Design

Each participant was required to visit the laboratory on four separate occasions. Each trial was completed in a randomised and counter-balanced order. During each trial subjects undertook either one (15 MIN), two (30 MIN) or three (45 MIN) 15 min bouts of exercise. Each bout was separated by a 15 min rest period. At the end of each trial a 30 min rest period was undertaken where hand cooling was applied. A further trial was undertaken where three 15 min bouts were undertaken with cooling applied after each bout (MID-COOLING) (Figure 3.1). This experimental design was undertaken in order to compare the effects of cooling at different levels of T_{core} to be achieved (15 MIN vs. 30 MIN vs. 45 MIN) as well as determining the effects of cooling vs. no cooling through 3 x 15min bouts of exercise (45 MIN vs. MID-COOLING).

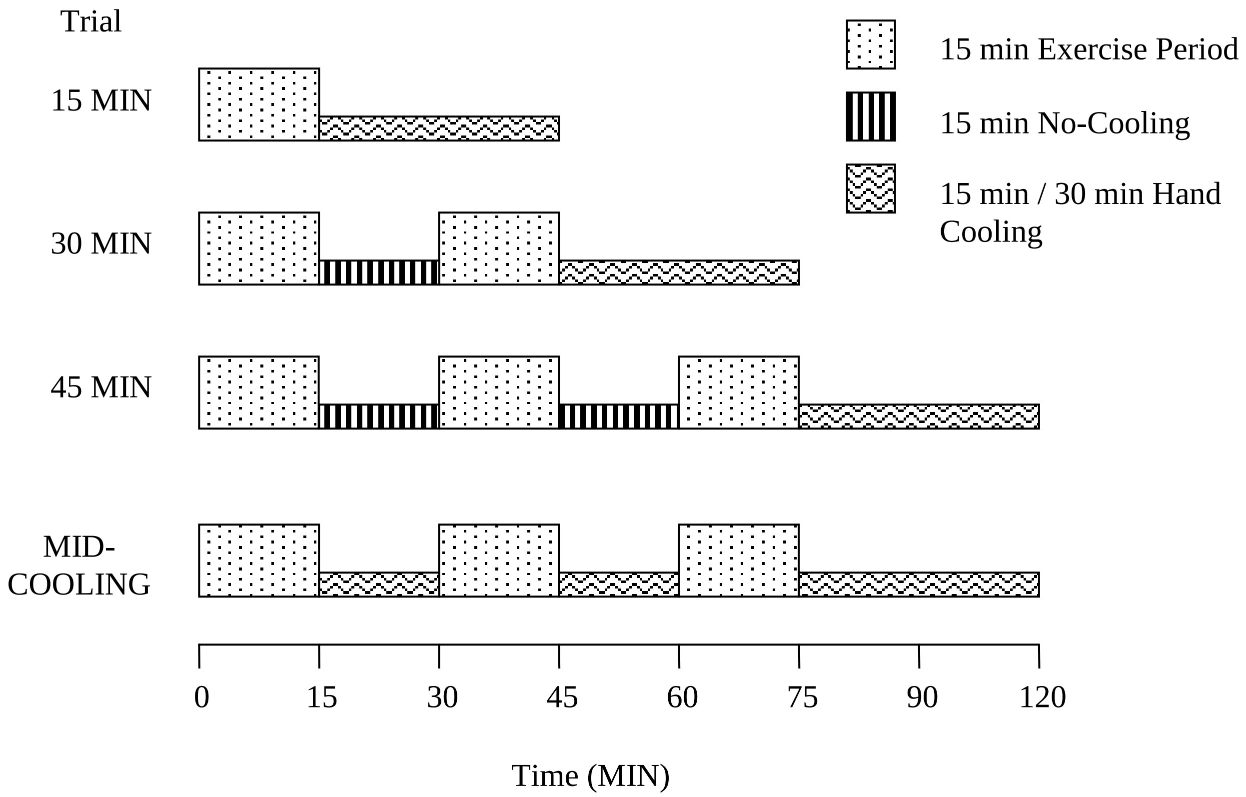

Figure 3.1: Schematic representation of each exercise trial.

3.3 Experimental Procedures

The test protocol (Figure 3.1) required the participants to perform stepping exercise at 12 steps·min^{-1} for 15 min intervals. On arrival at the laboratory participants completed a health screen questionnaire and sat quietly for 15 min. Participants were then prepared for each trial with a HR monitor and thermistors being attached, and resting blood samples collected. Participants then donned the suit which took 9-10 minutes and was consistent between trials. The participants were required to wear the same clothes for each trial. These were polyester shorts and a cotton t-shirt worn underneath a standard Explosive Ordinance Disposal (EOD) ensemble NP Aerospace mark IV Coventry, UK. The Ergotec 3010 lightweight suit weighed 37.5 kg and consisted of the protective lightweight trousers, jacket, boots, breast plate and helmet (Figure 3.2). Participants were gloveless throughout the whole trial.

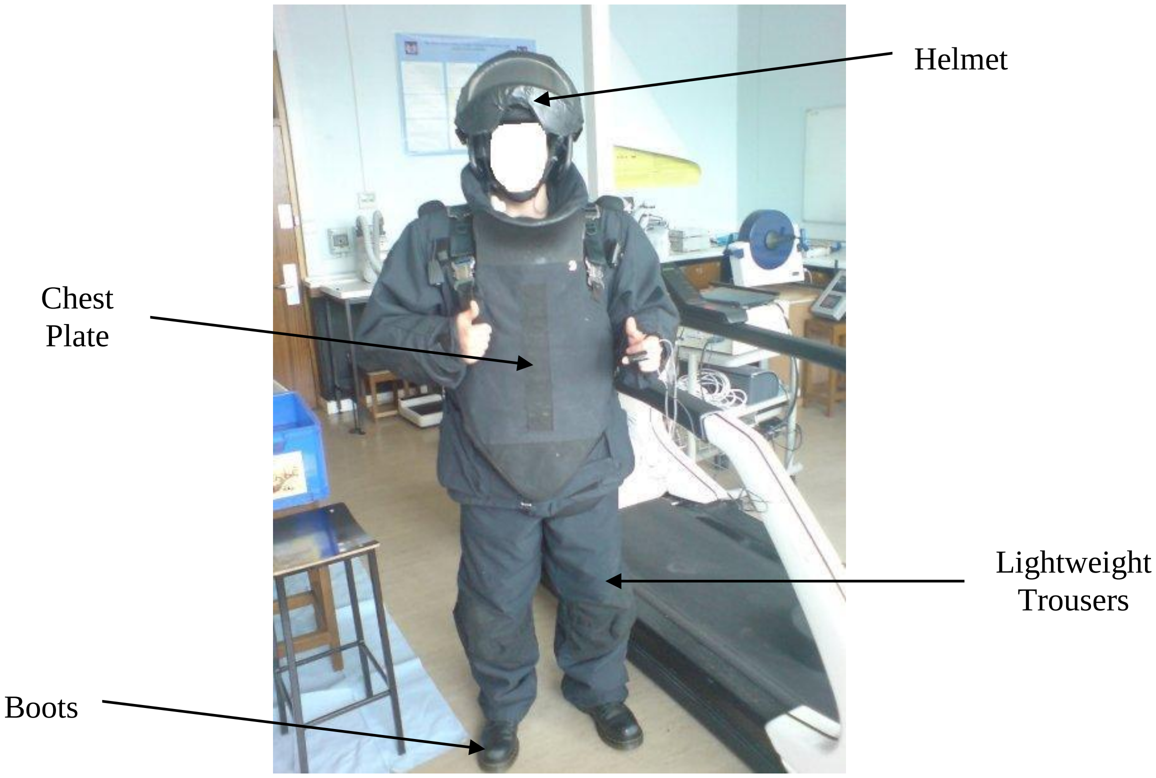

Figure 3.2: Full EOD Ergotec 3010 lightweight suit

During each 15 min rest period participants remained in the full EOD ensemble and were subjected to either hand cooling or rest in a seated position. Participants were seated for their comfort and safety, as standing may have exerted additional, unnecessary physiological strain and has been used in previous studies (House *et al.* 1997). When sitting the participants were helped onto a stool and remained seated until instructed to begin the next exercise period. During hand cooling the participants were helped into the same position and then immersed both hands up to the wrist in water. At the end of exercise 1 min was used to transfer subjects to the water bath and take blood samples. Participants then submerged their hands for 15 min with an additional minute at the end of cooling being used for the participants to return to the step to begin exercise. The water bath contained 15 litres of water at an initial temperature of 10^{o}C. Water bath temperature was measured using a standard mercury thermometer and was maintained by adding crushed ice. To maintain the thermal gradient between the hands and the surrounding water, the water was continually circulated by an aquatic pump (Aquaclear 3000, Rolf C Hagan Ltd, UK). This was used to disrupt the boundary layer between the hands and water.

3.4 Physiological Measures

Core (rectal and aural) and skin temperatures were monitored continuously at rest and during each trial. Rectal temperature (T_{rec}) was measured via a rectal probe inserted 10 cm past the anal sphincter. Aural temperature (T_{aur}) was measured via an aural probe inserted into the ear canal which was taped into position and insulated with cotton wool. Skin temperatures (T_{skin}) were measured at 5 sites (chest, back, arm, thigh and dorsal surface of the hand below the first, second and third metacarpelphalangeal joint) by skin thermistors at standardised anatomical landmarks. The thermistors were factory calibrated, with their accuracy checked by submerging them in a water bath at a range of physiological temperatures (25-40°C). The accuracy of the thermistors was within 0.2°C which is the standard. Data for skin and core body temperature was logged using a Squirrel data logger 1000 series (Grant Instruments Cambridge, UK). All temperatures were monitored via Grant thermistors except for T_{aur} which was monitored via an Edale thermistor (Edale Ltd, Surrey, UK). T_{core} and T_{skin} were recorded at 5 minute intervals before, during and after each trial. Although thermistors were not calibrated, the range of measurement of the themistors when in a water bath read within 2oC of the water temperature.

During hand cooling heat flow from the hands was measured via a heat flow disc placed on the dorsal surface of the hand (Easy sense advanced, UK). The temperature of the water was recorded before cooling and immediately after cooling in order to determine the change in water temperature. Heat loss from the hands was then calculated from the equation; $Q = mc.t^{-1} (T_i - T_f - k)$ $cal.s^{-1}$, where; Q = Watts, m = mass of water (g), c = Specific heat capacity of water ($cal.g^{-1}°C$), t = cooling period duration (s), T_i = water temperature when hands immersed, T_f = water temperature when hands removed and k = Δ water temperature without hands immersed (Livingstone *et al*. 1995). K was determined by placing the cooling bath into the laboratory under the same conditions of the experiment and monitored for the duration of cooling (30 min).

At rest and during each trial arterialised capillary blood samples were taken to determine the concentration of blood lactate. The skin was pierced using a Softclix Pro lancet (Roche diagnostics, East Sussex) and 50µl blood samples collected in capillary tubes which were then put into 5ml Eppendorf tubes for later analysis. Samples for blood lactate were collected at rest and the end of each exercise period. Blood samples were also collected at the start and end of each trial to measure haemoglobin concentration ([Hb]) and haematocrit (Hct) in order to determine changes in plasma volume according to Dill and Costill (1974). 3 samples for [Hb] and Hct were collected with [Hb] being analysed via an 80µl cuvette sample (Clandon Hemocue, Sheffield ltd) and Hct was determined in triplicate via Hawksley Hct tubes and a Hawksley Hct reader (Hawksley, Sussex, UK).

HR was continually monitored using a Polar Heart rate monitor. Data was recorded at rest and at 5 minute intervals throughout each protocol. Expired gas was collected in 150 litre Douglas bags (Cranlea, Bournville, Birmingham, UK) via a Harvard mouth piece which was attached to a two-way Salford breathing valve (Cranlea, Bournville, Birmingham, UK). The breathing valve was connected to a two way rotary stopcock valve (Cranlea, Bournville, Birmingham, UK) on the Douglas bag via plastic tubing (Cranlea, Bournville, Birmingham, UK). For all expired gas samples collections collected the participants wore a nose clip. Before each trial, two 5 minute samples were taken at rest prior to the participant wearing the EOD suit and the other when wearing the suit. One minute expired gas samples were collected during the last minute of each exercise stage. A gas analyser (Servomex 1440CO_2/O_2, East Sussex) was used to determine the percentage of oxygen and carbon dioxide in the expired gas samples. The volume of air expired was determined via a dry gas meter (Harvard, Hammersmith, London). Gas temperature, values for oxygen consumption ($\dot{V}O_2$), ventilation rate ($\dot{V}_E$) and respiratory exchange ratio (RER) were subsequently calculated.

Nude body mass was measured before and at the end of each trial using scales (Seca Balance scales, Cranlea, Birmingham, UK). Nude body mass was the main interest to determine whole body sweat rate within each trial.

3.5 Perceptual Measures

Throughout each trial participants were asked to rate their perceived exertion and thermal stain. Perceived exertion (RPE) was rated using the Borg 15 point scale (1974) which ranged from 6 (No exertion at all) to 20 (maximal exertion) (Appendix 1). Ratings of thermal strain were determined using Young *et al.* (1989) thermal strain index (TS) (Appendix 2). Participants were asked to rate both their RPE and TS at 5 minute intervals during each trial.

3.6 Statistical Analysis

All data are presented as mean ± sd. T_{core} and T_{skin}, $\dot{V}O_2$, $\dot{V}_E$, RER, Bla and perceptual measures were analysed via a two way anova of variance with repeated measures on both factors (time x trial). Baseline, end of exercise and 30 min cooling data was analysed for each trial for T_{core} and T_{skin}. Differences between changes in plasma volume, body mass loss and sweat rate were analysed via one way analysis of variance. Significance was accepted at $p \leq 0.05$. Where significance was obtained Tukey post hoc analysis was undertaken. All analysis was undertaken via SPSS.

For the 45 MIN vs. MC trials sweat rate and body mass loses were analysed via paired t-tests.

3.7 Pilot Work

Pilot work was carried out testing all trials. This testing found the protocol to cause a increase in T_{core}.

4.0 Results

4.1. Trial Completion

Three participants were unable to complete the 45 MIN trial, with two participants being unable to complete the MID-COOLING trial. One participant was unable to complete both the 45 MIN and MID-COOLING trials. One participant who completed the 45 MIN trial was unable to complete the MID-COOLING; however this was due to an unrelated injury.

4.2 Physiological responses to exercise duration (15 MIN vs. 30 MIN vs. 45 MIN)

4.2.i Core temperature responses

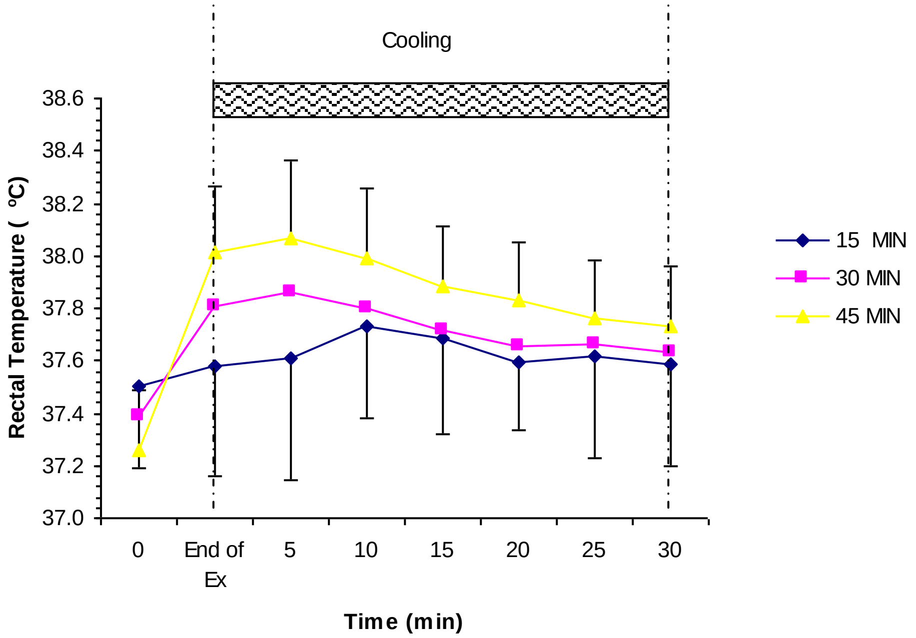

Figure 4.1: Rectal temperature at the end of exercise and during 30 min hand cooling for the 15 MIN, 30 MIN and. 45 MIN trials. There was a main effect for trial ($p < 0.05$).

There was no significant interaction between time and trial for T_{rec} ($p>0.05$) however, there was a significant main effect for trial (15 MIN vs. 45 MIN) ($p<0.05$). At rest T_{rec} were similar between trials (37.5 ± 0.2, 37.5 ± 0.3 and 37.4± 0.2°C for the 15 MIN, 30 MIN and 45 MIN trials respectively). At the end of exercise in the 15 MIN trial T_{rec} was 37.6 ± 0.4°C remaining at similar levels at the end of cooling 37.6 ± 0.4°C. In the 30 MIN trial T_{rec} was 37.5 ± 0.4°C at the end of the first bout and 37.8 ± 0.3°C at the end of the second bout of exercise. Thirty minutes hand cooling resulted in a T_{rec} of 37.6 ± 0.4°C. In the 45 MIN trial, T_{rec} was 37.4 ± 0.3°C, 37.6 ± 0.3°C and 38.0 ± 0.2°C at the end of the first, second and third exercise bouts respectively. At the end of 30 min cooling T_{rec} was 37.7 ± 0.2°C.

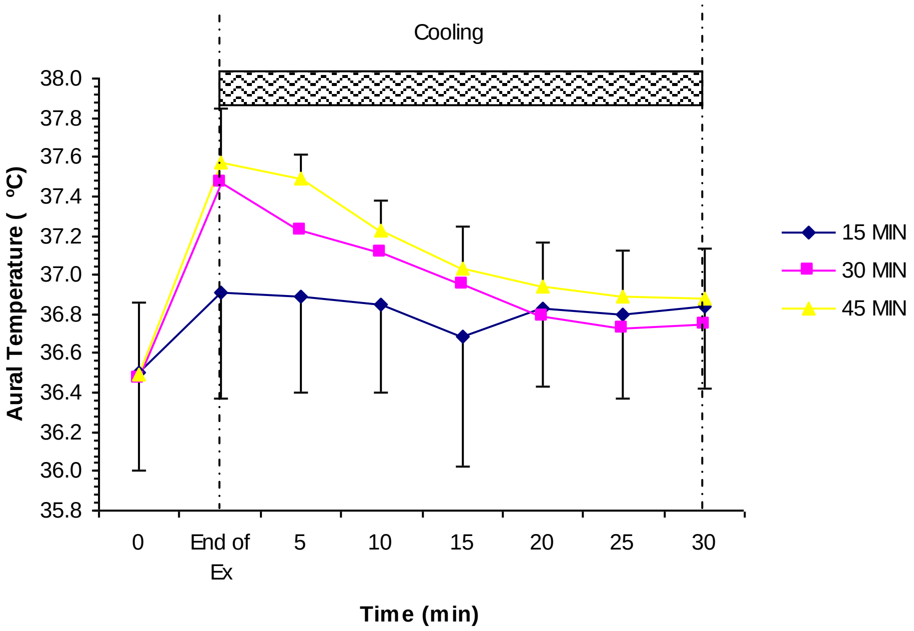

Figure 4.2: Aural temperature at the end of exercise during 30 min hand cooling for 15 MIN, 30 MIN and 45 MIN trials. Main effects for trial and time ($p<0.05$)

There was no significant interaction between time and trial for T_{aur} ($p>0.05$), however there was main effects for trial (15 MIN vs. 45 MIN) and time ($p<0.05$). For the 15

MIN trial, at the end of exercise T_{aur} was 36.9 ± 0.5°C, with hand cooling having little effect on T_{aur} after 30 min cooling (36.8 ± 0.4°C). In the 30 MIN trial T_{aur} was 36.9 ± 0.5°C after the first and 37.5 ± 0.5°C after the second exercise bout. Hand cooling resulted in a T_{aur} of 36.8 ± 0.4°C. In the 45 MIN trial T_{aur} at the end of the first, second and third exercise periods were 36.9 ± 0.3, 37.2 ± 0.3 and 37.6 ± 0.3°C respectively. At the end of cooling T_{aur} was 36.9 ± 0.3°C. T_{aur} did not return to resting values in any of the trials.

4.2.ii Skin temperatures

Table 4.1 Summary of skin temperatures at rest, end of exercise and recovery for 15 MIN, 30 MIN and 45 MIN trial

Measurement Sites	**Trial**	**Time**		
		Rest	**End of Ex.**	**Recovery**
Arm Temp (°C)	**15 MIN**	33.2 ± 1.3	36.0 ± 0.7	35.6 ± 0.5
	30 MIN	34.0 ± 1.4	36.5 ± 1.8	36.2 ± 0.6
	45 MIN	32.6 ± 1.5	37.6 ± 0.3	36.2 ± 0.6
Back Temp (°C)	**15 MIN**	34.6 ± 0.8	36.6 ± 0.7	36.7 ± 0.5
	30 MIN	35.2 ± 1.1	37.2 ± 0.6	36.8 ± 0.5
	45 MIN	34.3 ± 0.9	37.5 ± 0.3	36.8 ± 0.3
Chest Temp (°C)	**15 MIN**	33.0 ± 1.2	35.9 ± 0.9	35.8 ± 0.7
	30 MIN	33.8 ± 1.1	36.9 ± 0.6	36.4 ± 0.5
	45 MIN	32.4 ± 1.4	36.8 ± 0.4	35.8 ± 1.4
Thigh Temp (°C)	**15 MIN**	33.0 ± 0.9	35.9 ± 0.9	36.1 ± 0.7
	30 MIN	33.4 ± 1.0	36.9 ± 0.6	36.7 ± 0.5
	45 MIN	32.7 ± 0.7	37.0 ± 0.2	36.6 ± 0.6

Skin temperatures at rest, at the end of exercise and after 30 minutes hand cooling are shown in Table 4.1. The hand temperature (T_{hand}) response is shown in figure 4.3. Arm, back and chest temperature demonstrated main effects for trial between the 30 MIN and 45 MIN ($p<0.05$) and time ($p<0.05$). Thigh temperature demonstrated a main effect for time only ($p<0.05$). For T_{hand} significant main effects were found for trial (15 MIN vs. 30 MIN) and time ($p<0.05$) (Figure 4.3). Values at rest were similar between trials (31.3 ± 0.9°C, 31.9 ± 1.2°C and 31.6 ± 1.2°C for 15 MIN, 30 MIN and 45 MIN, respectively). T_{hand} at the end of exercise for each trial was 32.1 ± 1.3°C, 32.8 ± 1.1°C and 31.7 ± 2.0°C for 15 MIN, 30 MIN and 45 MIN. Cooling reduced hand skin temperature by similar amounts in each trial (13.7 ± 1.3°C, 15.1 ± 1.6°C and 15.6 ± 1.2°C, respectively, $p<0.05$)

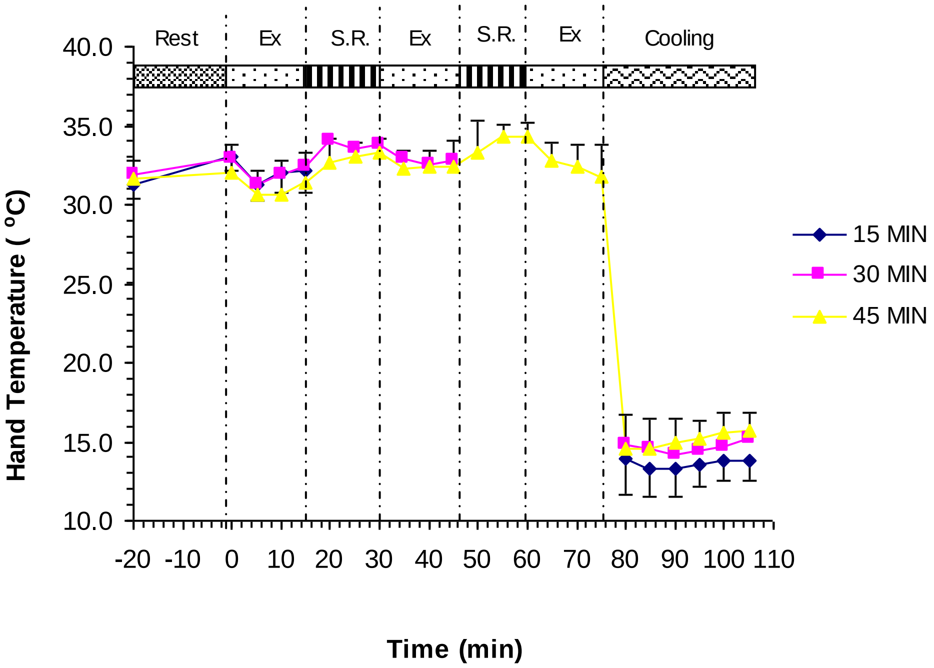

Figure 4.3: Hand temperature at rest, during exercise and cooling for 15 MIN, 30 MIN and 45 MIN trials. There was significant main effects for trial (15 MIN vs. 30 MIN) and time ($p<0.05$).

4.2.iii Heat flow

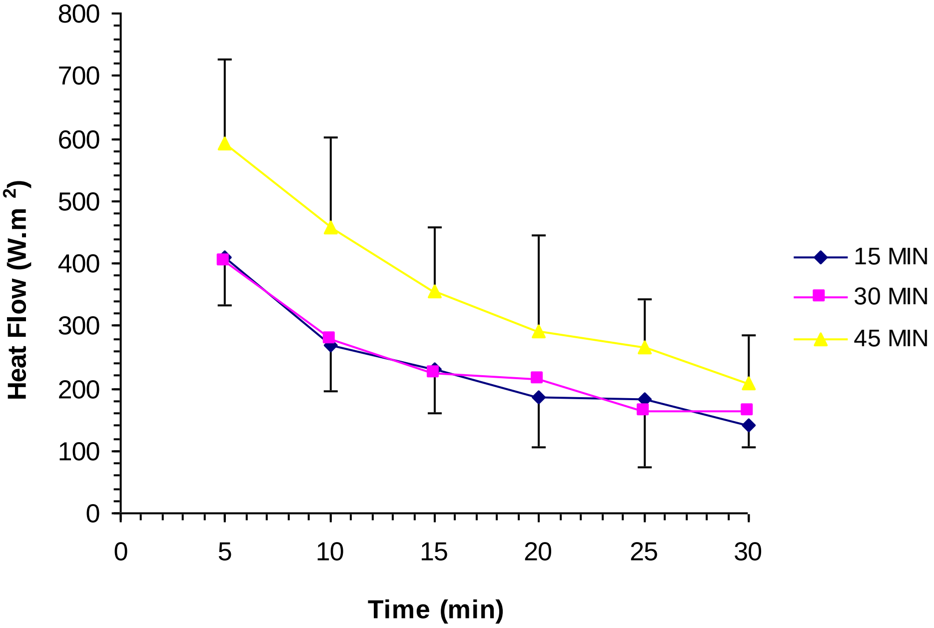

Figure 4.4: Heat flow during hand cooling at the end of exercise for the 15 MIN, 30 MIN and 45 MIN trials. There were significant main effects for both time and condition ($p<0.05$).

There was no significant interaction for heat flow during hand cooling ($p>0.05$), however there was a significant main effect for time and trial (45 MIN > 15 MIN and 30 MIN) ($p<0.05$). After 5 minutes of hand cooling heat flow was 411 ± 76, 404 ± 93 and 593 ± 134 W·m^{2} for the 15 MIN, 30 MIN and 45 MIN trials respectively. At the end of cooling heat loss was 142 ± 36 W·m^{2}, 162 ± 58 W·m^{2} and 209 ± 76 W·m^{2} for the 15 MIN, 30 MIN and 45 MIN trials. There was no correlation between T_{aur} and heat flow (R=0.14) or T_{rec} and heat flow (R=0.19) ($p>0.05$).

4.2.iv Cardiorespiratory and Perceptual Responses

Physiological responses for each of the trials are shown in Table 4.2. There was no significant interaction for heart rate (HR), RPE or thermal strain (TS)

In all trials VO_2, blood lactate (Bla), RPE and TS changed over time ($p<0.05$) with a main effect for trial being reported for TS (15 MIN vs. 30 MIN and 45 MIN). HR increased steadily during each exercise period before decreasing sharply and reaching a plateau in each cooling period. There was significant main effects for both time and trial (15 MIN vs. 30 MIN and 45 MIN) ($p<0.05$).

Changes in plasma volume were -1.13 ± 2.22, -0.04 ± 5.69 and -1.10 ± 4.15% for the 15 MIN, 30 MIN and 45 MIN trials respectively ($p>0.05$). There was a significant difference between trials for absolute loss of sweat, values were 0.43 ± 0.19, 0.88 ± 0.17 and 1.04 ± 0.20 (15 MIN vs. 45 MIN). Sweat rates were 0.57 ± 0.25, 0.70 ± 0.13 and 0.59 ± 0.11 $L \cdot hour^{-1}$ for each trial, respectively.

Table 4.2: Mean physiological and perceptual response at rest; end of exercise and during cooling in the 15 MIN, 30 MIN and 45 MIN trials

	Trial	Rest	End of Ex	5 min	10 min	15 min	20 min	25 min	End of cooling
HR (bpm)	**15 MIN**	80 ± 12.8	134 ± 20	86 ± 16.8	84 ± 12.9	82 ± 14.4	83 ± 10.6	80 ± 18.6	82 ± 13.5
	30 MIN	75 ± 13.0	156 ± 21.1	104 ± 13.1	96 ± 18.0	94 ± 14.4	92 ± 14.4	90 ± 11.7	89 ± 13.0
	45 MIN	77 ± 10.4	160 ± 22.6	101 ± 15.1	94 ± 16.1	94 ± 18.9	94 ± 16.9	92 ± 19.7	90 ± 18.1
$\dot{V}_E$ (L·min^{-1})	**15 MIN**	10.8 ± 2.2	32.9 ± 4.3						
	30 MIN	10.9 ± 1.8	38.9 ± 8.1						
	45 MIN	10.4 ± 1.4	49.9 ± 9.1						
$\dot{V}O_2$ (ml·kg^{-1}·min^{-1})	**15 MIN**	4.7 ± 0.6	20.6 ± 2.4						
	30 MIN	4.7 ± 1.0	22.4 ± 4.1						
	45 MIN	4.4 ± 0.9	21.1 ± 3.6						
$\dot{V}O_2$ (L·min^{-1})	**15 MIN**	0.37 ± 0.05	1.63 ± 0.19						
	30 MIN	0.37 ± 0.06	1.68 ± 0.27						
	45 MIN	0.50 ± 0.47	1.45 ± 0.42						
RER	**15 MIN**	0.89 ± 0.08	0.90 ± 0.08						
	30 MIN	0.90 ± 0.08	0.95 ± 0.07						
	45 MIN	0.95 ± 0.09	1.02 ± 0.13						
BLa (mmol·l^{-1})	**15 MIN**	1.0 ± 0.5	1.3 ± 0.9						0.7 ± 0.2
	30 MIN	1.0 ± 0.9	1.2 ± 0.5						0.5 ± 0.3
	45 MIN	0.8 ± 0.3	1.6 ± 1.0						0.6 ± 0.2
RPE	**15 MIN**	9 ± 2.1	14 ± 2.3	9 ± 1.8	8 ± 2.0	9 ± 2.3	8 ± 1.8	8 ± 1.9	8 ± 1.9
	30 MIN	8 ± 2.8	15 ± 2.5	10 ± 2.5	9 ± 2.2	9 ± 2.3	9 ± 2.2	9 ± 2.4	9 ± 2.2
	45 MIN	8 ± 2.8	16 ± 1.9	11 ± 2.7	10 ± 2.6	9 ± 2.6	9 ± 2.3	9 ± 2.3	8 ± 2.2
TS	**15 MIN**	4 ± 0.5	6 ± 0.6	5 ± 0.5	4 ± 0.7	4 ± 0.6	4 ± 0.5	4 ± 0.4	4 ± 0.4
	30 MIN	5 ± 0.7	7 ± 0.8	5 ± 0.5	5 ± 0.7	5 ± 0.5	5 ± 0.5	4 ± 0.5	4 ± 0.5
	45 MIN	5 ± 0.5	7 ± 0.4	6 ± 0.7	5 ± 0.8	5 ± 0.8	4 ± 0.7	4 ± 0.7	4 ± 0.7

4.3 45 MIN vs. MID-COOLING

4.3.i Core Temperature Responses

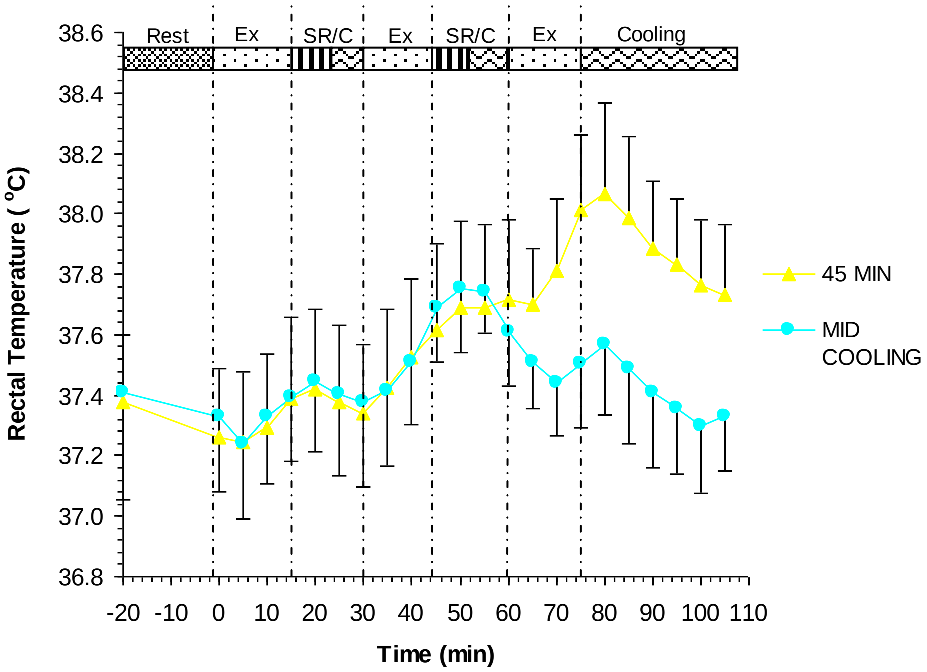

Figure 4.5: Rectal temperature at rest, during exercise and cooling for the 45 MIN vs. MID-COOLING trials. There was significant main effect for trial (*p<0.05*).

There was no significant interaction between trials for T_{rec} (*p>0.05*), however there was a significant main effect for trial (*p<0.05*). Resting T_{rec} was 37.4 ± 0.2 and 37.4 ± 0.4°C for the 45 MIN and MID-COOLING trials, respectively (Figure 4.5). T_{rec} then remained similar in each trial until 55 minutes. From this point on during the 45 MIN trial T_{rec} continued to increase whereas in the MID-COOLING trial T_{rec} decreased rapidly. At the end of exercise T_{rec} for the 45 MIN trial was 38.0 ± 0.2°C and for the MID COOLING trial 37.5 ± 0.2°C. At the end of hand cooling following the 45 MIN trial, T_{rec} was 37.7 ± 0.2°C. At the end of MID-COOLING T_{rec} was 37.3 ± 0.2°C.

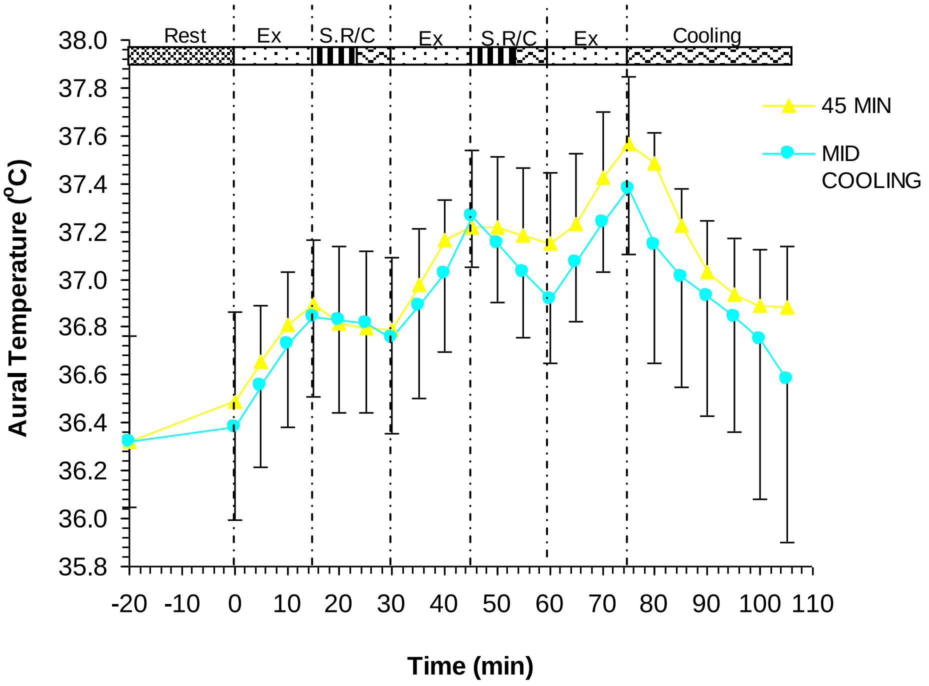

Figure 4.6: Aural temperature at rest, during exercise and cooling in 45 MIN vs. MID-COOLING. Main effects for time and trial (*p<0.05*).

There was no significant interaction for T_{aur} (*p>0.05*), however there was a significant main effects for both time and trial (*p<0.05*). At rest T_{aur} was similar for both trials, 36.3 ± 0.4 and 36.3 ± 0.3°C for the 45 MIN and MID-COOLING trial respectively. In both trials T_{aur} followed a similar pattern of increase. At the end of exercise in the 45 MIN trial T_{aur} reached 37.6 ± 0.3°C and in the MID-COOLING trial reached 37.4 ± 0.3°C. After 30 min hand cooling aural temperature was 36.9 ± 0.3°C in the 45 MIN trial and 36.6 ± 0.7°C in the MID-COOLING trial (*p<0.05*).

Table 4.3: Core temperature changes from rest to the end of exercise during the 45 MIN and MID-COOLING trials.

	Rectal Temperature (^{o}C)			**Aural Temperature (^{o}C)**		
	Rest	**End Ex.**	**Change in Temp**	**Rest**	**End Ex.**	**Change in Temp**
45 MIN	37.4 ± 0.2	38.0 ± 0.2	+ 0.6	36.3 ± 0.4	37.6 ± 0.3	+ 1.3
MID-COOLING	37.4 ± 0.4	37.5 ± 0.2	+ 0.1	36.3 ± 0.3	37.4 ± 0.3	+ 1.1

4.3.ii Skin Temperatures

There was no significant interaction for arm, back, chest or thigh skin temperatures ($p>0.05$), with mean values being similar at rest and during exercise between trials. There was a significant interaction for hand skin temperature ($p<0.05$). Figure 4.7 shows hand temperature at the start of each trial was similar during the first 15 minute exercise stage. In the MID-COOLING trial cooling reduced hand temperature to 13.5 ± 0.9^{o}C, 14.0 ± 0.9^{o}C and 14.9 ± 1.6^{o}C in the first, second and final cooling period, respectively ($p<0.05$). In the 45 MIN trial hand temperature fluctuated throughout the trial, remaining relatively constant during periods of seated rest. At the end of exercise hand cooling reduced hand temperature to 14.5 ± 2.2^{o}C. At the end of 30 minutes hand cooling hand skin temperature for both trials was similar ($p>0.05$).

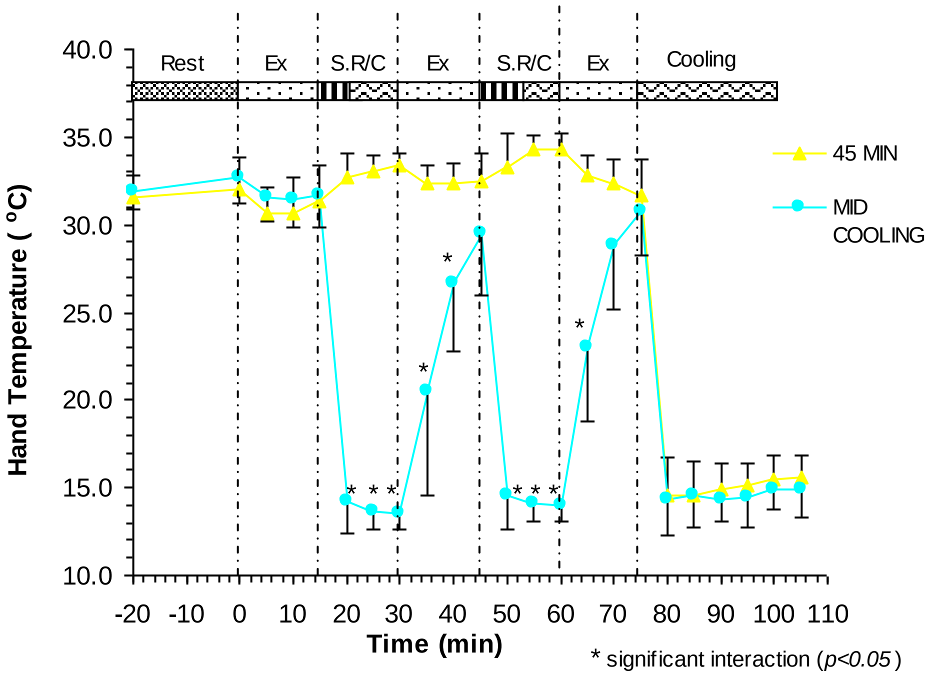

Figure 4.7: Hand Temperature at rest, during exercise and cooling for the 45 MIN and MID-COOLING trials.

4.3.iii Heat flow

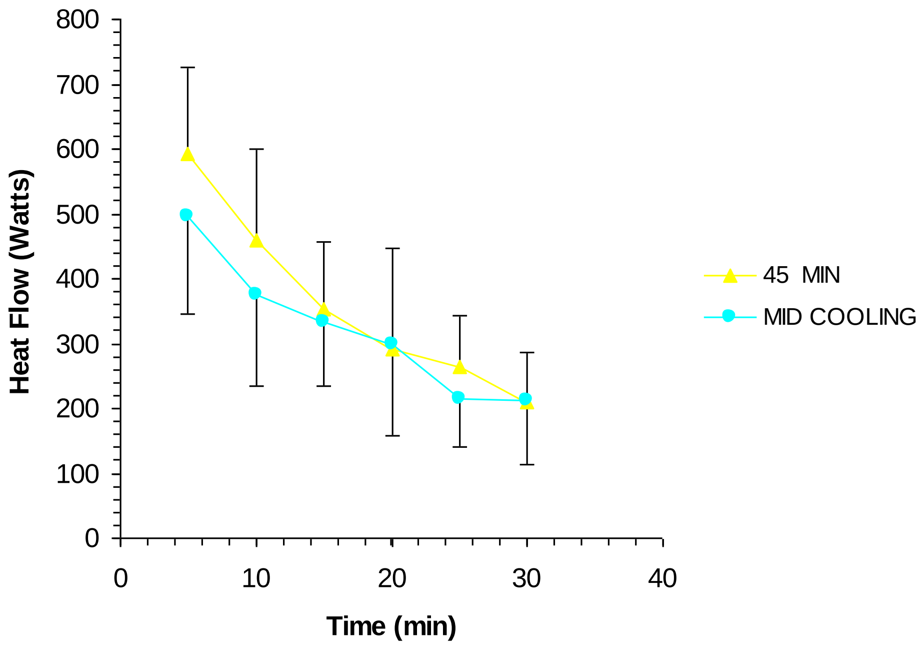

Figure 4.8: Heat flow from the hands during 30 min hand cooling at the end of exercise for the 45 MIN and MID-COOLING trials.

There was no significant interaction for heat flow between trials during 30 minutes hand cooling at the end of exercise ($P>0.05$). After 5 minutes of hand cooling heat flow was 593 ± 134 $W{\cdot}m^2$ and 497 ± 151 $W{\cdot}m^2$ for the 45 MIN and MID-COOLING trial, respectively ($P<0.05$). At the end of cooling heat flow was 209 ± 76 $W{\cdot}m^2$ and 213 ± 99 $W{\cdot}m^2$ for the 45 MIN and MID-COOLING trial, respectively.

4.3.iv Cardiorespiratory and Perceptual Responses

Heart rate, $\dot{V}O_2$, Bla, RPE and TS responses are shown in Table 4.4. There was no significant interaction for HR, RPE, TS, VO2 or Bla between trials ($p>0.05$).

No significant differences were observed for changes in plasma volume (-1.10 ± 4.15 and 2.16 ± 8.58 % for the 45 MIN and MID-COOLING trials, respectively) ($p>0.05$). There was no significant difference for absolute mass losses (1.04 ± 0.20 and 0.8 ± 0.27 kg) or sweat rates (0.59 ± 0.11 and 0.46 ± 0.16 $L{\cdot}hour^{-1}$) between trials ($p>0.05$).

Table 4.4: Mean physiological and perceptual response before, during and after the 45 MIN and MID COOLING trial

	Trial	**Rest**	**End of bout 1**	**End of bout 2**	**End of exercise**	**5 min**	**10 min**	**15 min**	**20 min**	**25 min**	**End of cooling**
HR (bpm)	**45 MIN**	75 ± 7.4	129 ± 19.5	148 ± 22.2	160 ± 22.6	101 ± 15.1	94 ± 16.1	94 ± 18.9	94 ± 16.9	92 ± 19.7	90 ± 18.1
	MC	74 ± 10.2	128 ± 15.5	141 ± 18.3	155 ± 17.8	95 ± 19.1	90 ± 13.7	92 ± 8.4	89 ± 14.8	88 ± 11.2	88 ± 12.2
$\dot{V}_E$ (L·min^{-1})	**45 MIN**	10.4 ± 1.4	33.2 ± 3.8	35.4 ± 3.7	49.9 ± 9.1						
	MC	10.8 ± 1.4	33.7 ± 4.6	36.3 ± 8.8	40.3 ± 13.1						
$\dot{V}O_2$ (ml·kg^{-1}·min^{-1})	**45 MIN**	4.4 ± 0.9	20.0 ± 2.4	19.9 ± 2.5	21.1 ± 3.6						
	MC	6.4 ± 4.5	20.2 ± 2.6	20.6 ± 3.5	21.0 ± 3.4						
$\dot{V}O_2$ (L·min^{-1})	**45 MIN**	0.5 ± 0.5	1.6 ± 0.1	1.6 ± 0.2	1.5 ± 0.4						
	MC	0.4 ± 0.1	1.6 ± 0.2	1.6 ± 0.1	1.6 ± 0.2						
RER	**45 MIN**	0.1 ± 0.1	0.9 ± 0.1	1.0 ± 0.1	1.0 ± 0.1						
	MC	0.1 ± 0.1	0.1 ± 0.1	1.0 ± 0.2	1.0 ± 0.1						
BLa (mmol·l^{-1})	**45 MIN**	0.8 ± 0.3	0.9 ± 0.4	1.1 ± 0.4	1.6 ± 1.0						0.6 ± 0.2
	MC	0.9 ± 0.3	1.7 ± 1.4	0.7 ± 0.2	0.8 ± 0.3						0.6 ± 0.3
RPE	**45 MIN**	8 ± 2.8	14 ± 2.1	15 ± 2.4	16 ± 1.9	11 ± 2.7	10 ± 2.6	9 ± 2.6	9 ± 2.3	9 ± 2.3	8 ± 2.2
	MC	7 ± 1.8	13 ± 1.9	14 ± 2.8	15 ± 1.9	10 ± 3.2	9 ± 3.0	9 ± 2.3	9 ± 2.1	8 ± 1.9	8 ± 1.9
TS	**45 MIN**	5 ± 0.5	6 ± 0.8	7 ± 0.7	7 ± 0.4	6 ± 0.7	5 ± 0.8	5 ± 0.8	4 ± 0.7	4 ± 0.7	4 ± 0.7
	MC	4 ± 0.5	6 ± 0.7	6 ± 0.6	7 ± 0.4	5 ± 0.9	5 ± 0.9	4 ± 0.6	4 ± 0.6	4 ± 0.6	4 ± 0.8

5.0 Discussion

The primary aim of this study was to determine the effectiveness of hand cooling after exercising in an EOD suit. Throughout each trial T_{core} rose, peaking at the end of exercise, with differences being reported for both T_{rec} and T_{aur} between the 15 MIN and 45 MIN trials during 30 min hand cooling. Having periods of exercise interspersed with seated rest appears to have attenuated the increase in T_{core} as levels is the present study did not reach values previously reported (House *et al.* 1997). T_{rec} during hand cooling at the end of exercise was significantly different between the 15 and 45 MIN trials with T_{aur} also being reduced and significantly different between trials (15 MIN vs. 45 MIN). Although these main effects were witnessed for both T_{rec} and T_{aur} there were no interactions.

A secondary aim was to determine whether having periods of 'mid' cooling during exercise (MID-COOLING) compared to no cooling periods (45 MIN) was effective at reducing heat strain. Significant differences for trials were found for T_{rec} and T_{aur} with a difference for time also being observed for T_{aur}. There were no significant interactions for either T_{rec} or T_{aur}. As reported in the other trials, T_{core} remained within 'safe' values with the highest T_{core} reported out of all the trials being 38.1 ± 0.3^{o}C.

5.1 Core temperature

5.1.i Aural Temperature Response

The T_{core} response in all trials was not as great as those previously reported. The maximum T_{aur} reached was 37.6°C (45 MIN), which is much lower than the maximum T_{aur} achieved by House *et al.* (1997) (38.5°C). Furthermore the reduction in T_{aur} at the end of exercise in the present study was again much lower than the reported values in House *et al*. (1997), who observed a reduction of 1.6°C (38.5°C to 36.9 ± 0.3°C) when participants immersed their hands in water at 10°C. In comparison, 30 min hand cooling in the present study, caused T_{aur} to remain constant (15 MIN and 30 MIN) or decrease slightly, with a reduction of 0.7°C in the 45 MIN and MC trials.

Lower cooling rates in the 15 MIN and 30 MIN trials can be attributed to the participants being under less physiological strain. As a result the shorter exercise time in the present study in comparison to House *et al.* (1997) resulted in smaller increases in T_{aur}. As the effectiveness of hand cooling is partly attributed to the thermal gradient between the cooling site and cooling medium (Giesbrecht *et al.* 2007) the greater $T_{core,}$ the greater the removal of heat from the hands and resulting heat loss. The lower rate of cooling in this study compared to that found by House *et al.* (1997) can be attributed to T_{aur} not reaching the same level, with a subsequently lower drive for heat loss. This finding is supported by Goosey-Tolfrey *et al.* (2008) who studied the effectiveness of hand cooling on a 3km endurance performance. Goosey-Tolfrey *et al.* (2008) found that although hand cooling reduced T_{aur} its effectiveness was related to the T_{aur} at which hand cooling commenced. These findings are also supported by Allsopp and Poole (1991) who found that at higher T_{aur} heat loss was much greater.

Comparing periods of no cooling (45 MIN) with periods of cooling (MID-COOLING) was undertaken to determine the time point at which hand cooling became effective in maintaining a lower T_{core}. There was a significant main effect between trials for T_{aur} ($p<0.05$), with T_{aur} changing over time ($p<0.05$), although no interaction was found ($p>0.05$). It would appear that from the data that during the latter stages of the trials, hand cooling begins to influence the change in T_{aur}. In the first 15 min of both the 45 MIN and MID-COOLING trials T_{aur} demonstrated similar responses reaching ~36.8oC at the end of the exercise bout. This similar response shows that the participants were being subjected to the same physiological strain in each trial. During the first cooling/rest periods there was no difference between trials for T_{aur}, further supporting data from the 15 MIN trial that hand cooling after 15 min of exercise is not effective at reducing T_{aur}. The lack of cooling observed in the early stages of the MID-COOLING trial is supported by Giesbrecht *et al.* (2007) who found that during the first 30 minutes of their protocol (one exercise bout and 20 minutes cooling), there were no difference in T_{aur} between cooling (hand and forearm) and no cooling trials. This lack of cooling is likely due to the low T_{core} reached in the first 15 min of exercise.

During the remainder of the 45 MIN and MID-COOLING trials there continued to follow a similar response, although it would appear that from 55 min onwards T_{aur} was diverging between trials. This finding is supported by Giesbrecht *et al.* (2007) who found that from the second bout of exercise onwards T_{aur} was significantly greater in a no cooling trial compared to a cooling trial. It should be noted that in Giesbrecht *et al.* (2007) the participants exited from the environmental chamber and removed all the protective clothing before the cooling was administered, whereas in the present study participants remained in full EOD clothing whilst subjected to cooling. The removing of PPC during cooling would increase heat loss through other pathways e.g. evaporation, and could explain the greater difference in cooling responses in Giesbrecht *et al.* (1997) in comparison to the present study

Although the amount of cooling achieved in the present study was lower than previously reported, when the present data is combined with that of House *et al.* (1997) a linear relationship is evident (Figure 5.1)

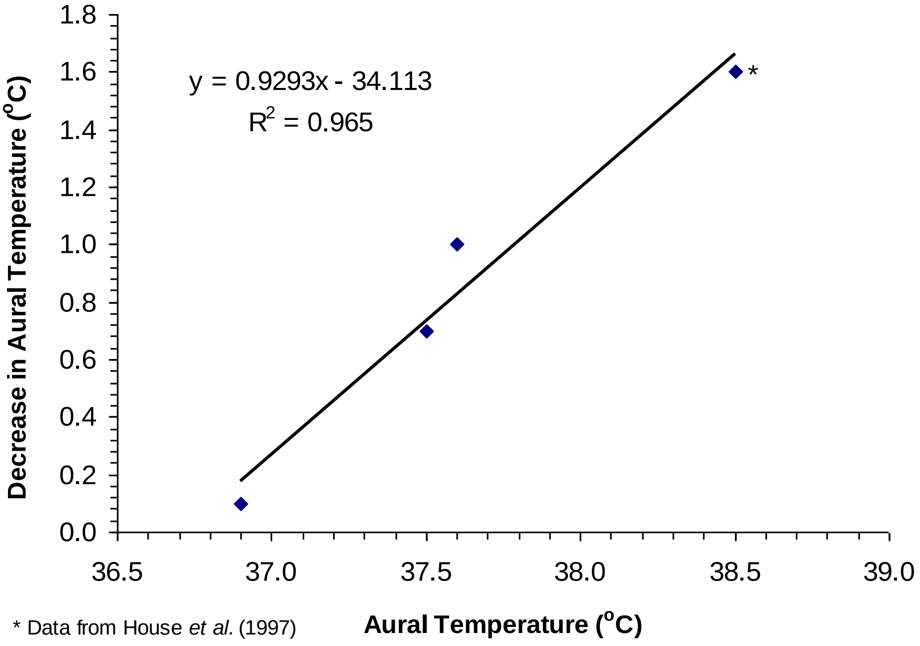

Figure 5.1: Comparison of the aural temperature at the end of exercise and the decrease in temperature during hand cooling, in the 15 MN, 30 MIN and 45 MIN trials in the present study and from House *et al.* (1997).

Figure 5.1 would appear to show that the reduction in T_{aur} although lower than reported in House *et al.* (1997), is proportional to the T_{aur} reached. This response supports the notion that hand cooling is a self-limiting process; so that the amount of heat allowed to be removed from the body is dependent on T_{aur} at which cooling commences. It would appear that the rate at which T_{aur} reduced in the 15, 30 and 45 MIN trials was proportional to the T_{aur} at which hand cooling commenced. This is further supported by Allsopp and Poole (1991), who also found that the T_{aur} at which hand cooling commenced determined the reduction in T_{aur}. The reduction of ~0.6^{o}C when T_{aur} is at 37.5^{o}C in the present study was also found by Allsopp and Poole (1991). Figure 5.1 shows that a reduction in T_{aur} although small can occur at ~36.9^{o}C, and also the reduction in T_{aur} can be predicted for a given T_{aur}.

5.1.ii Rectal Temperature Response

Previous studies have found that when T_{rec} is around 37.6^{o}C the effects of hand cooling are minimal, with very little heat loss being achieved (Allsopp and Poole 1991, Livingstone *et al.* 1989). In the present study there was a significant main effect for trial between both the 15 MIN vs. 45 MIN and 45 MIN vs. MID-COOLING trials, although there was no interaction. The lack of cooling observed in the present study can be explained by T_{rec} not reaching or only just being above the threshold of 37.6^{o}C when cooling began. At the end of the 15, 30, 45 MIN and MID-COOLING trials T_{rec} was 37.6 ± 0.4, 37.8 ± 0.3, 38.0 ± 0.2 and 37.5 ± 0.2^{o}C respectively. With T_{rec} not reaching or only just getting over the proposed ‘threshold’ this may have contributed to the reduced heat loss. The attainment of a minimum T_{rec} in order for cooling to occur is a safety response necessary to prevent T_{core} from becoming too low (Khomenok *et al.* 2008). The lack of heat removal particularly during 30 min hand cooling at the end of the 15 and 30 MIN trials can be explained by T_{rec} not reaching above 37.6^{o}C. Therefore rather than the blood vessels in the hand remaining dilated they constrict to limit the amount of blood flow through the hands to be cooled and therefore reduce the amount of cooled blood transported back to the 'core' (Khomenok *et al.* 2008). Therefore exercising for shorter periods of time may be sufficient to stem the rise in T_{rec}, waiting until the latter stages of exercise before hand immersion is required.

The delayed response hand cooling has on reducing T_{aur} (Giesbrecht et al. 2007) has also been found with T_{rec} (Selkirk *et al.* 2004). In the 45 MIN and MID-COOLING trials a main effect was found between trials for T_{rec}. The lack of difference for T_{rec} during the early stages of trials in the present study has also been found by Selkirk *et al.* (2004). Studying the effects of intermittent cooling on T_{rec} Selkirk *et al.* (2004) found that there was no difference between cooling and no cooling trials for T_{rec} until 60 min. In the present study as with Selkirk *et al.* (2004) from 55 min onwards it appear that hand cooling caused T_{rec} to decrease and remain lower in the MID-COOLLING trial in comparison to the 45 MIN trial. The reduction in T_{rec} at this time point can be related to the temperature threshold T_{rec} must reach before hand cooling becomes affective. It is not until 55 min into the MID-COOLING trial T_{rec} reaches ~37.6^{o}C, during the subsequent cooling period T_{rec} decreased and continued to be lower for the remainder of the trial.

In contrast to the findings in the present study House *et al.* (2003) found that during the first 60 min of the trials T_{rec} did indeed rise significantly faster when there was no cooling in comparison to cooling being applied. Furthermore House *et al.* (2003) also found T_{rec} to continue to be significantly higher throughout the whole of the no cooling trial compared to the cooling trial. The difference in T_{rec} during the earlier stages of trials in House *et al.* (2003) in comparison to the present study can be attributed to the differing environmental temperatures. The participants in House *et al.* (2003) although performed the same step rate, were exercising in temperatures of 36.3^{o}C in comparison to 19^{o}C in the present study. The higher environmental temperature would cause the participants suffer from UHS at a much earlier stage, resulting in T_{rec} reaching the threshold earlier and therefore hand cooling having a greater impact.

The T_{rec} responses during hand cooling in the present study, support previous suggestions on the transport of cooled blood. Selkirk *et al.* (2004) found that during the first 10 min of cooling T_{rec} would often decrease rapidly, a response found in the 30 MIN, 45 MIN and the latter 2 cooling periods in the MID-COOLING trial. Selkirk *et al.* (2004) suggested that the reduction in T_{rec} during the first 10 min of cooling is due to the cooled blood is being directly transported to the 'core'. The response did not occur during cooling in the 15 MIN trial or after the first 15 min of the MID-COOLING trial suggesting that T_{rec} had not reached sufficient levels. This would suggest that in the 30 and 45 MIN trials and in the final 2 cooling periods of the MID-COOLING trial that a degree of cooling, no matter how small did occur. The data from the present study would seem to support the suggestion that when at higher T_{core} cooled blood is transported directly to the 'core'.

From the T_{core} responses during the trials in the present study, the data seems to support the suggestion that the T_{core} at which cooling is administered determines its effectiveness at reducing T_{core} when the workload remains constant. It would appear that hand cooling at the early stages of exercise has little effect on T_{core}, although during the latter stages of exercise (>30 minutes) hand cooling did appear to have an influence on reducing T_{core}. Hand cooling resulted in a significant difference in trials for T_{rec} and T_{aur}, with hand cooling stemming the increase of T_{core}, maintaining it within safe parameters.

Although cooling during the early stages of the trials did not appear to reduce T_{core}, it did remain lower than temperatures reached in previous studies (House *et al.* 1997). The amount of cooling in all trials was not great as has been previously reported; however cooling may have been sufficient to prevent T_{rec} and T_{aur} increasing and therefore delay the onset of UHS. This response would mean that hand cooling would be a preventative rather than a reactive intervention to T_{core} reaching critically high levels. Stemming the increase in T_{core} would result in it staying within 'safe' parameters while delaying UHS and allowing individuals to perform to longer. Having alternating periods of seated rest and hand cooling separating periods of work would allow T_{core} to rise to levels that are not dangerous but sufficient to allow cooling to be effective at reducing T_{core}.

The maintenance of T_{core} at lower levels in all trials supports the possible use of shorter (15 min) alternating periods of work and rest. Comparing the T_{core} responses between the 45 MIN and MID-COOLING trials it would appear that hand cooling during the early stages of intermittent exercise may not be appropriate. Neither T_{rec} nor T_{aur} was significantly lower in the MID-COOLING trial than 45 MIN trial during the first 55 min of the trial. Therefore during the early stages of exercise having periods of seated rest may be just as effective as hand cooling. During the latter stages of exercise when T_{rec} is approaching or above 37.6^{o}C introducing periods of hand cooling can then be used to prevent the onset of UHS and maintain T_{core}.

Having a mixture of both seated rest and cooling periods throughout exercise may be the most effective structure. Delaying the onset of cooling until T_{rec} reaches over 37.6^{o}C would ensure that it is reducing T_{core} during rest periods. Introducing hand cooling at latter stages would eradicate issues of discomfort, which were reported by several participants in the MID-COOLING trial. Being at a higher T_{core} before placing the hands in cold water would result in the participants feeling less discomfort which could even allow for a colder water temperature (0^{o}C) to be used (House *et al.* 2003). Having cooler water would increase thermal gradient and therefore increase the amount of heat loss. Having alternating periods of exercise and both seated rest and hand cooling periods may also be an appropriate structure of work: rest cycles. Although having alternating periods of seated rest and hand cooling may allow for more cooling to occur, this would require T_{core} to be monitored continuously. When individuals are working in the field the monitoring of T_{core} may be difficult. Waiting to introduce hand cooling until T_{core} reaches 37.6^{o}C may not be possible as T_{core} cannot be continually monitored. Therefore by having hand cooling after every 15 min exercise period would eradicate the need to monitor Tcore because as the data in the present study suggests T_{rec} would stay below 37.6^{o}C.

5.2 Hand temperature and Heat loss

5.2.i Hand Temperature

At rest and throughout the first exercise stage, hand temperatures (T_{hand}) in all trials were similar. In the 30 MIN and 45 MIN trials T_{hand} followed a similar pattern of change, with temperature only changing when exposed to hand cooling. During the

MID-COOLING trial T_{hand} was significantly lower than 45 MIN during each cooling period and during the early stages of the following exercise period. When considering the 30 min cooling period post exercise, T_{hand} reduced sharply and being at similar levels in all trials.

Not only does the T_{core} at which cooling occurs has an influence on the rate of cooling, but previous research has also suggests that T_{hand} can also influence cooling. Research has shown that in order for hand cooling to be effective, T_{hand} must be above 15^{o}C (Davies 1995). Therefore the combination of the sensory threshold for T_{core} and T_{hand} being reached during hand cooling dictates its effectiveness.

The typical response when exposed to a cold stimulus in thermoneutral or warm conditions is for blood to be re-distributed away from the skin, through the deeper veins in order to maintain T_{core} (Livingstone *et al.* 1989). The reduction in blood flow occurs through the vasoconstriction of peripheral veins and is a safety response to protect T_{core} from sudden changes in environmental temperatures (Livingstone *et al.*1989). Davies (1995) found that when T_{core} is at ~37^{o}C when the hands are immersed in water below 30^{o}C mild vasoconstriction occurs in peripheral blood vessels. This response results in a reduction in the amount of blood flow through the hands causing a reduction in the amount of blood cooled and therefore returning to the core. Vasoconstriction occurs due to the cooling response being self-limiting, meaning that when the hypothalamus senses that when T_{core} is not critically high, there is no need for cooling. This response prevents individuals suffering from hypothermia. During the 30 min hand cooling period after the 15 MIN trial T_{core} remained relatively constant, with T_{rec} rising slightly a response similarly found in the MID-COOLING trial. It would appear that hand cooling in the 15 MIN and the beginning of the MID-COOLING trial resulted in the protective response to maintain T_{core}. At the onset of hand cooling T_{rec} was 37.6 ± 0.4°C, being at the reported threshold needed for hand cooling to be effective (Allsopp and Poole 1991) T_{hand} was 13.9 ± 2.2°C, being below the threshold of 15°C (Greenfield 1963). The lack of heat loss during this cooing period would appear to support Greenfield (1963) and Davies (1995) suggestion that T_{hand} also influences heat loss responses. Davies (1995) found that when T_{core} was at 'normal' levels (~37°C) when hands were placed in water below 15°C maximum vasoconstriction of blood vessels occurred. Therefore T_{core} not being above the required threshold and the hands being immersed in water below 15°C when at a 'normal' T_{rec} would contribute to the reduced heat loss.

Although the T_{rec} and T_{hand} response for the 15 MIN trial suggest the AVA's constricted during cooling, during the latter stages of the MID-COOLING trial T_{core} and T_{hand} responses suggest that the AVA's did remain dilated during cooling although T_{hand} was below 15°C. In the first cooling period of the MID-COOLING trial T_{hand} fell from 31.7 ± 1.9°C to 14.2 ± 1.7°C and in the second cooling period T_{hand} fell from 29.5 ± 3.5°C to 14.6 ± 1.9°C with T_{rec} being relatively constant in both. The T_{hand} values were significantly lower during rest periods in the MID-COOLING compared to the 45 MIN trial. In the following exercise periods T_{hand} gradually increased, peaking at the end of the 15 min exercise. The gradual increase in T_{hand} during the subsequent bouts of exercise suggests that the hands may continue to cool the core. The hands remaining cold may create a heat sink, which allows warm blood from the core to be transported to the hands where the blood is cooled and transported back to the core. The rapid increase in T_{hand} during the exercise periods would suggest that the veins in the hand were vasodilated as warmed blood from the core was still being transported to the hands even though they had been exposed to cold temperatures.

There were slight differences between trials for T_{core} although it remained more constant and closer to 'normal' values in the MID-COOLING trial in comparison to the other trials. It is not unreasonable to assume that having intermittent hand cooling periods have a cumulative effect on maintaining T_{rec} and T_{aur} at lower levels. However as alluded to earlier having periods of cooling during the early stages of exercise may not have sufficient benefits in comparison to seated rest to support their use. If an individual is exercising or working for prolonged bouts, having early hand cooling periods may help offset gains later.

5.2.ii Heat Loss

Although hand cooling did cause a significant reduction in T_{hand} during cooling periods the amount of heat loss from the hands was not as great as previously reported (Livingstone *et al.* 1989 and 1995). A water temperature of 10^oC was used in the present study as previous studies have shown it causes the greatest amount of heat loss (Allsopp and Poole 1991, Giesbrecht *et al.* 2007, Livingstone *et al.* 1989). Livingstone *et al.* (1989) studied the effect of using varying water temperatures for hand cooling. Heat loss was 124 W and 31 W for 10 and 20^oC water temperatures. Heat loss in the 10^oC trial was much higher than heat loss reported in any of the trials in this study which also used 10^oC water. The differences in heat flow between these two studies may be a result of the exercise performed. In Livingstone *et al.* (1989) study participants were subjected to cooling whilst exercising, whereas in the present study they were sat at rest. Cooling the participants whilst exercising would have resulted in a greater amount of peripheral blood flow. The greater amount of peripheral cutaneous blood flow, particularly through the hand would therefore allow for a greater amount of heat transfer.

Similarly heat loss in the MID-COOLING trial in this study was much lower than that reported by Selkirk *et al.* (2004) for intermittent cooling. In this study both hand and forearm immersion was used with the participants continuing to walk during the exercise period. The continued exercise as noted above may result in a greater volume of blood being transported from the core and muscles to the hands, resulting in more blood being cooled. However the much greater cooling may be a result of Selkirk *et al.* (2004) immersing both the hands and forearms which would also allow a greater heat transfer due to a greater surface area being exposed to the cooling medium.

As alluded to earlier the differences for heat loss data in this study and previous research could be a result of differing protocol's. The intensity, duration and type of exercise performed can all influence the effectiveness of cooling. If the participants exercise at a greater intensity, for a longer duration this will result in a greater amount of heat production, causing a greater thermal drive causing more heat removal. The timing of cooling can also influence the amount of heat transfer, with cooling whilst exercising appearing to cause a greater amount of heat removal.

5.3 Physiological Responses

5.3.i Oxygen Consumption

There were no significant differences between any of the trials for $\dot{V}O_2$. The similar values between trials suggest that participants were under the same physiological strain and exercise intensity in each trial. $\dot{V}O_2$ at the end of the 15 MIN, 30 MIN, 45 MIN and MID-COOLING trials were approximately 1.6 L.min^{-1}. These values are higher than those reported in previous studies. House *et al.* (2003) reported $\dot{V}O_2$ between 1.05 and 1.16 L.min^{-1}, while Selkirk *et al.* (2004) found that after 20 minutes of work $\dot{V}O_2$ was 12.1 ml.kg^{-1}.min^{-1} (1.05 L.min^{-1}) equivalent to 30% of the participants $\dot{V}O_{2peak}$.

The differences in $\dot{V}O_2$ values between studies may be due to differences in the structure of the studies. Although House *et al.* (2003) performed the same mode of exercise at the same intensity, the duration of exercise periods were shorter (10 minutes) as were the cooling periods (5 minutes). Differences in $\dot{V}O_2$ may be due to the participants in House *et al.* (1997) being more economical when stepping in comparison to the participants in the present study. In the study by Selkirk *et al.* (2004) the participants performed a different exercise mode; walking on a treadmill at 4km.h^{-1} although the exercise was also intermittent. The discrepancies between the protocols may explain the differences in the $\dot{V}O_2$ values reported. Furthermore Richardson *et al.* (1989) compared the $\dot{V}O_2$ and blood lactate concentrations of untrained participants during stepping exercise (~15 steps.min^{-1}) which were similar to those reported in the present study (~1.4 L.min^{-1}).

The higher $\dot{V}O_2$ values reported in the present study compared to previous research may be explained by the differences in PPC worn by participants. The EOD suit worn in the present study is extremely heavy, weighing around 37.5kg. In comparison to the NBC worn in House *et al.* (2003) the EOD suit worn in the present study is considerably heavier. The extra weight of the suit provides considerably more metabolic stress therefore causing an increase in $\dot{V}O_2$.

5.3.ii Heart rate

Heart rate was not significantly different between any of the trials; a finding supported by Giesbrecht *et al.* (2007) who also found no differences for heart rate between the no-cooling and cooling trials when performing intermittent stepping exercise. However, several studies that have found heart rate to be lower when hands are immersed in water in comparison to no cooling. Allsopp and Poole (1991), House *et al.* (2003) and Selkirk *et al.* (2004) all observed heart rate to be significantly lower in trials when the hands were immersed than when the participants sat at rest in a hot environment. Furthermore Selkirk *et al.* (2004) found heart rate to continue to be lower during the subsequent work and rest periods in comparison to no cooling. Selkirk *et al.* (2004) suggested that exhaustion was due to cardiovascular strain rather than an increase in T_{rec}. In the present study, exhaustion of participants was not due to them achieving high levels of T_{core} as ‘critical’ temperatures were not reached. However participants also did not reach cardiovascular limits either, therefore exhaustion of participants must be due to other factors.

5.3.iii Blood Lactate

There were no differences between trials for Bla. The blood lactate values recorded in this study were low, indicating that participants were performing aerobic exercise. In previous studies, blood lactate responses have not been reported and are therefore difficult to compare with previous research. From the low Bla values recorded in this study it can be concluded that the participants did not fatigue due to lactate build up and anaerobiosis, particularly in the 45 MIN trial. This would suggest that the participant's inability to continue exercising in these trials was due to other factors. As has already been noted, neither the attainment of a critical T_{core} or cardiovascular strain appears to be the cause of participants fatiguing. Instead the participants may have stopped in the trials not due to fatigue but because they were feeling uncomfortable. The weight of the NBC suit along with its structure can limit the participants' movements, coupled with its inability to allow heat evaporation this may have affected the participants perceived comfort and ultimately performance.

5.3.iv Plasma Volume and Sweating

There were no differences between trials for changes in plasma volume or sweat loss, which conflicts with the findings from previous studies. Sweat rates in the present study were 0.57, 0.70, 0.59 and 0.46 $L.hour^{-1}$ for the 15 MIN, 30 MIN, 45 MIN and MID-COOLING trial, respectively. In comparison to Allsopp and Poole (1991) sweat rates were lower in the present study which can be explained by differences in environmental temperature and step rate. Allsopp and Poole (1991) also found sweat production to be lower for participants when the hands were immersed in cold water. The reduction in sweat rate in these studies was attributed to lower core and skin temperatures (Allsopp and Poole 1991). As there were no significant differences for core or skin temperatures between trials in this study this may explain why there were no differences for changes in plasma volume.

5.4 Thermal Strain and RPE

There were no differences between any of the trials for Thermal Strain (TS) or RPE. In all trials during rest and cooling periods both TS and RPE decreased steadily throughout. During exercise periods both TS and RPE steadily increased, reaching peak values at the end of exercise periods. As there was no significant interaction between trials for TS, this would seem to suggest that TS was not related to cooling. Selkirk *et al.* (2004) measured the effects of intermittent cooling on TS, and found that there were no significant differences between trials until 65 minutes into the trial. From this point until the end of exercise TS was significantly lower.

From the physiological data in all the trials, it would appear that the exhaustion of participants was not due to reaching physiological limits. Those unable to complete trials were neither at critical T_{core} nor at maximum levels for HR or $\dot{V}O_2$. Therefore the exhaustion of participant's maybe a result of physical discomfort. At the end of the 15 MIN trial RPE was 14, the 30 MIN and MID-COOLING 15 and at the end of the 45 MIN trial 16. TS at the end of exercise were 6 for the 15 MIN and 7 for the 30, 45 MIN and MID-COOLING trials. Therefore although participants were not at physiological limits from the RPE and TS values show that they were struggling in the trials. As with the present study Kraning and Gonzalez (1991) found that although subjects were exhausted they hadn't reached physiological limits. However in the study by Kraning and Gonzalez (1991) participants were not cooling during rest periods.

6.0 Conclusion

The present study used an intermittent stepping protocol to determine the effectiveness of hand cooling after different durations of exercise whilst wearing a bomb disposal suit. This study also tried to determine whether having periods of ‘mid’ cooling during exercise compared to no cooling periods is effective at reducing heat strain. Although significant main effects for condition were found for T_{rec} and T_{aur}, no interaction was found between trials. A significant interaction was witnessed for T_{hand}, with temperatures during cooling periods being significantly different between 45 MIN and MC trials. Hand cooling successfully removed heat during periods of hand cooling; however the amount of heat removal was not significantly different between trials. Although there was no significant interaction, in the MID-COOLING trial there was a main affect on T_{core} from 50 minutes into the trial.

These results suggest that hand cooling may not be appropriate until the latter stages of exercise, when T_{core} have reached higher levels (> 37.6^{o}C). When wearing PPC, having a mixture of both seated rest and hand cooling periods may be the most effective. It should be noted however that although in the MC trial hand cooling did not cause much heat loss, T_{core} did not reached extreme levels. Therefore hand cooling may have an accumulative effect throughout exercise which may contribute to lower T_{core} as the hands act as a heat sink.

7.0 Limitations and Future Research

Certain aspects within the present study can be highlighted as possible limitations that may have influence the data collected. The main limitation of the present study is the failure to measure calf temperature (T_{calf}). Not having this data resulted in mean skin temperature being unable to be calculated. Having this measure would have allowed for an average skin temperature to be calculated and compared and determine overall skin temperature responses during no cooling and cooling periods.

The participants that volunteered for this study were not in the military or trained fire-fighters, therefore they were not as familiar with wearing NBC protective clothing as those required to wear it on a regular basis. Individuals who are required to frequently wear protective clothing may be more efficient when performing stepping exercise in comparison to those who haven’t worn it before. Individuals who have frequently worn protective clothing may have improved performance and physiological responses due to having a better stepping economy or a lower sweat threshold to dissipate heat sooner. Both these factors could result in a response differing from individuals who have no previous experience of wearing protective clothing. Making these findings applicable to military and fire-fighting personnel, participants with this training would need to be used.

One of the participants used in the present study had recently been involved in an acclimation study and had been exposed to hot environmental conditions on a regular basis. This exposure may have resulted in physiological changes associated with acclimation such as a reduction in resting T_{core}, a reduction in heart rate and sweat rate sensitivity and also a reduction in the amount of sodium lost through sweating

(Armstrong and Maresh 1991). If any of these physiological adaptations had occurred, this would cause the participant to have different physiological responses in comparison to the other volunteers; this could have cause alterations in the mean readings for each measure. Although this is a possibility there does not appear to be any significant difference in the data provided by this participant compared to the other participants involved.

Possible ideas for future research could include altering the protocol to extend or shorten work to rest or cooling periods, altering exercise intensity or including specific work tasks. If performing this protocol in cool environmental conditions, prolonging work periods for example to 30 min and continuing to have rest and cooling periods of the same duration may cause a greater cooling response, particularly in the 15 MIN trial. Alternatively studying the physiological responses of participants when performing these trials in warmer conditions may show greater Tcore responses and therefore highlighting more so the influence having periods of mid-cooling has on delaying the onset of UHS.

The influence of cooling of performance could also be assessed by testing the participants' performance in specific work tasks. These would include dexterity tasks which could determine whether hand cooling affects the participants' ability to complete tasks that they would be required to perform in the working environment.

8.0 References

Allsopp, A.J. and Poole, K.A. (1991) ‘The effect of hand immersion on body temperature when wearing impermeable clothing.’ *Journal of the Royal Naval Medical Service.* 77, 41-47

Armstrong, L. and Maresh, C. (1991) ‘The induction and decay of acclimatisation in trained athletes.’ *Sports Medicine*, 12, 302-312

Bomalaski, S.H. Chen, Y.T. and Constable, S.H. (1995) ‘Continuous and intermittent personal microclimate cooling strategies.’ *Aviation, Space and Environmental Medicine.* 66, 745-750

Byrne, B. and Lim, C.L. (2006) ‘The ingestible telemetric body core temperature sensor: a review of validity and exercise applications.’ *British Journal of Sports Medicine*. 41:123-133

Cheung, S. and McLellan, T. (1998) ‘Heat acclimatisation, aerobic fitness, and hydration effects on tolerance during uncompensable heat stress.’ *Journal of Applied Physiology*. 84 (5), 1731-1739

Cheung, S. McLellan, T. and Tenagila, S. (2000) ‘The thermophysiology of uncompensable heat stress: Physiological manipulations and individual characteristics.’ *Sports Medicine.* 29(5): 329-359

Davies, N. (1995) ‘The control of peripheral circulation of the hands and forearms and the effect of local cooling in hyperthermic subjects.’ *Final year project report, BSc applied biological sciences, University of the West of England at Bristol.*

Fogarty, A. Armstrong, K. Gordon, C. Groellert, H. Woods, B. Stockst, J. Taylor, N. (2004) ‘Cardiovascular and thermal consequences of protective clothing: a comparison of clothed and unclothed states.’ *Ergonomics*. 47 (10), 1073-1086

Fortney, S.M. and Vroman, N.B. (1985) ‘Exercise, performance and temperature control: Temperature regulation during exercise and implications for sports performance and training.’ *Sports Medicine*. 2, 8-20

Gavin, T.P. (2003) ‘Clothing and thermoregulation during exercise.’ *Sports Medicine.* 33(13), 941-947

Giesbrecht, G.G. Jamieson, C. and Cahill, F. (2007) ‘Cooling hyperthermic firefighters by immersing forearms and hands in 10°C and 20°C water.’ *Aviation, Space and Environmental Medicine.* 78, 561-567

Gleeson, M. (1998) ‘Temperature regulation during exercise.’ *International Journal of Sports Medicine.* 19, S96-S99

Gonzalez-Alonso, J. Teller, C. Andersen, S. Jensen, F. Hyldig, T. Nielsen, B. (1999) ‘Influence of body temperature on the development of fatigue during prolonged exercise in the heat.’ *Journal of Applied Physiology*. 86 (3), 1032-1039

Goosey-Tolfrey, M. Swainson, M. Boyd, C. Atkinson, G and Tolfrey, K. (2008) ‘The effectiveness of hand cooling at reducing exercise-induced hyperthermia and improving distance-race performance in wheelchair and able-bodied athletes.’ *Journal of Applied Physiology.* 105, 37-43

Grahn, D. Cao, V. Heller, H. (2005) ‘Heat extraction through the palm of one hand improves aerobic exercise endurance in a hot environment.’ *Journal of Applied Physiology*. 99, 972-978

Greenfield, A.D.M. (1963) ‘The circulation through the skin’ *Handbook of Physiology; Circulation,* 2, 1324-1251

Hargreaves, M. (2008) ‘Physiological limits to exercise performance in the heat.’ *Journal of Science and Medicine in Sport*. 11, 66-71

Havenith, G. (1999) ‘Heat balance when wearing protective clothing.’ *The Annals of Occupational Hygiene.* 289-296

House, J.R. Holmes, C. and Allsopp, A.J. (1997) ‘Prevention of heat strain by immersing the hands and forearms in water.’ *Journal of the Royal Naval Medical Service.* 81(1), 26-30

House, J.R. (2003) ‘Modelling the effectiveness of techniques for reducing heat strain in royal navy nuclear, biological and chemical cleansing stations’ teams.’ *Journal of the Royal Naval Medical Service.* 89(1), 19-26

House, J.R. Lunt, H. Magness, A. and Lyons, J. (2003) ‘Testing the effectiveness of techniques for reducing heat strain in royal navy nuclear, biological and chemical cleansing stations’ teams.’ *Journal of the Royal Naval Medical Service.* 89(1), 27-34

Hsu, A.R. Hagobian, T.A. Jacobs, K.A. Attallah, H. and Friedlander, A.L. (2005) ‘Effects of heat removal through the hand on metabolism and performance during cycling exercise in the heat.’ *Canadian Journal of Applied Physiology*. 30, 87-104

Kenny, W.L. and Johnson, J.M. (1992) ‘Control of skin blood flow during exercise.’ *Medicine and Science in Sports and Exercise.* 24(3), 303-312

Khomenok, G.A. Hadid, A. Preiss-Bloom, O. Yanovich, R. Erlich, T. Ron-Tal, O. Peled, A. Epstein, Y. and Moran, D.S. (2008) ‘Hand immersion in cold water alleviating physiological strain and increasing tolerance to uncompensable heat stress.’ *European Journal of Applied Physiology*. 104, 303-309

Kraning, K.K. and Gonzalez, R.R. (1991) ‘Physiological consequences of intermittent exercise during compensable and uncompensable heat loss.’ *Journal of Applied Physiology*. 71(6), 2138-2145

Kruz, A. (2008) ‘Physiology of thermoregulation.’ *Best practice and Research: Clinical Anaesthesiology*. 22(4), 627-644

Levine, L. Johnson, R.F. Teal, W.B. Merullo, D.J. Cadarette, B.S. Staab, J.E. Blanchard, L.A. Kolka, M.A. and Sawka, M.N. (2001) ‘Heat strain evaluation of chemical protective garments.’ *Aviation, Space and Environmental Medicine.* 72, 329-335

Livingstone, S.D. Grayson, J. Frim, J, Allen, C.L. and Limmer, R.E. (1983) ‘Effect of cold exposure on various sites of core temperature measurements.’ *Journal of Applied Physiology*. 54(4), 1025-1031

Livingstone, S.D. Nolan, R.W. Cattroll, S.W. (1989) ‘Heat loss caused by immersing the hands in water.’ *Aviation, Space and Environmental Medicine*. 60, 1166-71

Livingstone, S.D. Nolan, R.W. Keefe, A.A. (1995) ‘Heat loss caused by cooling the feet.’ *Aviation, Space and Environmental Medicine*. 66, 232-7

Marino, F.E. (2002) ‘Methods, advantages, and limitations of body cooling for exercise performance.’ *British Journal of Sports Medicine*. 36, 89-94

Marsh, D. Sleivert, G. (1999) ‘Effect of precooling on high intensity cycling performance.’ *British Journal of Sports Medicine*. 33, 393-97

Maughan, R. Shirreffs, S. (2004) ‘Exercise in the heat: challenges and opportunities.’ *Journal of Sports Sciences*. 22, 917-27

Mekjavic, I.B. and Eiken, O. (2006) ‘Contribution of thermal and nonthermal factors to the regulation of body temperature in humans.’ *Journal of Applied Physiology*. 100, 2065-2072

Mitchell, J. Schiller, E. Miller, J. Dugas, J. (2001) ‘The influence of different external cooling methods on thermoregulatory responses before and after intense intermittent exercise in the heat.’ *Journal of Strength and Conditioning Research.* 15 (2), 247-54

Montian, S.J. Sawka, M.N. Cadarette, B.S. Quigley, M.D. and McKay, J.M. (1994) ‘Physiological tolerance to uncompensable heat stress: effects of exercise intensity, protective clothing and climate.’ *Journal of Applied Physiology.* 77(1), 216-222

Moran, D.S. and Mendal, L. (2002) ‘Core temperature measurement: methods and current insights.’ *Sports Medicine.* 32(14), 879-885

Parsons, K.C. (1988) ‘Protective clothing: heat exchange and physiological objectives.’ *Ergonomics.* 31(7), 991-1007

Pascoe, D.D. Bellingar, T.A. and McCluskey, B.S. (1994) ‘Clothing and exercise II: Influence of clothing during exercise/work in environmental extremes.’ *Sports Medicine.* 18(2), 94-108

Price, M.J. and O’Doherty, A. (2007) ‘Effects of hand cooling on intermittent exercise performance in the heat.’ *Proceedings of International conquers on Environmental Ergonomics.*

Quod, M. Martin, D. Laursen, P. (2006) ‘Cooling athletes before competition in the heat: comparison of techniques and practical considerations.’ *Sports Medicine,* 36 (8), 671-82

Rasch, W. Samson, P. Cote, J. Cabanac, M. (1991) ‘Heat loss from the human head during exercise.’ *Journal of Applied Physiology,* 71, 590-5

Richardson, S and Hardman, A.E. (1989) ‘Endurance fitness and blood lactate concentration during stepping exercise in untrained subjects.’ *British Journal of Sports Medicine,* 23 (3), 190-193

Selkirk, G.A. McLellan, T.M. and Wong, J. (2004) ‘Active versus passive cooling during work in warm environments while wearing firefighting protective clothing.’ *Journal of Occupational and Environmental Hygiene.* 1, 521-531

Ückert, S. Joch, W. (2007) ‘Effects of warm-up and precooling on endurance performance in the heat.’ *British Journal Sports Medicine,* 41, 380-84

Wendt, D. van Loon, L. van Marken Lichtenbelt, W. (2007) ‘Thermoregulation during exercise in the heat: strategies for maintaining health and performance.’ *Sports Medicine,* 37 (8), 669-82

Yeargin, S.W. Casa, D.J. McClung, J.M. Knight, J.C. Healey, J.C. Goss, P.J. Harvard, W.R. and Hipp, G.R. (2006) ‘Body cooling between two bouts of exercise in the heat enhances subsequent performance.’ *Journal of Strength and Conditioning Research.* 20(2), 383-389

Young, A.J. Sawka, M.N. Epstein, Y. Decristofano, B. and Pandolf, K.B. (1987) ‘Cooling different body surfaces during upper and lower body exercise.’ *Journal of Applied Physiology.* 63(3), 1218-1223

9.0 Appendices

Appendix 1

Borg Scale: Rating of Perceived Exertion (Borg, 1973)

6	No exertion at all
7	Extremely light
8	
9	Very light
10	
11	Light
12	
13	Somewhat hard
14	
15	Hard (heavy)
16	
17	Very hard
18	
19	Extremely hard
20	Maximal exertion

Appendix 2

Thermal Strain Scale (Young *et al.* 1987)

8 = Unbearably Hot

7 = Very Hot

6 = Hot

5 = Warm

4 = Comfortable

3 = Cool

2 = Cold

1 = Unbearably Cold