Pre-Cooling During Steady-State Rowing Decreases Physiological Strain and Enhances Self-Paced Rowing Performance in Elite Rowers

by

Elizabeth Anne Rebecca Johnson
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University of Victoria

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ABSTRACT

Supervisor: Dr. Gordon G. Sleivert

To determine the effects of torso cooling with ice (ICE) or water-perfused (WP) vests during rest and warm-up on subsequent 1500 m time trial rowing performance in the heat. Eight male rowers (23 ± 4 y) completed 3 sessions on an ergometer in an environmental chamber (38ºC, 47% RH) 1 week apart. Pre-cooling was applied during rest (45 min) and warm-up (30 min) in 2 trials using ICE or WP vests, but not in the control condition (CON). Rectal (T_{re}) and skin (T_{sk}) temperature, HR, RPE, thermal comfort (TC) and sensation (TS) were monitored throughout. HR, RPE or TS were not different between conditions. TC, T_{re} and T_{sk} were lower in WP and ICE than CON post warm-up ($P<0.05$). The reduction in strain was reflected by increased power output during the 1500 m time trial in ICE (11±1.2 %) and WP (9.6±1.1%) compared to CON ($P<0.05$). Pre-cooling with ICE or WP vests enhanced performance in a 1500 m rowing time trial and power output was higher from the onset.

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SYMBOLS AND ABBREVIATIONS

BSA	Body surface area (m^2)
CON	Control condition
ICE	Ice vest
RPE	Rate of Perceived Exertion
TC	Thermal comfort
$\overline{T}_c$	Mean Core Temperature (°C)
T_B	Body Temperature (°C)
Tre	Rectal Temperature (°C)
TS	Thermal Sensation
T_{SK}	Skin temperature (°C)
$\overline{T}_{SK}$	Mean Skin Temperature (°C)
VO_2	Oxygen Consumption ($mL \cdot kg^{-1} \cdot min^{-1}$ or $L \cdot min^{-1}$)
$VO_{2\ max}$	Maximal Oxygen Consumption ($mL \cdot kg^{-1} \cdot min^{-1}$ or $L \cdot min^{-1}$)
WP	Water perfused vest

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1.0 INTRODUCTION

High ambient temperatures and associated thermal strain is a common challenge for athletes competing in summer sports. The environmental conditions during the Olympic Games in Athens, Greece ranged from 35 to 40ºC and 20 to 57% relative humidity. Hot, humid climates limit the body's ability to transfer this heat to the environment. The challenge of maintaining thermal homeostasis is intensified by endogenous heat production by working muscle during exercise. Consequently, core temperature becomes elevated above the resting level of 37ºC. Exercise in these conditions may be accompanied by adverse psycho-physiological responses and heat illness.

Heat illness is most common in hot, humid weather but can occur in thermoneutral conditions if there is excessive endogenous heat production or heat loss is compromised. Uncompensable heat stress occurs when the air temperature exceeds 30ºC and relative humidity becomes higher than 60%. These conditions limit the body's ability to dissipate heat through evaporation, which is the main method of heat dissipation in hot climates (Brearley and Finn, 2003). As a result, core temperature will rise as metabolic heat production exceeds the heat exchange capacity of the surrounding environment. Hyperthermia increases the physiological strain on the body, which can decrease exercise capacity or lead to exhaustion, heat injury and death. Furthermore, it has been demonstrated that elevated body heat increases cardiovascular, thermal and perceptual strain and consequently is a limiting factor during exercise (Cheung and McLellan, 1998; Gonzalez-Alonso et al., 1999; Olschewski and Bruck, 1988; Walters et al., 2000).

It has been well established that exercise performance is compromised in hot humid conditions, and that hyperthermia accelerates fatigue during prolonged exercise in the heat (Galloway & Maughan, 1997; Gonzalez-Alonzo et al., 1999). There is an emerging hypothesis that a critical internal temperature exists which accelerates fatigue and subsequent exhaustion (Nybo and Nielsen, 2001, Gonzalez-Alonzo et al., 1999); however the underlying mechanisms remain unclear. A number of reports have linked internal temperature to impaired physical performance in the heat in humans and animals.

Tests on exercising rats (Walters et al., 2000) and humans (Gonzalez-Alonzo et al., 1999) have revealed that exhaustion is reached at a critical core temperature of approximately 40ºC regardless of the core temperature at the initiation of exercise.

In hot environments, athletes are unable to maintain thermal balance regardless of their level of training, heat acclimation or hydration status. Consequently, athletes need to reduce the speed or intensity of work in these hot humid conditions. Otherwise, they risk suffering a heat injury. Coaches and athletes could benefit from implementing tactics improve heat tolerance and reduce the risk decreased performance due to heat injury and illness during competitions. Thus, finding an effective and practical method of dealing with heat strain is a salient issue in the preparation of athletes competing in tropical environments.

If a critical internal temperature is a limiting factor during exercise in the heat then reducing core temperature prior to exercise using a pre-cooling manoeuvre may widen the margin before reaching the body temperature at which performance is decreased or heat exhaustion occurs. Decreasing core temperature by approximately 0.5ºC has been shown to improve exercise performance in hot humid conditions in the time range of performance lasting several minutes (Marsh & Sleivert, 1999; Cotter et al., 2001) up to an hour (Kay, Taaffe & Marino, 1999; Booth, Marino & Ward, 1997). A number of studies have examined pre-cooling and its effect on the thermoregulatory system (Appendix A). Thermoregulatory responses to pre-cooling during exercise include decreased rectal temperature (Shvartz, 1972), decreased esophageal temperature (Bolster, et al., 1999; Duffield, Dawson, Bishop, Fitzsimons & Lawrence, 2003), decreased mean skin temperature (Gonzalez-Alonzo et al., 1999), improved thermal comfort (Kay et al., 1999; Nunneley, Reader & Maldonado, 1982), and decreased sweat rate (Shvartz, 1972).

Several methods of pre-cooling have been explored. They include cold water immersion, refrigerated air, ice jackets, fans and water perfused suits. The pre-cooling modalities vary in their effectiveness and in their practicality for use in the field. Two strategies which appear to be both effective and practical for use before competitions are ice vests and water perfused suits. Both methods appear to have adequate cooling power to attenuate thermal strain (Cotter et al., 2001; Nunneley et at., 1982). The water perfused suit (WP), known as a liquid conditioning garment, is a relatively new way of cooling which was initially designed for industrial, military and space use. It relies on convective heat transfer from the body to cold water circulating through the suit. However, from an applied perspective the water perfused vest expensive and less portable than the ice vest. Thus, ice vests are appealing because they are affordable, easy to use and have good cooling power due to their large heat capacity. Ice vests are also portable, requiring only access to a freezer to make the ice and an insulated cooler to keep it cold. To date there have been no comparison of the effectiveness of these two pre-cooling methods as an ergogenic aid.

The effect of pre-cooling on exercise performance has received limited attention, and very few studies have included both elite athletes and measure of performance. Thus, pre-cooling still needs to be explored over a variety of sports and optimal pre-cooling strategies defined.

1.1 Purpose

This study sought to determine the thermoregulatory and psychophysical effects of selectively cooling the torso during rest and warm-up on subsequent performance in a 1500 m self-paced rowing ergometer time trial in the heat compared to a control condition. Secondly, two cooling method ice (ICE) or water-perfused (WP) vest were compared to determine their effectiveness.

1.2 Hypotheses

It was hypothesised that selectively cooling the torso during rest and steady state exercise in the heat would be associated with reduced thermal, cardiovascular, and psychophysical strain. Which would translate into enhanced 1500 m time trial performance would be enhanced following pre-cooling by either method, as individuals would self-select a higher absolute rowing speed. Additionally, it was hypothesized that there would be equal enhancement from both cooling methods.

1.3 Delimitations

The study was delimited to rowers who are members of the Canadian National Rowing Team.

1.4 Limitations

The participants in this study were elite male athletes working on specific training programs under the guidance of the national team coaches; thus it was not possible to maintain a consistent level of training throughout the study. In addition the volume and intensity of training was not controlled. However, the random balanced design was intended to account for any systematic effects of training. In addition, the invasive nature of the testing protocol, may have made the participants feel anxious, possibly affecting the results. Participants were extensively familiarised with testing procedures to limit such effects.

2.0 REVIEW OF LITERATURE

2.1 Introduction

Humans possess the ability to maintain a relatively constant core temperature of approximately 37ºC despite being subjected to ambient temperatures that vary widely and that are constantly changing. Tolerating large variation in environmental temperature is critical because any deviations in core temperature from its normal limits, either up or down, are pathogenic and potentially lethal. Unlike the cardiovascular or respiratory system, the thermoregulatory system does not function as an independent unit. Rather the thermoregulatory control center located in the hypothalamus coordinates many of the systems of the body and integrates their activities with the common goal of maintaining a stable core body temperature under most conditions. The hypothalamus receives input from local and peripheral receptors regarding the thermal state of different parts of the body. Its job is to evaluate the incoming signals and to activate the appropriate effectors mediated responses to maintain body temperature at its set point (Blatteis, 2001). The overall response is heat production or dissipation depending on the conditions.

The combination of environmental heat load and metabolic heat call greater heat dissipation in order to maintain thermal homeostasis. Athletes competing in thermo-stressful environments face this challenge regularly. One potential method of dealing with the increase in heat strain is by lowering core temperature prior to exercise through pre-cooling. However, the practical application of pre-cooling is yet to be fully assessed. This chapter will review the physiological responses to exercise induced hyperthermia and strategies to minimize its detrimental effects on performance including current methodologies of pre-cooling. Particular attention will be given to the physiological responses that are thought to contribute to the enhanced exercise capacity associated with a pre-cooling manoeuvre.

2.2 Heat illness

Exertional heat illness is traditionally defined by three categories: heat cramps, heat exhaustion and heat stroke (Binkley et al., 2002). Heat cramps are non life-threatening and may be related to sodium deficit, but more likely to the fatigue of the muscle spindles and alterations to the spinal neural reflexes. Heat exhaustion is characterized by an elevated core temperature (typically below 40ºC) and the inability to continue exercise. Athletes often collapse with heat exhaustion at the end of exercise. This is generally not associated with extreme dehydration; rather it is the result of postural hypotension due to the large amount of cutaneous blood flow and the cessation of the muscle pump action of the lower limbs (Binkley et al., 2002). Core temperature begins to decline rapidly once exercise has stopped because muscle heat production has been reduced. This is in contrast to heat stroke, where core temperature continues to rise above 40ºC because of central and biochemical abnormalities. This condition is life threatening because the thermoregulatory control system is overwhelmed and cannot compensate for the increased endogenous heat production or challenging environmental conditions. Later symptoms of heat stroke include collapse while exercising, loss of motor control, irrational behaviour, and in extreme cases death.

A study on the cause of non traumatic exercise related deaths in the US military revealed 12% of exercise related deaths in the US military personnel on active duty during 1996-1999 were attributable to exertional heat illness (Gardner 2002). Exertional heat illness is considered one of the major preventable causes of death among young adults 17 and 39 years of age, accounting for 14 deaths and the authors' note that the frequency is probably underestimated. Indeed, an earlier study in college athletes found that nearly 15% of exercise related deaths were attributable to heat stress (Van Camp et al., 1995).

2.3 Thermal homeostasis

Core temperature in humans is maintained within a narrow range, which corresponds to optimal temperature for efficient body function (Blatteis, 2001). This stability implies that heat produced in the body and that lost from it stay in relative balance, despite large variation in ambient temperature. Thermal balance consists of a complex interaction of factors that cause heat gain and heat loss. Heat gain is the product of endogenous (metabolic) and exogenous (environmental) thermal loads, while heat loss is the result of thermal exchange with the environment through conduction, convection, radiation and evaporation. During exercise, heat gain often occurs due to increased basal metabolic rate, increased muscle activity and in some cases augmented heat transfer from a warm environment (Blatteis, 2001). When heat production exceeds heat dissipation, such as during exercise, heat storage occurs causing a corresponding increase in core temperature.

The body does a poor job converting chemical energy into mechanical work and consequently a significant amount of energy produced during muscle contractions (up to 80%) is lost as heat (Blatteis, 2001). Heat produced by working skeletal muscles is transferred primarily through convective heat flow of blood from the core to the skin. It is then dissipated to the surrounding environment by conduction, convection, radiation and evaporation. Under most conditions humans are able to maintain thermal homeostasis during exercise as heat loss balances heat production and core temperature reaches a new equilibrium at an elevated level.

Body core temperature is determined by metabolic heat production and the transfer of body heat to and from the surrounding environment using the following heat production and heat storage equation: (Blatteis 2001)

$$S = M \pm R \pm K \pm Cv - E$$

Where S is the amount of stored heat, M is the metabolic heat production R is the heat gained or lost by radiation, K is the conductive heat lost or gained, and E is the evaporative heat loss.

2.3.1 Thermoregulation - afferent inputs

The thermoregulatory control centre is located in the hypothalamus and receives input from local and peripheral receptors regarding the thermal state of different parts of the body. The active components of the thermoregulatory system form a highly redundant feedback loop. Recently the theory of teleoanticipation has suggested that hypothalamus also sends out feed forward signals based on previous experiences, arousal and motivation (Lambert et al., 2004). The teleoanticipation model is specific to exercise and associates higher regulatory centers with the predicted end point of exercise and pacing strategies. This model relies on both feed forward planning and feedback from metabolic structures and the external environment. Teleoanticipation also incorporates knowledge acquired from prior exercise bouts. Ultimately the thermoregulatory control center responsible for evaluating the incoming signals and activating the appropriate effectors mediated responses to maintain body temperature at its set point (Blatteis 2001). The end result is heat production or dissipation depending on the conditions.

It is well accepted that both cutaneous temperature and core temperature (T_c) reception provides afferent input for the regulation of body temperature. The existence of extra-hypothalamic deep body sensory was proposed in early research using birds, however it has not been confirmed in humans and their inputs would likely play a secondary role to those from the hypothalamus (Simon et al., 1986). Cutaneous thermoreceptors are typically only ~10% as important as core thermoreceptors in influencing thermal response mechanisms (Simon et al., 1986; Cotter et al., 1996). An elegant study by Frank and colleagues (1999) supports these earlier findings. In this study the participants' skin and core temperature were independently manipulated while measuring thermal comfort, vasomotor changes metabolic heat production and systemic catecholaminergic responses. Their results suggest that core and skin temperature contribute equally towards thermal comfort, whereas core temperature dominates the regulation of the autonomic and metabolic responses.

Cutaneous thermoreceptors are sensitive to ambient temperature and provide information regarding the surrounding environmental conditions. These receptors fire constantly and modify their firing frequency based on changes in the environment. For example receptors fire spontaneously at 33ºC (mean skin temperature) and firing rates increase during moderate skin warming (Blatteis 2001). Central thermoreceptors are located directly in the hypothalamus in particular the preoptic and anterior portions. These thermosensitive neurons respond to both increases and decreases in temperature by altering their firing frequency. During exercise, warm blood perfused to the brain stimulates the thermosensitive neurons in the hypothalamus with a concomitant increase their firing rate. Thermal signals from either central or peripheral receptors are compared and integrated in the hypothalamus which activates the thermoregulatory effectors to alter body temperature in a direction opposite to the direction of the stimulus.

2.3.2 Effector mechanisms

The hypothalamus controls core temperature by transforming afferent thermal inputs into efferent signals that direct the thermoregulatory effectors and provide physiological adjustments. There is experimental evidence derived from studies on mammals with extensive hypothalamic lesions and clinical observations in paraplegics that indicate lower sections of the brain stem and the spinal cord are capable of transforming thermal afferent inputs into efferent signals (Simon et al., 1986). However, for the purpose of this review we will focus on efferent signals initiated in the hypothalamus. The effector response to thermal stimulation can be both behavioural and physiological. Behavioural thermoregulation is a potent strategy used by mammals to minimize the effects of heat stress. Responses to thermal discomfort include exercising during the coolest part of the day, wearing minimal clothing, staying well hydrated, acclimatizing and pre-cooling prior to exercise in the heat. These strategies may be limited in certain sporting situation either during competition or due to the nature of the activity.

The physiological effector response to heating includes increased cutaneous vasodilation to enhance heat transfer from the core to the body surface where it can be dissipated through radiation or evaporation. The major mechanisms by which skin blood flow is increased during heat stress include reduced activity of sympathetic vasoconstrictor nerves, increased activity of the cutaneous vasodilator system, and local effects of increased skin temperature (Johnson and Proppe 1996).

When the heat gradient between the skin and the environment is reduced (i.e. ambient temperature = 35ºC) then there is an increased dependency on evaporative heat loss. During heat stress the sweat glands secrete sweat onto the skin surface, which cools the body when it evaporates. One gram of sweat requires 2.43 kJ of heat to evaporate at

30ºC (Wenger 1972). Sweating is initiated by a sudomotor signal descending from the brain to the sweat glands where acetylcholine is released to stimulate the sweat glands (Johnson and Proppe 1996).

2.4 Critical temperature hypothesis

It has been well established that exercise is limited in hot humid conditions, and that hyperthermia accelerates fatigue during prolonged exercise (Galloway and Maughan 1997). During uncompensable heat stress, heat exchange capacity with the environment is less than the rate of heat production. Thus the ability to dissipate heat effectively is reduced, which ultimately leads to an increase in core temperature. A decrease in exercise intensity or a change in pacing strategy is often necessary so that exercise can continue with a reduced risk of cellular injury (Marino, 2002).

It has been suggested that a critical internal temperature limits exercise in the heat. A number of reports have linked internal temperature to impaired physical performance in the heat in humans and animals. Tests in exercising rats (Walters et al., 2000; Fuller et al., 1998), goats (Caputa et al., 1986), cheetahs (Taylor and Rowntree 1973) and humans (Nybo and Nielsen 2001, Gonzalez-Alonzo et al., 1999) have revealed that exhaustion is reached at a critical core temperature of approximately 40ºc regardless of the core temperature at the initiation of exercise. Preheating to core temperature to 38ºC via active (treadmill running at 70% VO_{2max}) or passive heating (water immersion 44ºC) also reduces sub-maximal exercise capacity in a moderate environment (~21ºC and 37% relative humidity) independent of the method of pre-warming and rectal temperature at exhaustion (39.4ºC) was consistent with previous findings (Gregson et al., 2002).

It appears that aerobic fitness influences the ability to exercise during uncompensable heat stress. Trained individuals possess enhanced ability to tolerate elevated core temperature at exhaustion. A recent study found core temperature variations as great as 0.9ºC between subjects with differing fitness levels matched for low body fatness (Selkirk and McLellan 2001), indicating that individuals with lower aerobic fitness fatigue at lower critical core temperature. Untrained participants started at similar resting core temperature but fatigued at 38.7ºC, whereas the trained participants' final core temperature reached 39.5ºC regardless of body fatness. This is consistent the findings from Latzka and colleagues (1998) that untrained men fatigued at a core temperature of approximately 39ºC during uncompensable heat stress exercise even after participating in 6-10 day heat acclimation protocol. Assessment of thermal sensation tended to be higher for untrained versus trained participants for the same increase in core temperature, indicating lower perceived heat tolerance of the untrained subjects. Lower core temperature values for untrained individuals may be due to the premature termination of exercise independent of high level of thermal strain or the attainment of the critical core temperature. It has been documented that high fit individuals generally terminate an exercise trial due to the attainment of the ethical limit for core temperature (as determined by research ethics boards; typically 39.5 to 40.0ºC) while moderately fit participants cease exercising due to exhaustion (Cheung and McLellan, 1998). Results point to the conclusion that trained individuals underestimate their physiological strain. This may place endurance trained individuals at potentially greater risk of heat strain injuries if they are allowed to continue exercising in the heat according to their perception.

2.5 Physiological effects of hyperthermia

2.5.1 Neuromuscular effects

Although research in this area is growing, the mechanisms (either central or peripheral) responsible for the earlier onset of fatigue while exercising in uncompensable heat remain unclear. There is increasing evidence to support the notion that the decrease in force observed during hyperthermia is the result of decreased central drive to the muscle (Nybo and Nielsen 2001; Morrison et al., 2004). Nybo and Nielsen (2001) reported reduction in voluntary activation and force production following cycling to hyperthermia (core temperature 40.0ºC) regardless of whether the muscle was exercised (knee extensors) or not (hand grip muscles). It was concluded that the impaired ability to generate force during hyperthermia is associated with a reduction in the voluntary activation percentage. However, it is difficult to isolate the role of the central nervous system in the development of fatigue during exercise induced hyperthermia because the length of time required to induce a significant elevation in baseline temperature eventually leads to the introduction of confounding variables such as dehydration, electrolyte imbalances and cardiovascular strain, which hasten fatigue.

A recent study which used passively induced hyperthermia to determine its effects on voluntary activation and force production found that hyperthermia per se was the main factor in attenuating force development. Passive heating to a core temperature of 39.4ºC using a water perfused suit significantly reduced both voluntary activation (Figure 2.1) and force production (Figure 2.2) and function was not restored with the application of skin cooling. Cardiovascular strain was significantly reduced by skin cooling however force production remained depressed until core temperature returned to baseline values. Two theories have been proposed to explain the decrease in central drive during hyperthermia. The descending message from higher brain centers to the motor neuron pool may be compromised. Alternatively there may a reduction of the excitability of the motor neurons at a spinal level due to sensory feedback from Type III and IV afferent fibres (Cheung and Sleivert 2004).

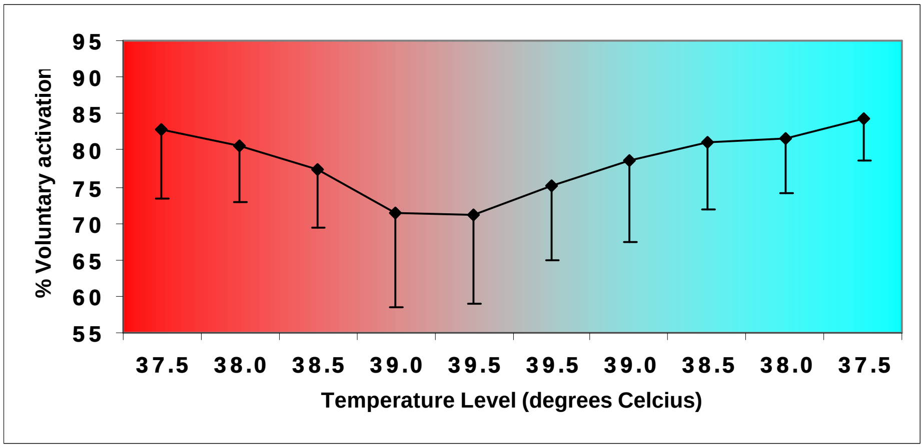


Figure 2. 1 Mean (SD) percent of voluntary activation of the knee extensor muscles during passive heating from rectal temperature of 37°C to 39.5°C and subsequent cooling back to baseline. N=22 Matching letters indicate significant differences (P<0.001). (Adapted from Morrison S, Sleivert GS,

Cheung SS (2004) Passive hyperthermia reduces voluntary activation and isometric force production. Eur J Appl Physiol 91:729-736. Copyright 2004 Springer-Verlag.)

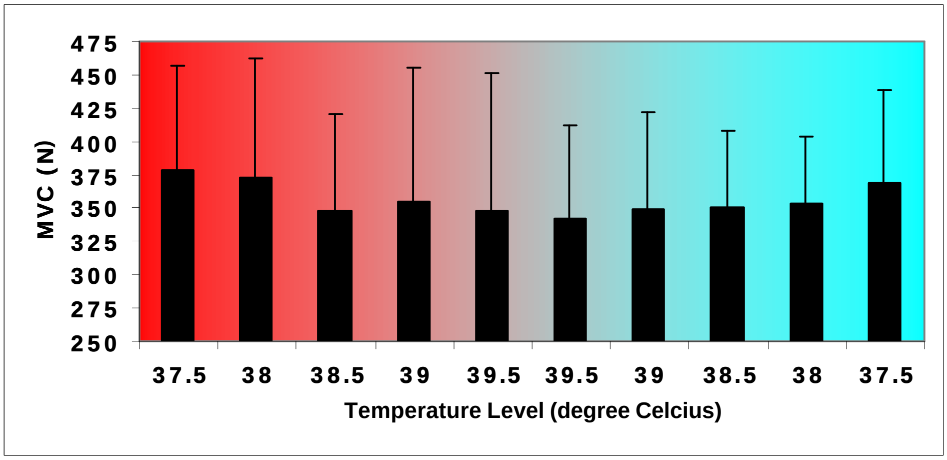


Figure 2. 2 Mean (SD) maximum voluntary contraction of the knee extensors during passive heating from rectal temperature of 37°C to 39.5°C and subsequent cooling back to baseline. N=22 Matching letters indicate significant differences (P<0.001). (Adapted from Morrison S, Sleivert GS, Cheung SS (2004) Passive hyperthermia reduces voluntary activation and isometric force production. Eur J Appl Physiol 91:729-736. Copyright 2004 Springer-Verlag.)

2.5.2 Brain activity

Despite being the most likely site for critical temperature effects, brain temperature has not yet been measured in humans. Studies on mammals revealed that exhaustion during running is coincident with a brain temperature of 42.5ºC in goats (Caputa et al., 1986) and 40.2ºC in rats (Fuller et al., 1998). Fuller and colleagues (1998) determined that rat brain temperature is higher than simultaneously measured abdominal temperature throughout exercise. Despite the inability to directly measure brain temperature, brain activity during hyperthermia has been explored in humans. A rise in core temperature in trained athletes cycling to exhaustion has been linearly related to increases in EEG (Nielsen et al., 2001). EEG frequencies shifted toward slower frequency a-waves which are typically associated with drowsiness or sleep indicating a lower state of arousal. The associated EMG amplitude and frequency of the exercising muscle remained unaltered during prolonged exercise with progressive hyperthermia.

Thus, present results demonstrate that hyperthermia does not affect the electrical patterns of active skeletal muscles; rather the development of fatigue during prolonged exercise in the heat seems to be associated with altered cerebral function (Figure 2.3). Furthermore, participants' perceived exertion was highly associated with an increase in core temperature and frequency changes of the EEG obtained over the prefrontal cortex (Nielsen et al 2001).

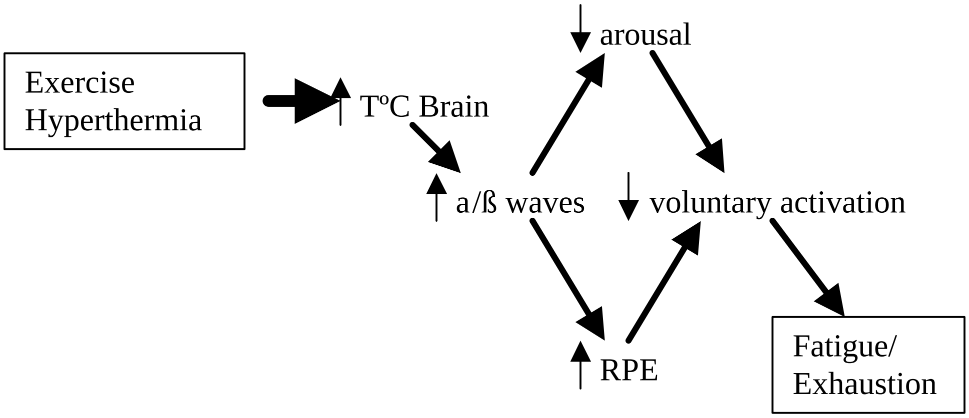


Figure 2. 3 Psychophysical contributors to hyperthermic fatigue and exhaustion (Adapted from Cheung SS, and Sleivert GS (2004) Multiple triggers for hyperthermic fatigue and exhaustion. Exerc Sport Sci Rev 32:100-106. Copyright © 2004 American College of Sports Medicine.)

Hyperthermia appears to give rise to central fatigue; however the neurobiological mechanisms underlying this type of fatigue remained unknown. Nybo and Nielsen (2003) evaluated the cerebral balances of tryptophan, the precursor to serotonin, during prolonged exercise with normal or elevated core temperature. It appeared that the influence serotonin levels only became relevant for central fatigue during exercise of very long duration. Cerebral blood flow is depressed during hyperthermia. Interestingly, an 18% decrease in cerebral blood flow has not been shown to alter cerebral lactate production (Nybo et al., 2002). Cerebral metabolism and glucose utilization actually increased during prolonged exercise in the heat. This may be partially attributed to an increased degree of mental exertion near the end of the exercise bout. However, at present the relationship between cerebral blood flow and metabolism during hyperthermia remains unclear.

2.5.3 Muscle function & metabolism

Hyperthermia results in a shift towards increased carbohydrate utilization and reduced fat metabolism during exercise. Kozlowski et al., (1985) studied muscle metabolism in dogs exercising to exhaustion (core temperature ~ 41.8ºC). High energy phosphate breakdown and glycolysis were accelerated in the absence of trunk cooling compared to the cooling condition. Muscle lactate content was highly positively correlated to muscle temperature suggesting a temperature induced perturbation in metabolism during fatiguing exercise. These results contrast more current work in humans. In fact, a recent study reported that muscle glycogen concentration at fatigue in hyperthermia was higher compared to the cooling and control condition (Parkin et al., 1999). Fatigue in these conditions does not appear to be related to carbohydrate availability. One possible explanation for the discrepancy in the results of these two studies may be that the ambient conditions which were 20ºC and 40ºC for the dog and human study respectively. The equivocal results on the effect of hyperthermia on muscle metabolism make it difficult to draw any firm conclusion.

Two mechanisms have been suggested to explain the alterations in metabolism associated with hyperthermia. During exercise induced hyperthermia, epinephrine concentrations can be markedly increased up to two fold resting levels. Plasma epinephrine concentrations were significantly higher following 20 minutes of exercise in the heat when compared to the cool and normothermic conditions (Parkin et al., 1999). However, elevation of muscle temperature, increased glycogenolysis and lactate accumulation have been observed in the absence of changes in body temperature or plasma catecholamine levels (Febbraio 2000). Thus, it has been proposed that the increase in anaerobic glycolysis may be due to a Q10 effect or a decreasing in the total adenine nucleotide pool (TAN). Interestingly the same lab used a protocol that involved heating one of the participants legs and cooling the other prior to exercise and found that the heated leg had a higher muscle temperature and elevated glycogen metabolism. These results would suggest that muscle temperature per se plays a role in metabolism during heat stress.

2.5.4 Cardiovascular function

Exercise induced hyperthermia is associated with high levels of cardiovascular strain. The use of both exercise and heat to elicit hyperthermia result in heart rates exceeding 95% of maximum predicted values (Nybo and Nielsen 2001; Gonzalez-Alonzo et al., 1999). It has been suggested that increased blood flow to the skin due to cutaneous vasodilation during hyperthermia results in an inability to sustain adequate cardiac output, blood pressure thus reducing critical blood flow to the brain (Nybo et al., 2002). Nielsen et al. (1990) proposed the decreased ability to perform in the heat could be attributed to the increased demand for blood flow to the skin may be competing with the blood supply to the working muscles. However, subsequent testing revealed that there is no reduction blood flow to the exercising limbs when subjects exercised in very warm environments with a core temperature of approximately 40ºC.

The effects of manipulating starting core temperature in trained cyclists revealed that increases in heart rate and decreases in stroke volume paralleled the rise in core temperature from 36 to 40ºC (Gonzalez-Alonzo et al., 1998). Skin blood flow plateaued at 38ºC, suggesting that the elevated heart rate was the primary contributor to decreased stroke volume due to reduced cardiac filling time, with the net result being a decrease in cardiac output during hyperthermia. Hyperthermia causes elevated cardiac temperature which may influence cardiac contractility directly, thereby reducing stroke volume.

2.6 Strategies to improve performance in the heat

A conventional strategy to improve exercise performance in the heat is through heat acclimatization. Humans adapt to hot humid environments by undergoing physiological and behavioural changes that reduce the strain associated with exercising in these conditions. Some physiological changes include a reduction in resting core temperature and cardiovascular adaptations that aid in heat loss (Nielsen et al., 1993). Acclimatization has been shown to increase a person's ability to exercise in the heat. For example, run time increased nearly two-fold following 9 to 12 days of acclimatization to dry heat, 41°C and 12% relative humidity (rh) compared to controls (Nielsen et al., 1993). Evidence of acclimatization included increased sweating rate, lowered rate of rise in core temperature and heart rate, increased plasma volume and prolonged exercise time to exhaustion. It is also possible to decrease initial core temperature through pre-cooling. This is a behavioural strategy used to create negative heat storage and decrease thermal strain prior to the initiation of exercise or thermal stress.

2.6.1 Heat acclimation

Exercising in the heat enhances the ability to maintain homeostasis during subsequent exposure to heat stress. Adaptations occur peripherally in the sweat glands and at the level of the central nervous system. Roberts et al. (1977) showed the onset of sweating (x intercept) was not altered by 10 days of physical training (Figure 2.4) in a cool environment however the slope of the line was altered indicating peripheral (sweat gland) changes. The onset of sweating decreased approximately 0.4ºC subsequent to 10 days of heat acclimatization, suggesting central adaptations. Conversely, active unacclimated males participating in a 6 day heat acclimation protocol which involved cycling in a heat chamber (39.5ºC, 59.2% rh) reduced the sweating threshold temperature and heart rate without a concomitant redistribution of sweating towards peripheral skin regions (Cotter et al., 1997). The authors suggested that this is an indication that the acclimation regimen elicited central sudomotor changes with no evidence of peripheral changes. The high level of humidity used in this study combined with differences in the number of heat exposures (10 vs 6) and the population used (unfit vs fit) may account for the disparity between these two studies.

Evidence of acclimatization included increased sweating rate, lowered rate of rise in core temperature and heart rate, increased plasma volume, decrease core temperature and decrease sweat sodium and chloride concentrations. (Armstrong and Stoppani, 2002). Heat acclimation also affects the choice of fuel substrate in muscle. The body relies more on carbohydrates as a fuel when it is first exposed to a hot environment, thus more lactate is produced. Following acclimatization fuel selection is similar to that in a cooler environment. Exercise in humid heat has also been shown to prolong exercise time to exhaustion and improve performance.

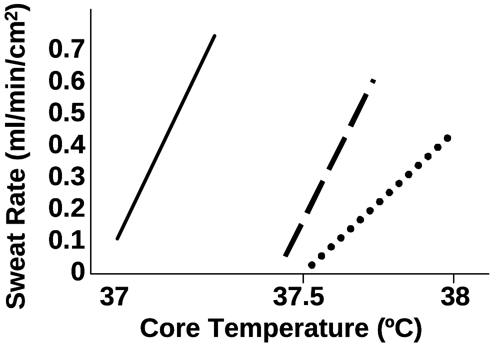


Figure 2. 4 Evidence that the CNS regulation of sweating is altered by heat acclimation. Symbols: pre-training (dots), post training at 25ºC (dashes) post-acclimation at 35ºC (solid) (Adapted from Roberts MF, Wenger CB, Stolwijk JAJ, Nadel ER (1977) Skin blood flow and sweating changes following exercise training and heat acclimation. J Appl Physiol 43:133-137)

Acclimatization increases the ability to exercise in the heat. Run time increased nearly two-fold following 9 to 12 days of acclimatization to dry heat (41ºC and 12% rh) compared to controls (Nielsen et al., 1993). Performance improvements following acute repeated exposures to exercise in hot humid (35ºC and 87% rh) environments are not as pronounced. Fit participants increased cycling time from 45 min to 52 min subsequent to 8-13 consecutive days of heat exposure (Nielsen et al., 1997). Physiological adaptations included increased plasma volume, lower heart rate at exhaustion and a 26% increase in sweat rate. The relatively small improvements in performance following humid heat exposure (15% as compare to 71% in hot dry heat) may be due to the physical limitations for evaporative heat loss.

Heat Acclimatization strategies typically involve 10 to 12 days of exercising in the heat, but changes can occur in as few as four days. This can be achieved naturally in a warm climate or it can be simulated artificially using sweat clothing which creates a hot wet microenvironment close to the skin surface, however this method is less effective. The guidelines for heat acclimation are 90 minutes per day of light intensity exercise (40-50% VO_{2max}) in a warm environment to increase core temperature to 39ºC.

2.7 Pre-cooling

The development of fatigue and subsequent exhaustion occurs earlier during exercise in uncompensable hot environments. Although the underlying mechanism for the onset of premature fatigue has yet to be clearly identified, it is generally accepted that exhaustion coincides with a critically high core temperature. If absolute heat storage limits the duration of exercise at a given intensity then pre-cooling may widen the temperature margins before the critical limiting temperature is reached. The implementation of cooling strategies could delay the onset of heat build-up by decreasing core temperature prior to the initiation of exercise. Hence, by delaying the attainment of a critical upper temperature overall work output should increase. Indeed, pre-cooling prior to exercise has been shown to improve performance during subsequent endurance exercise in heat stressful environments. This improvement has been associated with reductions in thermal and cardiovascular strain, measured by a decrease in rectal temperature, heart rate, and skin temperature (Cotter, Sleivert, Roberts, & Febbraio, 2001; Booth, Marino, & Ward, 1997; Kay, Taaffe, & Marino, 1999).

2.7.1 Efficiency of pre-cooling methods

The general objective of pre-cooling is to achieve maximal thermal comfort and to decrease heat storage during exercise. Several methods have been used for pre-cooling in the past however there is no consensus on which method is most effective (Appendix A). Pre-cooling techniques have included cold-water immersion (Bolster et al., 1999; Booth, Marino, & Ward, 1997b; Marsh & Sleivert, 1999; Kay, Taaffe, & Marino, 1999d), refrigerated air (Sleivert, Cotter, Roberts, & Febbraio, 2001; Cotter, Sleivert, Roberts, & Febbraio, 2001), water cooled suits (Shvartz, 1972; Nunneley, Reader, & Maldonado, 1982) and ice vests (Cotter, Sleivert, Roberts, & Febbraio, 2001b; Duffield, Dawson, Bishop, Fitzsimons, & Lawrence, 2003b). Some of these techniques are more effective in reducing core temperature than others. For example, ice vests lower skin temperature and make the athlete feel cooler. However, if only a small area is cooled it may fail to confer a meaningful reduction in core temperature (Brearley & Finn, 2003). This may lead to improved performance due to the perception of greater acceptability of the conditions in which the activity is taking place. Pre-cooling could be potentially dangerous if an athlete ignores physiological clues that would otherwise cause them to reduce their exercise intensity, thereby increasing the risk of heat illness. Conversely, cooling a greater proportion of the body surface area as in water immersion, may lead to lower core temperature but this method of cooling may be impractical in the field. Nevertheless, water immersion can be appealing because of water's high heat transfer characteristics, which are 2 to 4 times greater than air at the same temperature (Booth, Marino, & Ward, 1997a). In addition, during water immersion skin temperature is clamped near the water temperature so that a more uniform cooling results (Kay, Taaffe, & Marino, 1999c).

Pre-cooling by water-cooled suits is another potentially effective way to reduce core body temperature prior to performance. Shvartz (1972) reviewed 11 studies comparing the use of water-cooled suits under various conditions with respect to their efficiency and effectiveness in reducing heat strain. This review suggests that the head is the most efficient body region for heat removal, reducing heat strain by approximately 1/3. There was also evidence to suggest that a significant amount of heat may be absorbed from the arms, while the legs do not play a major role in heat dissipation. However, these comparisons were made on the basis of tube length in the suits as well as the percent body contact with the tubes and their effect on heat strain. It did not take into consideration the water temperature, the duration of cooling, the subjects' fitness level, or their body fatness.

2.7.2 Cooling selective body regions

The most effective pre-cooling strategy would maximize the physiological benefits of a decreased core temperature while minimizing any adverse effects, such as physical discomfort or increased metabolic heat production. Selective body cooling may be a practical strategy to attain this goal. For example, White, Davis and Wilson (2003) compared the effectiveness of lower body vs. whole body pre-cooling on thermoregulation, metabolism and perception during sub-maximal exercise. A direct comparison of the effects of these two immersion techniques revealed that they were similar in their ability to prevent excessive increases in core temperature during subsequent sub-maximal exercise. These data suggested that both cooling techniques resulted in similar net heat storage during the experimental protocol. Thus, lower body cooling produced significant physiological benefits; however it also minimized the metabolic and perceptual effects resulting from whole body cooling. Lower body cooling also has the advantage of being more practical than whole body immersion for use in the field.

The head is a unique area for a pre-cooling manoeuvre and warrants serious consideration. Although it represents only 10% of the body surface area, it has high potential for heat transfer, making it an effective target for reducing heat load (Shvartz, 1972b). Furthermore, head cooling is much more practical for use in the field when compared with water immersion or refrigerated air. An early study by Nunneley et al. (1982) manipulated head and body temperature using water perfused vests (WP) and measured perceived comfort in addition to accuracy and reaction time on a computer task. The WP is essentially a water-cooled suit that provides a microclimate that resembles a temperature controlled bath. Each subject participated in four stress experiments (head/body = hot/hot, cold/hot, hot/cold, and cold/cold) and one control trial. It was shown that head temperature had a marked effect on physiological responses and perceived comfort even when core temperature was strongly driven by the suit. High core temperatures tended to shorten reaction time and diminish performance accuracy, while head cooling largely reversed these trends. The practicality of head cooling in addition to its ability manipulate thermal sensation and heat load make is an excellent potential site for pre-cooling and deserves further exploration in the future.

2.7.3 Thermal dependence of muscle function

One consideration associated with pre-cooling is whether or not the application of surface cooling should include the limbs involved in subsequent exercise. Lower muscle temperature is generally associated with lower mechanical power output (Bigland-

Ritchie, Thomas, Rice, Howarth, & Woods, 1992) so pre-cooling could be detrimental to subsequent performance. A recent study examined whether pre-cooling by ice vest and cold air, with and without thigh cooling, influenced endurance cycling performance (Cotter, Sleivert, Roberts, & Febbraio, 2001a). The results of the study indicated that pre-cooling effectively reduced physiological and psychophysical strain and improved endurance performance in the heat, irrespective of whether the thighs were warmed or cooled.

2.8 Pre-cooling and exercise performance

Research in the area of pre-cooling and its effects on the thermoregulatory responses to exercise in hot humid environments is growing. However, performance changes associated with pre-cooling have not been studied extensively and definite strategies have not been established. Discrepancies in the cooling methods used, the experimental ambient conditions, the different exercise loads implemented and variations in the subjects' physical characteristics make it difficult to compare the results of studies in this area. One of the primary problems with evaluating the effectiveness of pre-cooling on performance is the type of exercise protocol used during testing is inconsistent.

2.8.1 High intensity exercise

Marsh and Sleivert (1999) were the first to report that pre-cooling could enhance short-term high intensity exercise. They employed torso only water immersion for 30 minutes to decrease core temperature and found that pre-cooling increased sprint cycling performance significantly by 2.7% when compared to the control condition. It was speculated that the decreased core and skin temperature reduced the need for blood at the skin. Ultimately this would lead to an increase in central blood volume and greater blood availability to working muscle, allowing for improved oxygen delivery and waste removal. This is in line with evidence showing that lower stroke volume, central venous pressure and central blood volume associated with whole body heating are reversed by whole body cooling (Gonzalez-Alonso et al., 1999b). These explanations of the functional mechanism of pre-cooling rely on muscle blood flow being a limiting factor during exercise. However, there has not been strong support for this theory. In fact, Nielsen et al. (1993) showed leg blood flow to be unaffected by exercise in hot dry environments. Similarly, an investigation into the effect of heat stress on blood flow in exercising leg muscle concluded that it is not a limiting factor to exercise in the heat (Nielsen, Savard, Richter, Hargreaves, & Saltin, 1990). More recent research examining the effects of torso only pre-cooling on high-intensity exercise performance revealed that pre-cooling did not reduce peak or mean power, either with or without a warm-up (Sleivert, Cotter, Roberts, & Febbraio, 2001a). In fact the lower muscle temperature resulted in decreased performance for 45-s high intensity cycling exercise relative to the control. It is possible that differences between this study and the results from Marsh and Sleivert lie in the duration of the exercise protocol. The 70-s trial used by Marsh and Sleivert required a mix of anaerobic and aerobic energy supplies, whereas the 45-s sprint only recruited the anaerobic energy system. Pre-cooling has typically been shown to be effective in improving aerobic exercise, while the results for high intensity exercise remain inconclusive.

2.8.2 Endurance exercise

There is mounting evidence to suggest that pre-cooling improves endurance performance in hot environments. One of the earlier studies by Olschewski and Bruck (1988) investigated the effects of lowered body temperature on cycling endurance time at an ambient temperature of 18°C. The pre-cooling treatment involved double exposure to cold air (~ 0°C), which was successful in reducing mean skin and core temperature resulting in 205 kJ/m2 negative heat storage. Cycling time to exhaustion was increased by 12% and sweat rate was significantly decreased during exercise after cooling when compared to the control. This study is no doubt a precursor to more recent studies on pre-cooling.

Booth and colleagues (1997) also explored the potential benefits of pre-cooling on endurance exercise. Five male and three female endurance runners were required to run as far as possible in 30 minutes at an ambient temperature of 31.6°C, 60% relative humidity. Subjects were pre-cooled by cold-water immersion to the level of the neck. In order to minimize subject discomfort and shivering the water temperature was gradually reduced from 28°C at the beginning to 24°C over 60 minutes of cooling. Core and skin temperature were significantly reduced following pre-cooling and mean body temperature remained lower throughout exercise. Run distance increased significantly by 304 m (~4%) following pre-cooling. These results suggest that the athletes were able to maintain a faster running speed throughout the thirty minutes and in some cases increased their speed near the end of the trial.

A second study that used self-pacing strategies to evaluate the usefulness of pre-cooling prior to cycling performance found similar results (Kay, Taaffe, & Marino, 1999b). This study employed whole body pre-cooling by water immersion to lower skin temperature. However, in this case the goal was to cool the skin without a concomitant reduction in core temperature. Following pre-cooling, or 30 minutes of rest, subjects completed a 30-minute self-paced cycling trial under warm, humid conditions (31°C and 60% rh). Mean skin temperature of the pre-cooling group was lower than that of the controls throughout the cycling trial. However, rectal temperature was similar between conditions at the start of, and for at least 10 minutes into exercise. This is most likely the result of warm blood at the skin moving to the core as consequence of vasoconstriction at the skin. There was a significant decrease in rectal temperature after 10 minutes of exercise. Pre-cooling significantly increased heat storage and decreased total body sweat throughout cycling compared to the control. The distance cycled increased by 0.9 km over the control trial. Hence, the authors concluded that pre-cooling of the ‘shell’ alone significantly improves cycling performance in uncompensable heat.

Recent research by Cotter et al. (2001) supported the previous findings. They pre-cooled subjects using ice vest and refrigerated air (3°C) prior to endurance cycling performance in the heat (35°C, 60% rh). Subjects were cooled for 45 minutes then they performed a short warm-up, a maximal cycling trial (Sleivert et al., 2001), a cool down and another 45 minute cooling session prior to the actual endurance cycling. The cycling trial consisted of 20 minutes at a fixed work rate of approximately 65% $VO_{2\,max}$, followed by a 15 minute self-paced maximal performance trial. Mean core temperature, heart rate and rating of exertion were lower following the pre-cooling and remained lower through the 20 minutes of fixed rate exercise. Interestingly, pre-cooling increased power output by approximately 17% compared to the control trial during self-paced exercise, despite the fact that the physiological variables had become equivalent. One factor that may have enhanced the effect of pre-cooling in this study was the double cold exposure. This strategy involves two cooling sessions separated by a quick re-warming interval. It has been used previously (Olschewski & Bruck, 1988) and was successful in lowering core temperature while minimizing the shivering and thermal discomfort associated with cold exposure.

A noteworthy study in the area of thermal strain and fatigue was conducted by Gonzalez-Alonzo and colleagues (1999a). The aim of this study was to determine whether fatigue occurred at the same critical core temperature despite differences in initial starting temperature and its rate of rise. Core temperature was manipulated to three different levels (pre-cooling – 36°C, control – 37°C and preheating – 38°C) via water immersion. Subjects were then required to cycle at 60% $VO_{2\ max}$ until volitional exhaustion. The data indicated that despite differences in initial core temperature, all subjects fatigued at the same level of hyperthermia, esophageal temperature ~ 40°C. Time to exhaustion was significantly shorter for the subject in the higher heat storage condition suggesting that the critical limiting core temperature is directly related to the rate of heat storage. In addition, the time to exhaustion increased when core temperature was reduced prior to exercise, as in the pre-cooling condition.

In contrast, a study focused exclusively on the thermoregulatory response to pre-cooling and subsequent exercise during simulation of a triathlon (swim 15 min, bike 45 min) has not shown favourable results. Although the pre-cooling manoeuvre reduced the starting core temperature by 0.5°C, it had limited effect, if any on the physiological responses measured. The authors concluded that pre-cooling is of no significant benefit for athletes competing in triathlons under similar environmental conditions. However, they did not report any exercise performance results. Furthermore, it is possible that the swimming portion of the protocol may have minimized the effects of pre-cooling because swimming would have lowered core temperature in the control trial and intensified cooling in the experimental trial. It may have even reduced core temperature past the limit that would be advantageous to subsequent performance. One final thing to note was that the running portion of the triathlon was excluded from the exercise protocol. This was on the basis that the benefits of pre-cooling are diminished after 30 minutes of exercise.

2.8.3 Intermittent exercise

The effects of pre-cooling on intermittent activity have also been evaluated. One study designed to simulate team sports played in hot humid conditions by using sprints and active recovery with quarter and half time breaks (Duffield, Dawson, Bishop, Fitzsimons, & Lawrence, 2003a). Seven male hockey players performed an 80 minute intermittent, repeated sprint cycling exercise protocol in a 30°C, 60 % rh controlled climate. Pre-cooling was implemented for two 5-minute periods and one 10-minute period during the test, simulating quarter and half time breaks respectively. Although pre-cooling resulted in a significant reduction in skin temperature and thermal discomfort, it was ineffective in reducing core temperature or improving power output and the amount of work done during the trial. So the intermittent use of an ice-cooling jacket did not benefit intermittent physical activity. One factor that may have played a role in the results of this study is the duration of the cooling sessions. It is likely that the application of an ice vest for five or ten minutes was inadequate for relieving thermal load from the body. Effective pre-cooling durations are generally in the area of 15-60 minutes. In addition, the duration and intensity of the exercise protocol were probably not sufficient to invoke significant heat stress or a thermoregulatory response, thus the limit for body heat storage is not readily reached (post exercise core temperature ~ 38.6°C). So although, the results of this study would indicate that pre-cooling does not appear to be an effective strategy for improving intermittent exercise performance, further investigation is required to confirm these results.

2.8.4 Physiological response during exercise following pre-cooling

Although many pre-cooling studies have used exercise protocols in their methods, most have failed to include a measure of exercise performance. These studies are typically focused on the physiological responses to exercise following pre-cooling. One study used steady state sub-maximal exercise at equal relative intensities to provide a consistent thermal load to allow for better inter-subject comparisons (Wilson et al., 2002). Subjects were cooled for 30 minutes using lower body immersion in approximately 18°C water or 35°C (thermoneutral) water for the control trial. They then exercised for 60 minutes at 60% $VO_{2\ max}$ on a cycle ergometer at an ambient temperature of 21.3°C. The treatment by immersion in cold water significantly ($P<0.001$) removed more body heat than the control treatment and allowed for more body heat storage during exercise. Pre-cooling doubled the exercise time until a 0.5C increase in rectal temperature was observed and it delayed the onset of sweating by 19.6 minutes compared to the control trial. In contrast, there were no significant differences in metabolic rate, O_2 pulse or rating of perceived exertion between the two conditions.

Similar results were found by Booth et al. (2001b). These researchers investigated pre-cooling and its effect on muscle metabolism during subsequent exercise. In this study participants cycled for 35 minutes at 60% $VO_{2\ max}$ in a hot humid environment following either pre-cooling or thermoneutral water immersion. Muscle and esophageal temperature were reduced by 4.8 and 0.8°C, respectively at the commencement of exercise, compared to the control condition ($P<0.05$). Thermal strain remained lower throughout the 35 minutes of cycling for the pre-cooling condition. Despite the marked reduction in core temperature following pre-cooling cardiac frequency, muscle metabolism and end muscle lactate and creatine phosphate concentrations were not significantly different between the two conditions. Thus it is unlikely that the increased endurance previously noted after exercise in at a similar intensity (Booth, Marino, & Ward, 1997d; Kay, Taaffe, & Marino, 1999a) can be explained on the basis of altered muscle metabolism. These results are in line with the conclusions made in previous review on the effects of muscle function and metabolism on exercise performance in the heat (Febbraio, 2000). In this review Febbraio suggests that fatigue during exercise and heat stress seems to be unrelated to substrate availability or muscle metabolism.

The Gonzalez-Alonzo et al. (1999) were interested in determining the effects of the different core temperatures on heart rate, stroke volume and skin blood flow. Subjects performed two bouts of cycling exercise at 60% $VO_{2\ max}$ in the heat until exhaustion while wearing a water-perfused jacket. The rate of heat storage during exercise was manipulated by changing the water temperature perfusing in the jacket to either 42°C or 17°C representing high and low heat storage, respectively. An interesting observation of this study was that marked elevations in thermal load and skin blood flow resulted in a significant reduction in cardiac output, largely due to the reduction in stroke volume. However, whole body VO2 remained unaltered suggesting that a decrease in cardiovascular function is not a limiting factor during hyperthermia.

Most studies have reported that exercise performance is improved after pre-cooling. This would suggest that limiting the rate of rise in core temperature is a determining factor in the ability to exercise in the heat. However, the actual mechanism that leads to the enhanced exercise performance following pre-cooling remains unclear. Researchers have proposed that the reduced core temperature impacts cardiovascular, muscle and central nervous system function but there is no consensus among the literature reviewed. There is an emerging theory that fatigue during exercise in the heat may be due to a reduce central motor drive (Nybo & Nielsen, 2001) but this theory is yet to be explored in a pre-cooling study. Thus it appears that pre-cooling merits further investigation. It is expected that the research outcomes will prove valuable for local and non-heat acclimatized athletes competing in tropical environments and such as the 2004 Athens Olympics.

2.9 Limitations in the literature

When investigating the effects of pre-cooling on performance, the differences in responses between males and females should not be discounted. However the majority of studies to date have used exclusively males as subjects. Although there are difficulties associated with using female subjects in thermoregulatory studies, such as fluctuating core temperature due to their menstrual cycle, they should not be totally ignored. Women make up a significant part of the athletic population and participate at an elite level in most sports. Thus, it would be interesting to see if there were any discrepancies between men and women in their performance response following pre-cooling.

All of the pre-cooling studies thus far have been conducted in the laboratory setting. However, by doing so they have failed to take into account heat gain from solar radiation, which would typically be a factor in outdoor sports. Solar radiation adds to the thermal load and may diminish the small benefits of pre-cooling observed in the laboratory studies. Another challenge of using cooling strategies in the field is portability and access to freezers and power sources. Both of these factors must be taken into consideration prior to use of pre-cooling for athletic competitions.

2.9.1 Placebo effect

It is possible that there is a placebo effect with pre-cooling, attributable to the expectation that pre-cooling will improve performance. Most studies have failed to control for this effect. A few exceptions are Booth et al. (2001a) and Wilson et al. (2002), both of which had subjects sit in normothermic water during the control trial. Although these studies failed to include a performance measure, they were able to isolate the effects of pre-cooling. Other studies have not used an experimental control during their control trial. In most studies, the investigators had the subjects sit quietly in a normothermic room during the control trial for a period of time equivalent to the pre-cooling trial. In failing to account for a placebo effect the majority of studies may be overestimating the physiological contribution of pre-cooling to observed performance improvements.

2.10 Summary

Researchers and athletes alike continue to search for ways in which endurance performance may be improved. Prolonged exercise in a hot environment creates a condition in which an athlete must contend with considerable thermal stress. In order to maintain thermal balance, an exercising person often has to cope with the double challenge of increased metabolic heat production and environmental factors such as high ambient temperatures and relative humidity. One strategy for dealing with performance in uncompensable heat is pre-cooling. Pre-cooling manipulates the heat storage capacity of the body in order to create a deficit or negative heat content to allow for greater heat storage and to possibly attenuate the rise in core temperature. Studies designed to evaluate the effectiveness of pre-cooling on endurance exercise have shown favourable results. However, more work is required to explore the potential benefits of pre-cooling across a range of sporting events. In addition, not all athletes will respond positively to pre-cooling, therefore it should be experimented with during training prior to its implementation as a competitive aid. Pre-cooling, if warranted, must be convenient and accessible to an athlete; otherwise findings may only be limited to a research environment.

In summary whole body pre-cooling has been achieved by a variety of methods. The thermoregulatory responses to pre-cooling are variable and are dictated by many factors such as the method used, the water temperature, and the duration of exposure. Cooling differences between subjects is also dependent on their percent body fat and metabolic response to cold (i.e. shivering). Regardless of the method used the practical application of pre-cooling is limited because of the time required to achieve sufficient body cooling to attenuate heat stress and improve performance. So until a more practical strategy for pre-cooling is found it is unlikely that it will become commonplace in the athletic world.

If an elevated core temperature per se is a limiting factor during exercise in the heat then reducing core temperature prior to exercise using a pre-cooling manoeuvre may widen the margin before a critical core temperature is reached, thereby delaying fatigue and exhaustion. Decreasing core temperature by approximately 0.5ºC has been shown to benefit performance in hot humid conditions in the range of several minutes (Marsh and Sleivert 1999; Cotter et al., 2001) up to an hour (Kay et al., 1999; Booth et al., 1997). Thermoregulatory responses to pre-cooling during exercise include decreased rectal temperature, decreased esophageal temperature, decreased mean skin temperature, improved thermal comfort, and decreased sweat rate (Galloway and Maughan 1997; Kay et al., 1999). The effect of pre-cooling on exercise performance has received limited attention, and very few studies have included performance measure in their studies. Thus, pre-cooling still needs to be explored as a strategy for coping with elevated core temperature associated with exercising in thermo stressful environments and optimal pre-cooling strategies must be defined.

2.11 Conclusion

Athletes competing in the heat are often unable to maintain thermal balance in regardless of their level of training, heat acclimation or hydration status. Consequently, athletes need to reduce the speed or intensity of work in these hot humid conditions, thereby compromising their performance. Otherwise they risk suffering a heat illness or injury. Competitions will continue to be held in these thermal stressful conditions where an increase in core temperature is inevitable. Guidelines for heat acclimation have been suggested however definite strategies for pre-cooling as an ergogenic aid are yet to be developed. Thus, finding an effective and safe method of dealing with heat strain is a salient issue in the preparation for athletes heading international events in tropical countries. At present, studies seem to indicate that changes in cardiovascular strain and muscle metabolism are not the limiting factors during exercise induced hyperthermia. Rather, high core temperature seems to have an effect on the central nervous system in decreasing the central drive to exercise. Taken together, the present and previous research indicates that hyperthermia per se is the main limiting factor causing fatigue during exercise in the heat.

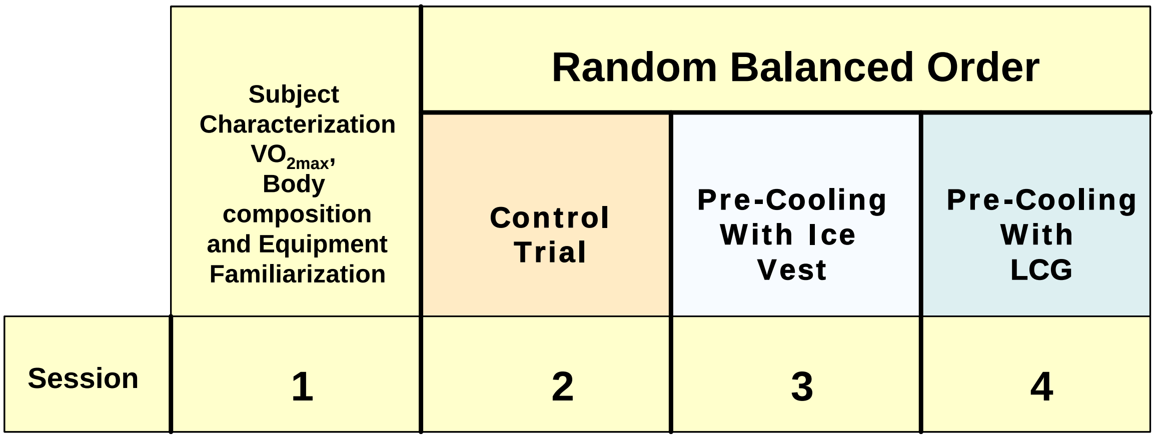
3.0 METHODS

3.1 Subjects

Eight male National Team rowers were recruited for this study. All participants were informed of procedures (Appendix B) and signed a consent form (Appendix C). Participants completed a Physical Activity Readiness questionnaire (Appendix D). This project was conducted following the Canadian Tri-Council Policy for ethical treatment of human participants as part of the Helsinki Declaration II and received approval from the University of Victoria Human Research Ethics Board.

3.2 Experimental design

A counter-balanced repeated measured design was implemented for this study (Figure 3.1). Each participant attended four sessions. The first session involved familiarization with the laboratory, test apparatus and procedures. During this session, descriptive data – including height, weight, and skin-folds – were recorded and a sub-maximal test was performed on a Concept 2 indoor rowing ergometer (Concept 2 Inc., Vermont, USA) to determine lactate threshold.



	Subject Characterization VO_{2max}, Body composition and Equipment Familiarization	Random Balanced Order		
		Control Trial	Pre-Cooling With Ice Vest	Pre-Cooling With LCG
Session	1	2	3	4

Figure 3. 1 Experimental design.

Following familiarization, subjects participated in three sessions of steady state and time trial rowing protocols on a Concept 2 rowing ergometer in an environmental chamber (38.7 ± 1.3°C, 47.5 ± 1.8% RH) under three experimental conditions (Figure 3.2):

1. Control condition (CON) in which the subjects wore a Liquid Conditioning vest not perfused with water during the 45 minute rest period and 30 minute warm-up.
2. Experimental pre-cooling condition (VST) in which the subjects wore an ice vest during the 45 minute rest period and the 30 minute warm-up.
3. Experimental pre-cooling condition (WP) in which the subjects wore a CardioCool liquid conditioning vest perfused with 5.37 ± 1.66°C water during the 45 minute rest period and the 30 minute warm-up.

The first participant was randomly assigned to one of the three conditions: control (no pre-cooling), or pre-cooling (using and ice vest or water perfused vest) (Figure 3.3 & 3.4). Each subsequent participant was assigned to a balanced sequence of the three protocols so as to minimize any ordering effects. Trials were separated by 1 week to allow for recovery and to reduce the potential for heat acclimation. Sessions were conducted on the same day of the week and at the same time of day to minimise the effects of circadian rhythms on heart rate and core temperature.

Subjects were requested to abstain from consuming alcohol or caffeine and from participating in strenuous exercise for 24 hours prior to each experimental trial. Subjects were asked to arrive at the laboratory well hydrated. Food and activity questionnaires were completed during each testing session and the information was sent to the participants prior to subsequent testing sessions in attempt to keep extraneous variables as consistent as possible. During the testing session, participants were allowed to consume 250 ml of water in the seated rest period and 250 ml during the warm-up. Precise volume of fluid intake was calculated during the first trial and repeated during subsequent trials if the participants did not drink all of their allotted water. This was done to ensure consistency between trials and to have an accurate measurement of fluid intake to adjust body mass and estimate sweat loss. Additionally, if participants needed to urinate during the protocol, the volume was measured and used to account for changes in body mass when calculating an estimation of sweat loss.

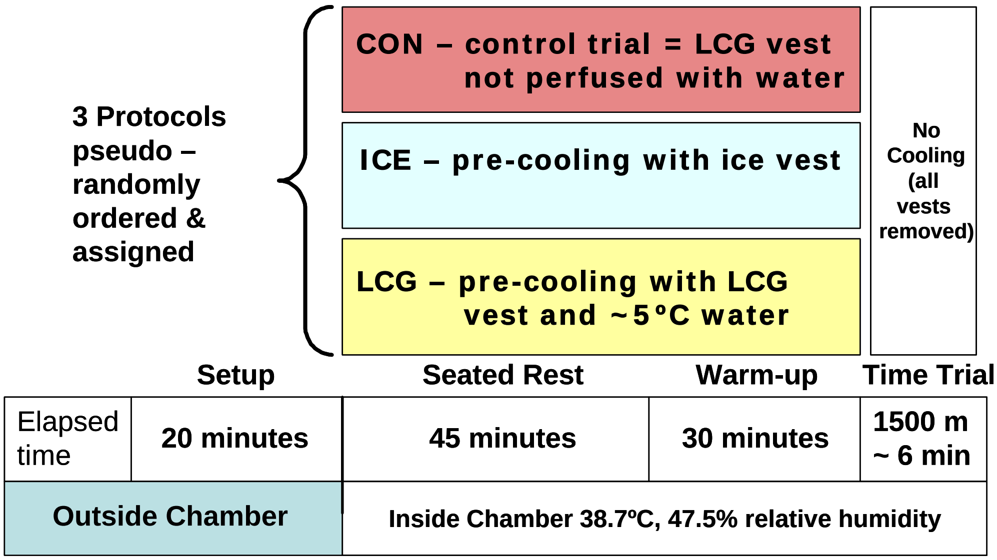


Figure 3. 2 Time course of events during each testing session, trials were completed on a Concept 2 rowing ergometer.

3.3 Anthropometric measures and lactate threshold test

Skin-fold thickness was measured at seven sites (chest, triceps, subscapular, axilla, abdominal, suprailiac, and front thigh) in triplicates using skin-fold calipers (Harpenden, John Bull British Industries Ltd., England) and the median value was used to calculate total skin-folds. Percent body fat was estimated using the skin-fold measurements and a seven-site skin fold formula (Jackson & Pollack, 1978). Both height (m) and nude body weight (kg) were taken following the Canadian Physical Activity, Fitness and Lifestyle Appraisal protocol (CSEP, 1998). Body mass was measured to the nearest 50 g using an electronic precision balance (digital weighing scales, model D1-10, Teraoka weigh system, PTE Ltd, Singapore) prior to and immediately following each testing session. Body surface area (AD, m^2) was estimated according to the formula of Du Bois & Du Bois, (1916):

$$BSA = 0.202 \text{ x } Wt\ 0.425 \text{ x } Ht\ 0.725$$

The participant's lactate threshold was determined by a progressive incremental submaximal test on a Concept 2 rowing ergometer. The test began with a 10 minute warm-up rowing at a pre-assigned wattage. During the test, each stage was five minutes long, followed by 1 minute rest. Wattages were increased to 180, 190, 230, 270, 310, and 350 Watts at each stage. Wattages were determined by the participant's category (i.e. lightweight or heavyweight). Stroke rate was held constant throughout the test and ranged between 22 and 26 strokes per minute. Since the average watts reading was used for this test the participants were encouraged to be as consistent as possible during each stage and between stages.

Lactate samples were taken from the finger tip after each stage and 3 minutes following the end of the test. Blood samples were obtained via finger prick using a lancet device (Softclix Pro) under sterile conditions during the recovery period and analyzed for blood lactate with a Lactate Pro Portable Lactate Analyzer (Lactate Pro, Appendix I). The ergometers had drag factor setting of 160 to ensure specific wattage for lactate testing as outlined by the Canadian National Rowing Team physiologist.

3.4 Experimental session

Two participants were tested during each testing session to simulate race conditions and increase motivation to perform maximally during the time trial. Upon arrival at the laboratory, participants voided, nude body mass was recorded and a rectal probe was self-inserted. Skin temperature thermistors were attached at four sites and a heart rate monitor was secured around the participants' chest. Once the participants were instrumented, baseline data was collected in the thermo-neutral environment. The participants then put on their vest (either Ice vest or WP) and entered the environmental chamber. The participants rested for the first 45 minutes in the chamber to allow for pre-cooling and adjustment to the hot conditions. While the participants were seated, thermoregulatory variables, including core and skin temperature, were monitored continuously. Psychophysical variables, (HR, TC, TS, RPE) were measured every few minutes. Following 45 minutes of rest the participants began a 30 minute standardized warm-up on the rowing ergometer. The warm-up was intended to simulate an actual pre-race warm-up and was constructed with the assistance of the athletes' coach (Appendix J). The protocol involved an initial steady state row at 40 W below lactate threshold as well as intervals at varying stroke rates and a start piece. Thermoregulatory and psychophysical variables were recorded throughout the warm-up. Immediately following the warm-up participants had 5 minutes to rest and remove their vests prior to beginning the 1500 m time trial. During the time trial the participants were allowed to monitor stroke rate, power output and elapsed distance. Following the completion of the self-paced trial the participants exited the environmental chamber, all instrumentation was removed, towelled dry and nude body mass was again recorded.

3.5.1 Rest period

Following instrumentation with thermoregulatory and cardiovascular monitoring equipment the participants remained seated in an environmental chamber (38.7 ± 1.3ºC, 47.5 ± 1.3%RH) for 45 minutes. During this time, participants completed a dietary recall questionnaire and a physical activity log for the previous 24 hours. This log was returned to the participants two days prior to returning to the lab for subsequent testing sessions in attempt to minimize any variations in diet, hydration and fatigue. Core and skin temperature (four sites) were monitored continuously throughout the seated rest period. Heart rate and psychophysical variables were determined at 2, 5, 10, 15, 25, 30, 40, and 45 minutes.

3.5.2 Warm-up

At the end of the 45 minute seated rest period the participants began a standardized warm-up. The entire testing protocol was performed on a Concept 2 rowing ergometer. The first 10 minutes of the warm-up consisted of steady state rowing at a power output equivalent to 80% lactate threshold, as determined during the familiarization session. Thermoregulatory variables, heart rate and psychophysical variables were monitored throughout the 30 minute warm-up. Specifically, values were recorded at 2, 5, 10, 15, 25 and 30 minutes. Total distance covered in the 30 minute session was determined using the computer on the Concept 2 ergometer and recorded for each session. The drag factor on the ergometers was set at 120 before each trial.

3.5.3 Time trial

There was a 5 minute transition period between the warm-up and the self paced time trial. During this time participants removed all vests and finished any remaining water in their water bottles. An attempt was made to keep transition times consistent for each trial. However, any deviations which occurred were recorded and repeated in subsequent trials with the same participants. Following the rest period they then began the 1500 m time trial on the Concept 2 rowing ergometer. The rowers were instructed to complete the trial in the shortest time possible. No verbal encouragement was given during the time trial in order to maintain consistency between trials and participants. Two rowers performed the trial at the same time to simulate competition. The aim of the self-paced time trial was to complete the 1500 m in the shortest time possible, by adjusting stroke rate and power output. Thermoregulatory variables including core and skin temperature were recorded continuously throughout the time trial. Heart rate, stroke rate, power output and distance covered were recorded every 500 m. Psychophysical variables were determined prior to beginning the time trial and immediately following it.

3.6 Pre-cooling manoeuvre

Pre-cooling garments were worn by the participants during the rest period and warm-up but removed prior to the time trial.

3.6.1 Ice vest

The Thermoblazer (Frank White's Scuba Shop, Victoria, BC, Canada) was developed by Dr Gordon Sleivert of PacificSport National Training Center, Victoria

(Figure 3.3). The vests are constructed from 2 mm neoprene and have pile lining to which Cryopaks ice packs are attached using Velcro. Four ice packs (450 ml each) were positioned to cover the chest, and the back. The vests were available in 5 sizes so each participant was ensured an optimum fit. The ice vest weights approximately 2 kg. Participants wore a thin cotton t-shirt under the vests so that the ice was not in direct contact with their skin to minimize skin damage or ice burns.

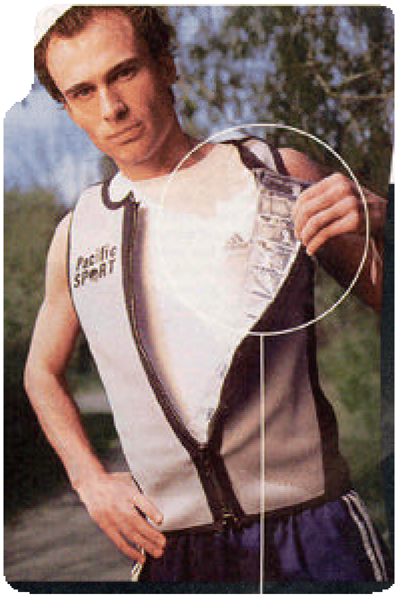


Figure 3. 3 Thermoblazer with cryopack showing

3.6.2 Water perfused vest

The CardioCOOL vest was commercially produced by Med-Eng (Ottawa, ON, Canada). The vest provides full torso coverage and a snug fitting design that allows maximal contact for optimal cooling. The garments are constructed from polyester with a network of medical grade polyvinyl chloride tubing (24 mm inner diameter x 41 mm outer diameter) continuously stitched throughout. The 36 meters of tubing in the vest is intended to provide an approximately uniform cooling over the torso. The wearing weight of the water perfused vest ranges from 0.6kg to 0.99kg (small to XXL) when filled with liquid. Water was perfused throughout the suit using a pneumatic pump (inlet temperature: 5.37 ± 1.66°C; flow rate: 500 mL×min^{-1}). Inlet and outlet water temperatures were determined from thermistors positioned in the water cooler and in the outflow tube from the vest respectively. Water temperature was controlled using a water cooler and ice (Figure 3.5).

Figure 3. 4 The CardioCool water perfused vest

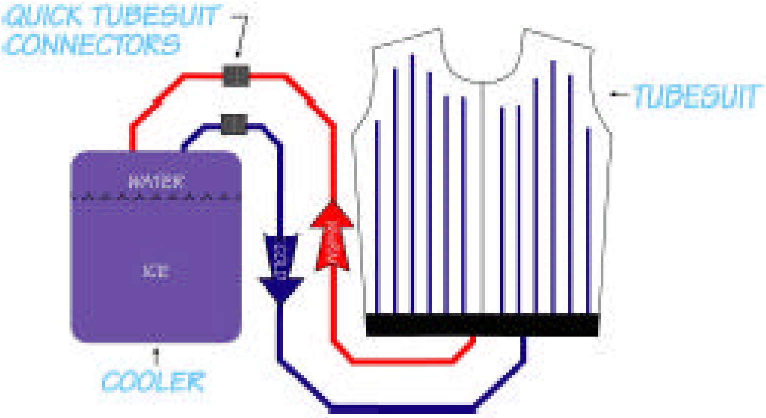


Figure 3. 5 Schematic of the water perfused vest depicting the cold water entering the suit and the warm water, which has picked up heat from the participant, leaving the suit and returning back to the cooler.

3.7 Temperature measurements and calculations

Both skin and core temperature were monitored continuously in real time during each session using an 8-channel data logger (SmartReader 8 Plus, ACR Systems, Surrey, BC, Canada). Rectal temperature was monitored as an index of core temperature and was measured using a disposable negative temperature coefficient thermistor specifically designed for biological monitoring of rectal temperature (Mon-a-Therm General purpose, Mallinckrodt, St. Louis, MO, USA). Subjects were required to insert the rectal thermistor into the anal canal to a depth of 10 cm. The same thermistor was used for each participant for all three conditions. They were sterilized using Glutacide and kept in zip-lock bags with the subjects name on it between trials.

Skin temperature was monitored using biomedical ceramic chip thermistors (MA 100, 10KO negative temperature coefficient, Thermometrics, NJ, USA) placed on the left side of the body and secured using 25mm Transpore tape (3M$_{TM}$). Skin temperature was measured at four sites (chest, upper arm, thigh, calf):

1. Upper arm - lateral aspect of the right arm, approximately half way between the olecranon process and the radio-carpel joint.
2. Chest - midway along the horizontal line between the right axilla and the right nipple
3. Quadriceps - anterior aspect of the right quadriceps midway between the inguinal crease and the base of the patella.

4. Calf - posterior aspect of the lower right leg at a level of maximal calf girth.

Mean skin temperature ($\overline{T}_{SK}$) was calculated using an area-weighted formula (Ramanathan, 1964):

$$\overline{T}_{SK} = 0.3\ (T\text{chest} + T\text{left arm}) + 0.2\ (T\text{left thigh} + T\text{left leg})$$

Mean body temperature ($\overline{T}_{B}$) was calculated using the following formula:

$$\overline{T}_{B} = (\overline{T}_{c} \times 0.85) + (\overline{T}_{SK} \times 0.15) \times 0.5$$

3.8 Total body sweat

Nude body weight was measured to the nearest 50g before and immediately following the testing protocol using an electronic precision balance (Digital weighing scales, model D1-10, Teraoka Weigh System, PTE Ltd, Singapore). Sweat loss was estimated by mass loss after accounting for water intake. Measurements were taken at the end of the exercise session and compared to the baseline values obtained prior to the rest period.

3.9 Cardiovascular and psychophysical strain

Heart rate was monitored using a Polar heart rate monitor (Polar Electro Inc., Port Washington, NY, USA).Thermal comfort (Appendix F) and sensation (Appendix G) were determined (Gagge, Stolwijk, & Hardy, 1967) at 2, 5, 10, 15, 20, 30, 40, and 45 minutes during rest and 2, 5, 10, 15, 25 and 30 minutes during the standardized warm-up.

Subjanects were asked to rate their perceived exertion using the Borg scale (Appendix E) during exercise (Borg, 1982).

3.10 Environmental chamber

The temperature and relative humidity of the environmental chamber were set at 38.7±1.3ºC and 47.5±1.8% respectively during the experimental sessions. The temperature and relative humidity of the environmental chamber were monitored continuously using a Questemp 34 heat stress monitor (Quest Technologies, Elmhurst, Il) positioned at 1m off the ground.

3.11 Statistical analysis

Means and standard deviations were used to describe all data. A repeated measures analysis of variance (two-way) was used to determine any time x treatment effect. Post-hoc comparisons were conducted with Bonferroni adjusted paired t-tests. Type I error was protected at the 5% level. All statistical procedures were performed using SPSS for Windows version 11.5 statistical software (SPSS, LEAD Technologies Inc., USA).

Comparisons were made within each of the 3 stages of the protocol – rest, warm-up and time trial. The thermoregulatory and psychophysical variables were contrasted from the beginning to the end of the rest and warm-up, and at each 500 m interval during the self paced time trial to determine whether there was as there a significant difference (for a given variable) between the three experimental conditions: 1) the initial entry into the environmental chamber and the end of the rest period; 2) the beginning to end of the standardized 30 minute warm-up; 3) each 500 m split during the 1500 m time trial. Paired T-tests were conducted to determine where differences existed, when a significant main or interaction effect was observed for a given variable, and tested at the 0.05 level of significance.

4.0 RESULTS

4.1 Subject characteristics

Of the 8 men who participated in this study, three were unable to complete all 3 of their experimental trials. Two subjects were unable to complete the control trial. One of these participant's trials was terminated by the investigators because his core temperature reached 39.5ºC, violating the ethics guidelines set for this study. The second participant suffered from vertigo, nausea and numbness in the extremities and chose to finish the trial at the end of the warm-up, although his rectal temperature did not reach 39.5ºC. One other subject voluntarily withdrew from the WP trial during the warm-up. He reported that he was tired from previous training and unable to complete the session. The participants who withdrew completed their other 2 trials, and were thus excluded from repeated measures comparisons but included in the paired-t tests. The physical characteristics are described in Table 4.1.

Table 4.1 Physical characteristics of subjects

Subject	**Age (yrs)**	**Height (m)**	**Weight (kg)**	**BMI (kg/m^2)**	**A_D (m^2)**	**%BF**	**LT (Watts)**
1	19	1.935	73.6	20	75.8	4.9	270
2	20	1.797	72.2	22	72.4	4.4	270
3	18	1.895	88.8	25	86.1	8.0	270
4	25	1.730	70.9	24	70.3	6.6	270
5	23	1.842	72.1	21	73.1	5.4	270
6	29	1.774	75.3	24	74.3	7.9	270
7	26	1.738	68.5	23	68.8	8.1	265
8	25	1.780	72.4	23	72.3	5.4	280
Mean	23	1.811	74.2	23	74.1	6.0	283
SD	4	0.073	6.2	2	5.3	1.5	39

Note: Nude body mass was recorded at the participant's first visit to the lab. Body surface area (A_D) was estimated using the formula of Dubois and Dubois (1916). See section 3.3 for explanation regarding lactate threshold (LT).

4.2 Thermal strain

4.2.1 Rest

Skin temperature was significantly cooler during the 45 minutes of seated rest in the two pre-cooling trials. This reduction in mean skin temperature was primarily due to reduced chest temperature from cooling being applied directly over the chest skin temperature thermistor (Figure 4.2, P=0.000). When the un-weighted mean of the other 3 skin temperature sites were compared, there appeared to be no significant change in temperature (P = 0.536). Torso cooling did not significantly affect rectal temperature and consequently participants began the warm-up with the same mean core temperature in all three conditions (P = 0.516).

4.2.2 Warm-up

Rectal temperature was similar between conditions at the beginning of the warm-up (CON, 37.27 ± 0.21ºC; VST 37.26 ± 0.24ºC; WP 37.21 ± 0.26ºC). Core temperature increased throughout the warm-up for all three conditions. However, torso cooling minimized the increase in rectal temperature compared to the control condition (F = 2.58, P= 0.033, power = 0.416). The difference in T_{re} between the control trial and the two cooling trials increased progressively, becoming statistically significant after 25 minutes for the WP trial and 30 minutes for the ICE vest trial. During the warm-up T_{re} increased continuously reaching a peak value of 38.53 ± 0.51ºC upon the completion of the control trial protocol (Figure 4.1), which was 0.40ºC and 0.35ºC higher than T_{re} in the ICE vest and WP trials respectively (VST, P = 0.000 ; WP, P = 0.126).

The elevation in T_{re} was accentuated by an increase in skin temperature throughout the warm-up. The mean increase in skin temperature tended to be higher in the control trial than during the cooling trials (Figure 4.2). Skin temperature continued to be lower in the two cooling conditions than in the control condition throughout the standardized warm-up, this primarily reflected the effect of the chest skin temperature thermistor under the vest.

4.2.3 Time trial

There were no differences in skin temperature between conditions at the beginning of the self paced time trial once the participants removed their cooling vests. Rectal temperature was 0.47ºC and 0.36ºC cooler in the ice vest and WP vest conditions respectively than the control condition (F = 6.94, P = 0.018, power = 0.786). There were no differences in T_{re} at the end of the time trial.

Total body sweat loss was estimated from the change in nude body mass from the beginning of the experiment to the end of the time trial, corrected for water intake. Sweat loss tended to be higher in the control condition (1.09 ± 0.33 kg) compared with ICE vest (0.85 ± 0.51 kg) and WP (0.82 ± 0.61 kg) conditions, but the differences were not significant (P = 0.853).

Figure 4.1 Mean (±SD) core temperature (T_{re}) during 45-minutes seated rest, 30-minutes standardized warm-up, and 1500 m self-paced time trial on a rowing ergometer in a environmental chamber (33°C, 55% rh) in response to 3 experimental conditions. Torso pre-cooling was applied using an ice vest (¦) or WP (?) during the rest period and warm up or no pre-cooling in the control trial (?). (The line indicates significant difference between conditions from the beginning to the end of the stage P<.05. Significant differences between VST and CON = *, and WP and CON = †, P<.05)

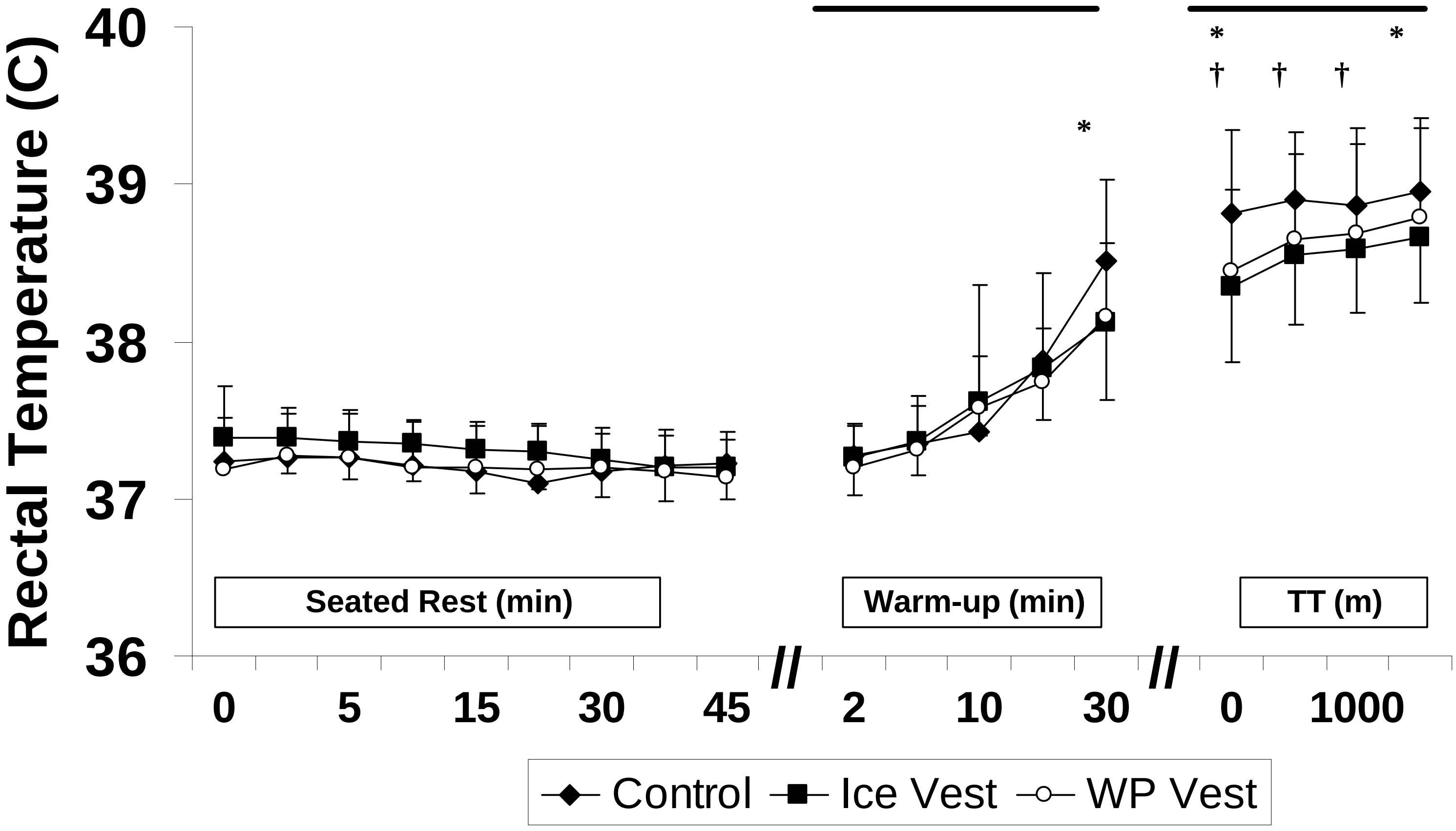

Rectal Temperature (C)
40
39
38
37
36
*
*
†
†
†
*
Seated Rest (min)
Warm-up (min)
TT (m)
//
//
0
5
15
30
45
2
10
30
0
1000
Control
Ice Vest
WP Vest

Figure 4.2 Mean (SD) calf, thigh and bicep temperature (top), mean chest temperature (middle) and mean skin temperature (bottom) during 45 min rest, 30 min standardized warm up and 1500 m time trial on a rowing ergometer in an environmental chamber 36ºC, 40%rh under 3 experimental conditions. Torso pre-cooling using an ice vest (¦) or WP (?) during the rest period and warm up or no pre-cooling was applied in the control trial (?).(The line indicates significant difference between conditions from the beginning to the end of the stage P<.05. Significant differences between VST and CON = *, and WP and CON = †, P<.05)

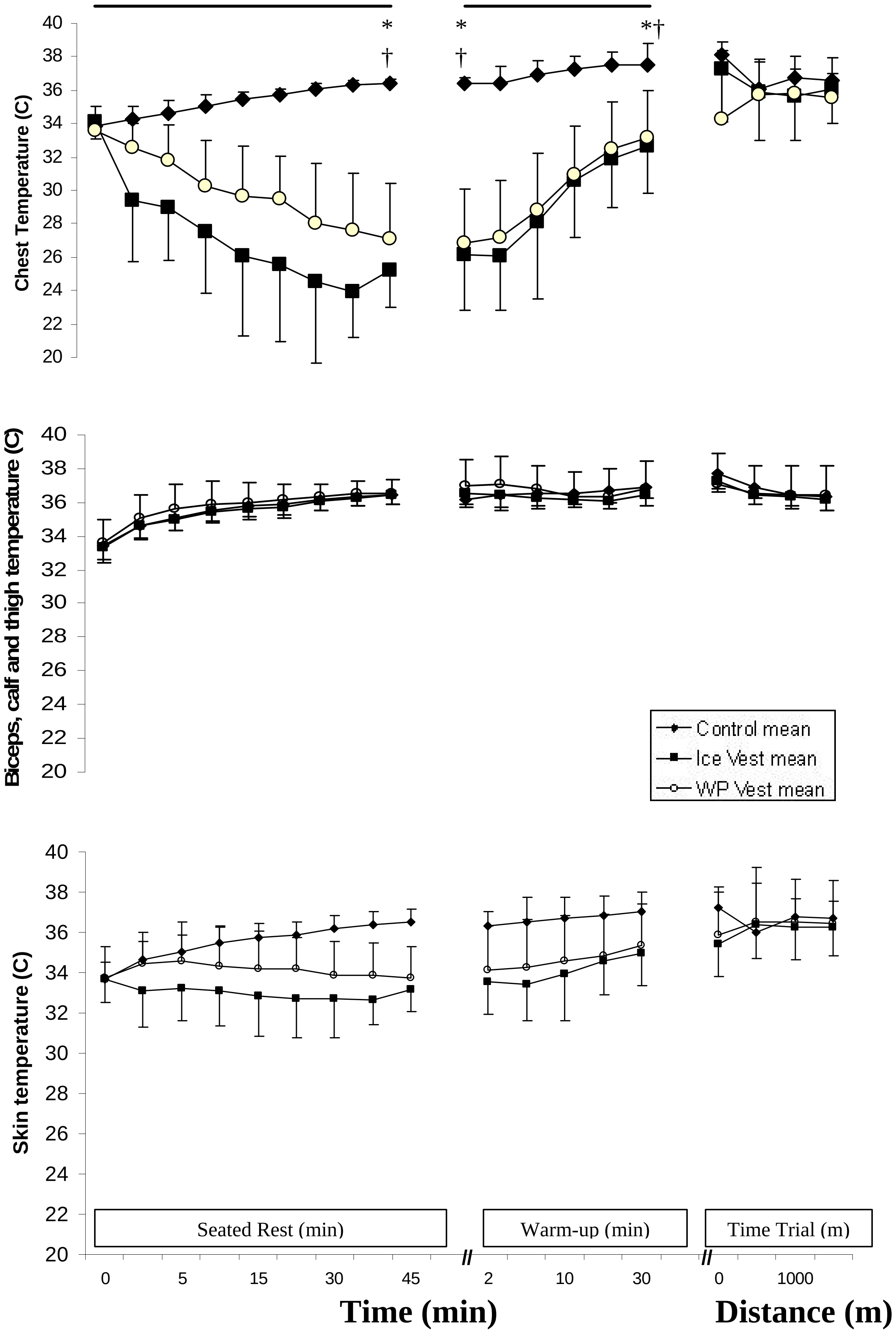
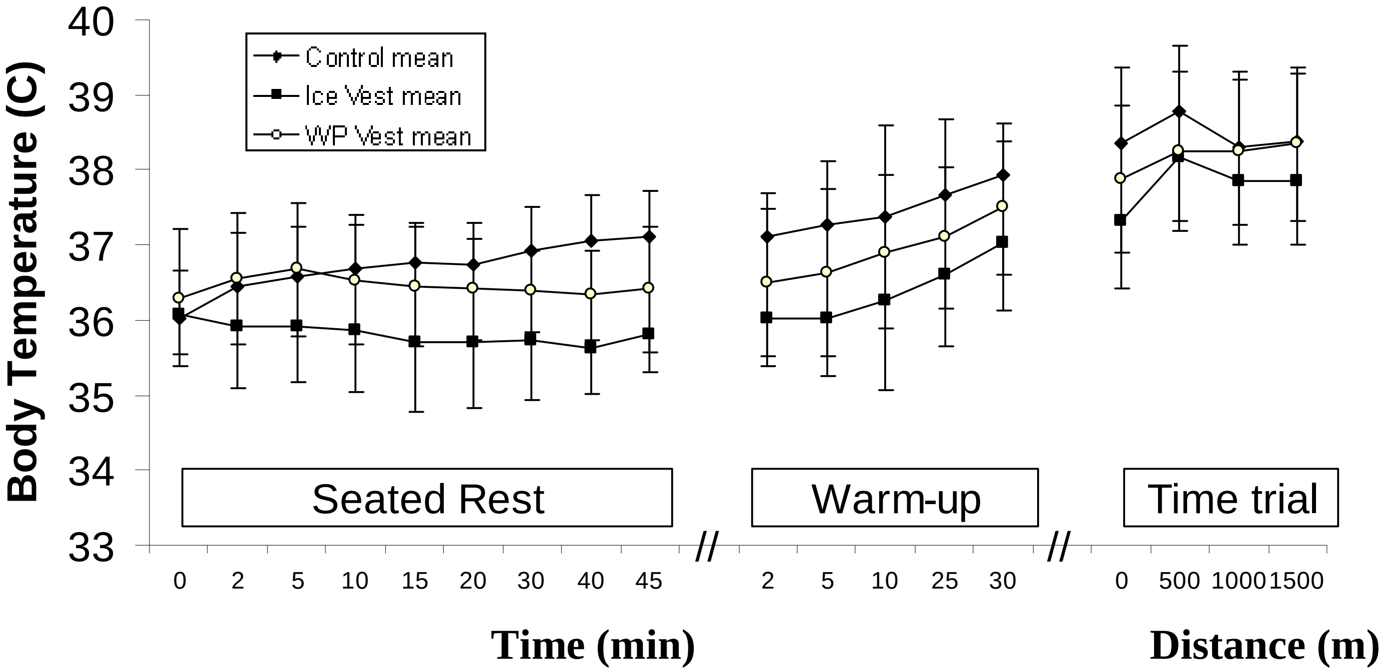

Chest Temperature (C)
40
38
36
34
32
30
28
26
24
22
20
*
†
*
†
*†
Biceps, calf and thigh temperature (C)
Control mean
Ice Vest mean
WP Vest mean
Skin temperature (C)
Seated Rest (min)
Warm-up (min)
Time Trial (m)
0
5
15
30
45
2
10
30
0
1000
Time (min)
Distance (m)

Figure 4. 3 Mean (±SD) body temperature (T_B) (see calculation section 3.7) during 45-minutes seated rest, 30-minutes standardized warm-up, and 1500 m self-paced time trial on a rowing ergometer in a environmental chamber (33ºC, 55% rh) in response to 3 experimental conditions. Torso pre-cooling was applied using an ice vest (¦) or WP (?) during the rest period and warm up or no pre-cooling in the control trial (?).



Body Temperature (C)
40
39
38
37
36
35
34
33
Control mean
Ice Vest mean
WP Vest mean
Seated Rest
Warm-up
Time trial
//
//
0
2
5
10
15
20
30
40
45
2
5
10
25
30
0
500
1000
1500
Time (min)
Distance (m)

4.3 Psychophysical strain

4.3.1 Rest

Participants reported being significantly more thermally comfortable (P = 0.000) and cooler (P = 0.000) during the torso cooling trials as compared to the control condition throughout the 45 minute seated rest period (Figure 4.4 & 4.5). The participants felt significantly cooler when wearing the WP vest than in both the control and the ICE vest condition by the end of the rest period.

4.3.2 Warm-up

There was no significant effect of condition on thermal sensation during the 30 minute standardized warm-up (P = 0.133); although there was an interaction effect (P= 0.003). Participants felt cooler at the beginning of the warm-up in both of the cooling trials (VST/CON, P = 0.008; WP/CON, P = 0.002). However by the end of the standardized warm-up thermal sensation was only lower in the WP condition (P = 0.047). The participants reported being more thermally comfortable in both of the cooling conditions throughout the standardized warm-up (P = 0.012). The improved comfort was evident from the beginning of the warm-up and persisted through to the end (VST/CON, P = 0.012; WP/CON, P = 0.011). There were no differences in either thermal sensation or thermal comfort between the two cooling conditions.

Ratings of perceived exertion increased throughout the warm-up for all conditions (Figure 4.6). RPE tended to be slightly lower in the two cooling trials compared to the control trial, though not significant (Fig 4.6; P = 0.811). There was a significant difference between trials pre to post the 1500 m time trial (P= 0.035), however there was a lot of variability in the pre time trial measurement. RPE was significantly lower in the vest condition than in the control condition prior to beginning the self paced trial (P = 0.031), there were no differences between the other two conditions.

4.4 Cardiovascular strain

There were no differences in heart rate between the 3 experimental conditions during the seated rest period (P = 0.738). During the control protocol heart rate increased from 137 ± 17 beats per min at the beginning of the warm-up to 176 ± 9 beats per minute after 30 minutes of exercise (Figure 4.7). These values were slightly higher than the vest or the WP conditions though not significant ($P = 0.911$). Heart rate remained similar between conditions throughout the 1500 m self paced time trial ($P = 0.221$).

Figure 4. 4Mean (SD) thermal sensation ratings during 45 min rest and 30 min standardized rowing warm-up on an ergometer in an environmental chamber (36C, 40%rh) under 3 experimental conditions. Torso pre-cooling was applied during the rest and warm up in two trials using an ice vest (¦) or a WP (?) perfused with 5ºCwater, the control trial (?) did not involve pre-cooling. (The line indicates significant difference between conditions from the beginning to the end of the stage P<.05. Significant differences between VST and CON = *, and WP and CON = †, P<.05)

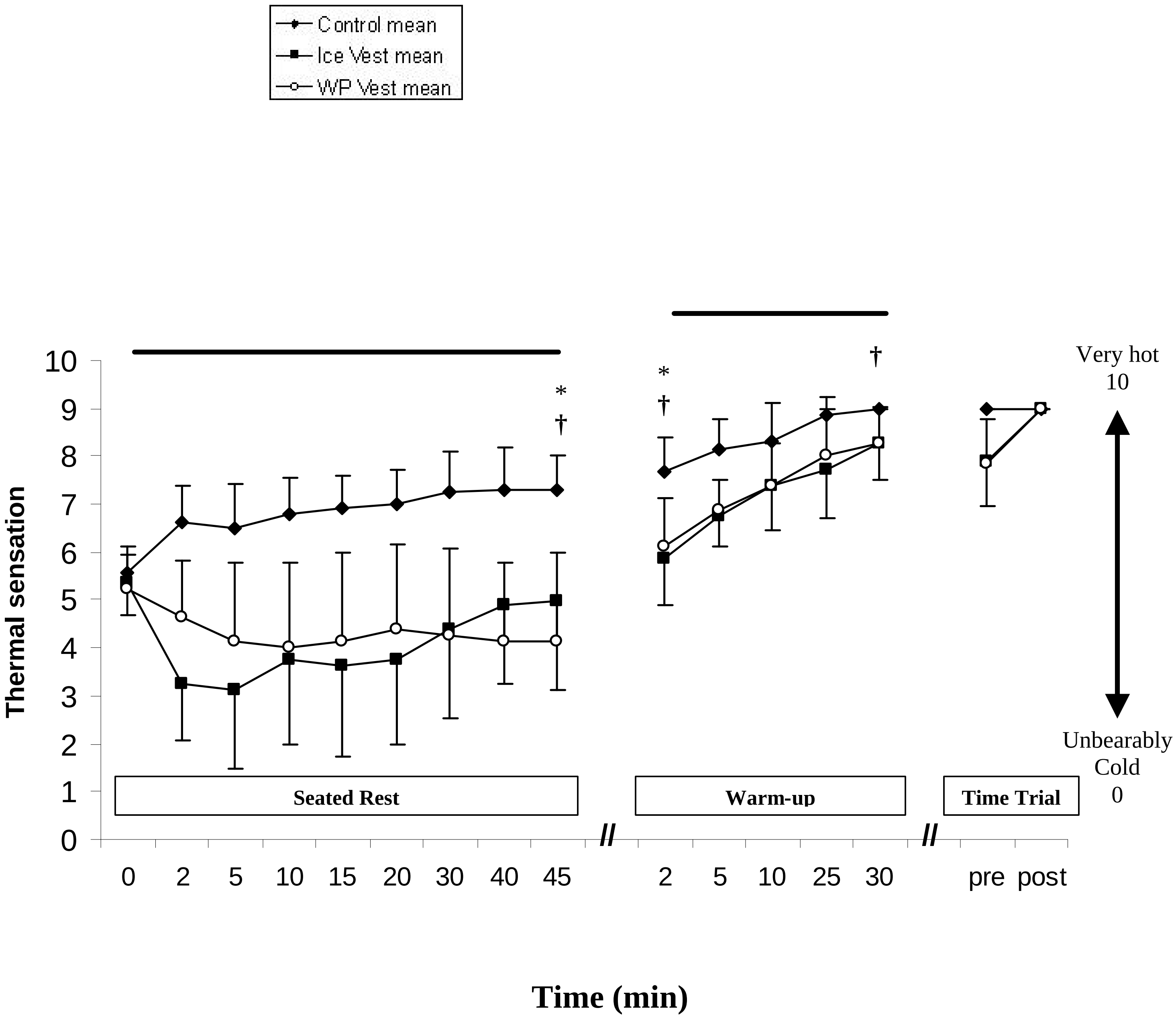

Control mean
Ice Vest mean
WP Vest mean
Thermal sensation
10
9
8
7
6
5
4
3
2
1
0
*
†
*
†
†
Very hot
10
Unbearably
Cold
0
Seated Rest
Warm-up
Time Trial
//
//
0
2
5
10
15
20
30
40
45
2
5
10
25
30
pre
post
Time (min)

Figure 4.5 Mean (SD) thermal comfort during standardized 30 minute warm up on a rowing ergometer in an environmental chamber (36ºC, 40%rh) under 3 experimental conditions. Torso pre-cooling was applied during the rest and warm up in two trials using an ice vest (¦) or a WP (?) perfused with 5ºCwater, the control trial (?) did not involve pre-cooling. (The line indicates significant difference between conditions from the beginning to the end of the stage P<.05. Significant differences between VST and CON = *, and WP and CON = †, P<.05)

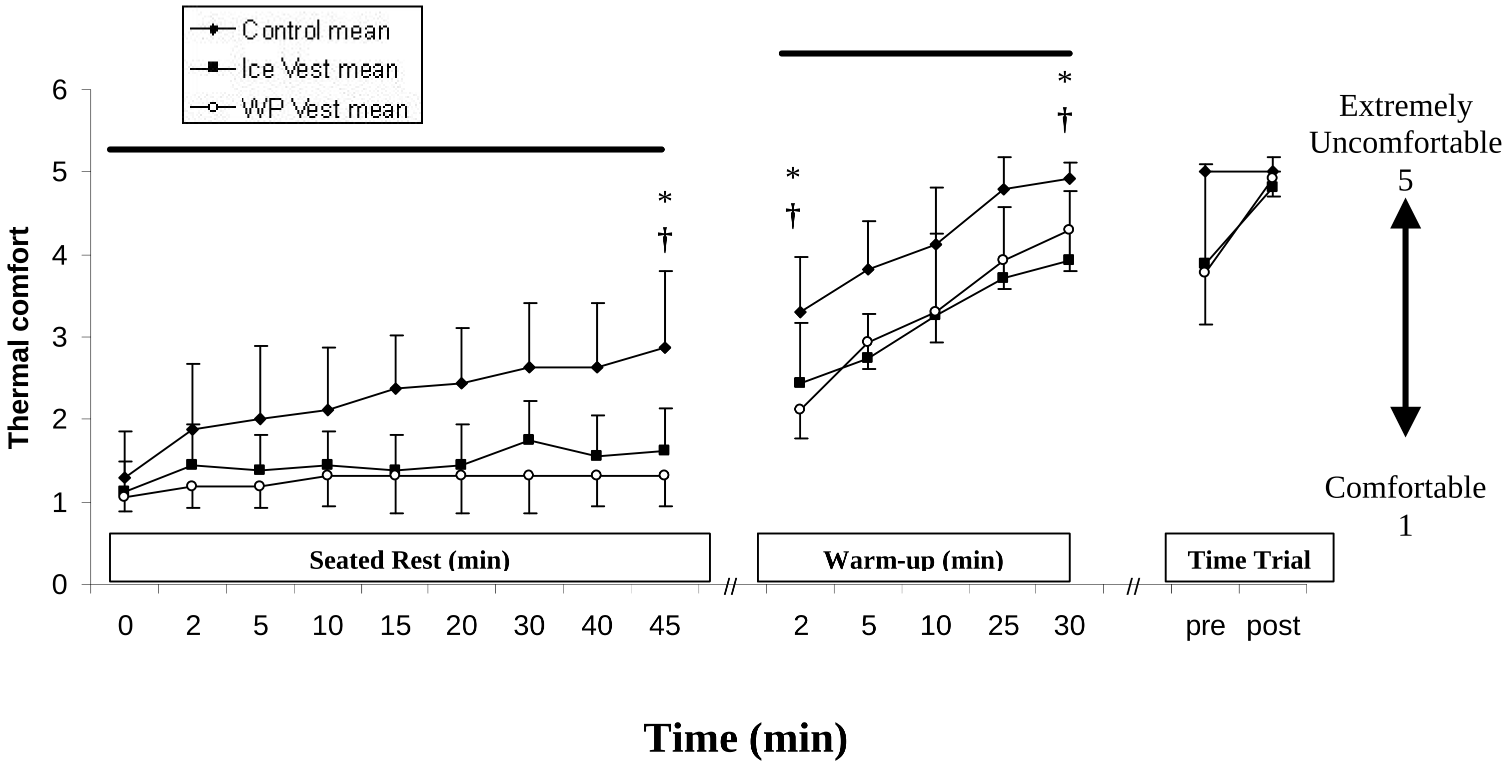

Control mean
Ice Vest mean
WP Vest mean
Thermal comfort
0
1
2
3
4
5
6
*
†
Extremely Uncomfortable 5
Comfortable 1
Seated Rest (min)
Warm-up (min)
Time Trial
0
2
5
10
15
20
30
40
45
2
5
10
25
30
pre
post
Time (min)

Figure 4. 6 Mean (SD) ratings of perceived exertion during standardized 30 minute warm up on a rowing ergometer in an environmental chamber (36ºC, 40%rh) under 3 experimental conditions. Torso pre-cooling was applied during the rest and warm up in two trials using an ice vest (¦) or a WP (?) perfused with 5ºCwater, the control trial (?) did not involve pre-cooling. (The line indicates significant difference between conditions from the beginning to the end of the stage P<.05. * indicates a significant difference between VST and CON, P < 0.05)

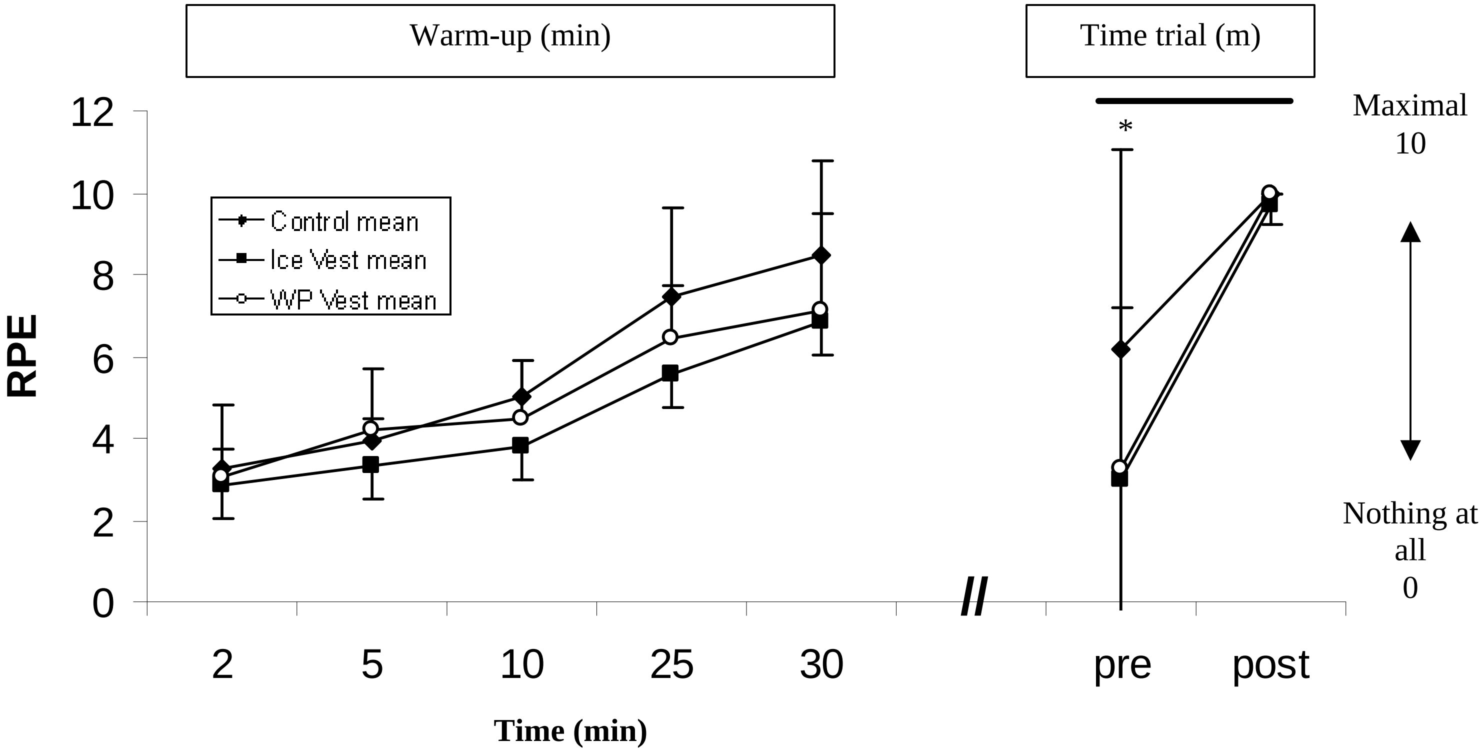
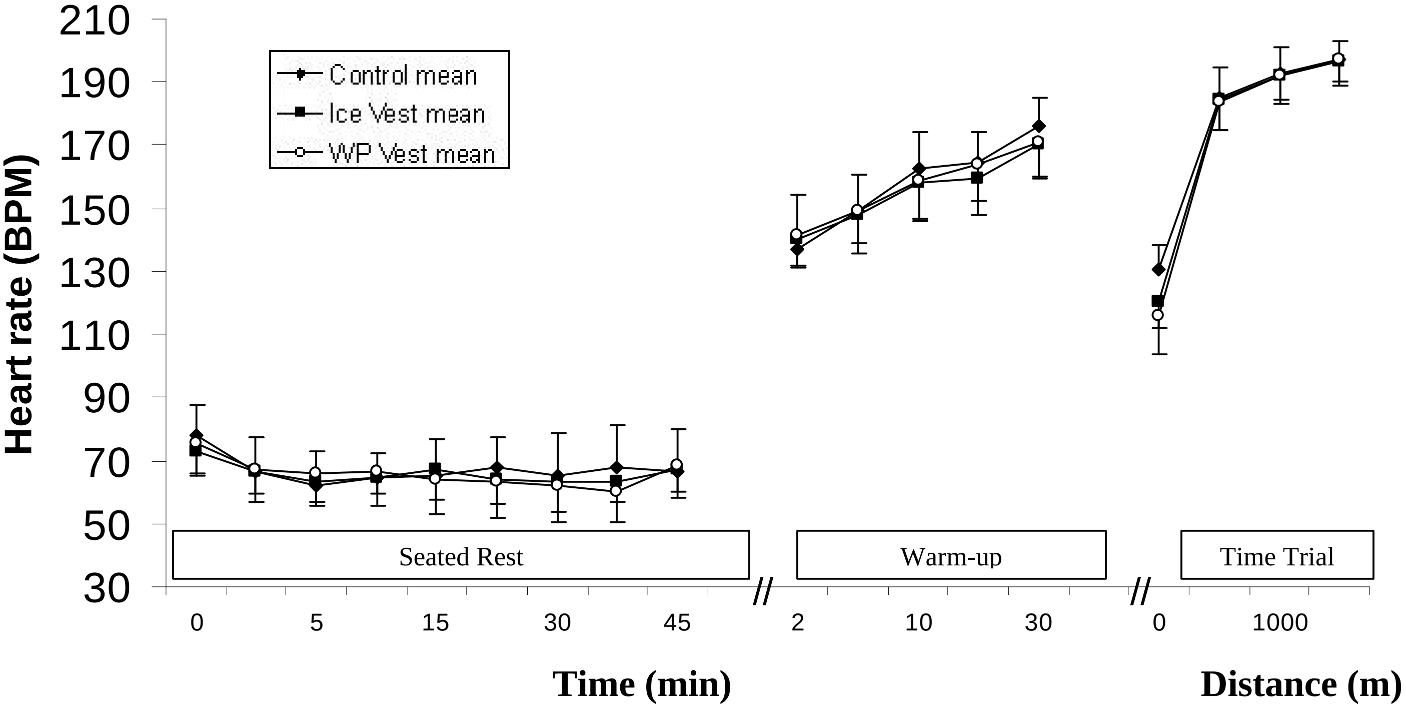

Warm-up (min)
Time trial (m)
RPE
12
10
8
6
4
2
0
Control mean
Ice Vest mean
WP Vest mean
*
Maximal
10
Nothing at all
0
//
2
5
10
25
30
pre
post
Time (min)

Figure 4. 7 Mean (SD) heart rate during 45 min rest, 30 min standardized warm up and 1500 m time trial performance on a rowing ergometer in an environmental chamber (36C, 40%rh) under 3 experimental conditions. Torso pre-cooling was applied during the rest and warm up in two trials using an ice vest (¦) or a WP (?) perfused with 5ºCwater, the control trial (?) did not involve pre-cooling.


Heart rate (BPM)
210
190
170
150
130
110
90
70
50
30
Control mean
Ice Vest mean
WP Vest mean
Seated Rest
Warm-up
Time Trial
0
5
15
30
45
2
10
30
0
1000
Time (min)
Distance (m)

4.5 Self paced performance

4.5.1 Power output

Power output was significantly higher following the two pre-cooling trials compared to the control condition during the 1500 m time trial (P = 0.001). The power output profile followed a similar pattern for all three protocols; high during the first 500m, a slight taper during the second 500m and an increase for the final 500m split. Mean power output values were not significantly different from onset of the time trial to the first 500m split in the two cooling conditions compared to the control (Figure 4.8). Mean power output was reduced in the control condition during the second 500 meters compared with the ICE vest (P = 0.013) and WP (P = 0.002) trials. Mean power output for the entire 1500 m trial was higher in the two cooling trials than in the control trial (Table 4.2). Power output tended to be higher in ICE vest than in the WP condition though this difference was not significant (P = 0.213).

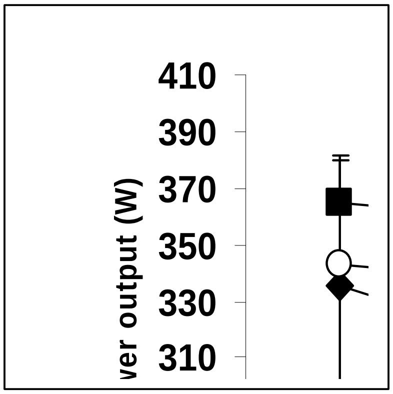
4.5.2 Split time and pacing

There was a condition effect on split times during the 1500 m self paced trial (P = 0.001). Split times were consistently faster in the ICE vest trial than in the control trial at each 500m split (P = 0.023, 0.006, 0.002 for 500, 1000, and 1500 m respectively). The WP trial was faster during the second 500m only (Figure 4.9). Mean split times for the entire 1500 m were higher for both of the cooling trials compared to the control condition, thought there were no differences between the two cooling trials (Table 4.2).

4.5.3 Total time

Total time to complete the 1500 m self-paced time trial was different between conditions (P = 0.000). Time to complete the 1500 m in the control condition (303.7 ± 10.8s) was slower than both the ICE vest trial (295.1 ± 10.3s, P = 0.002) and the WP trial (297.8 ± 14.1s, P = 0.002). There were no differences between the two cooling conditions (Table 4.2).

Figure 4.8 Mean (SD) power output at each 500 m split during a 1500 m time trial on a rowing ergometer in an environmental chamber (36ºC, 40%rh) following torso pre-cooling during 45 min rest and 30 min standardized warm up with an ice vest (¦) or a water perfused vest (?) or no pre-cooling during the control condition (?). * indicates significant difference between the cooling and control conditions P<0.05).


410
390
370
350
330
310
ver output (W)

*

Figure 4. 9 Mean (SD) split times at each 500 m split during a 1500 m time trial on a rowing ergometer in an environmental chamber (36°C, 40%rh) following torso pre-cooling during 45 min rest and 30 min standardized warm up with an ice vest (¦) or a water perfused vest (?) or no pre-cooling during the control condition (?). * indicates significant difference between the cooling and control conditions P<0.05).

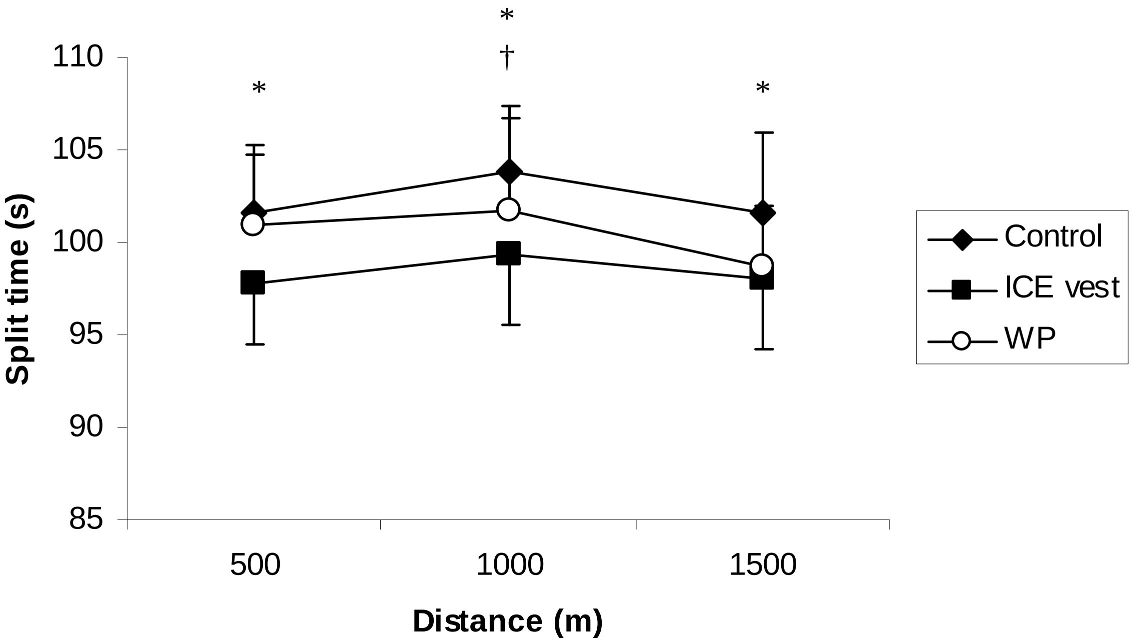

*
†
*
*
110
105
100
95
90
85
Split time (s)
500
1000
1500
Distance (m)
Control
ICE vest
WP

Table 4.2 Mean and SD split times, total time, power output and stroke rate during the 1500m time self paced time trial on a rowing ergometer in an environmental chamber (* indicates significant difference from control trial P<0.05)

	Control		Ice vest		WP vest	
	mean	sd	mean	sd	mean	sd
Split time (s)	102	4	98	3	100	4
Total time (s)	307	11	295	10	298	14
Power output (W)	328	34	370	40	354	39
Stroke rate (spm)	31	2	32	1	32	2

5.0 Discussion

The purpose of this study was to examine the thermoregulatory and psychophysical effects of selectively cooling the torso during seated rest and standardized warm-up on a rowing ergometer in trained competitive lightweight male rowers. The effect of torso pre-cooling on pace selection and 1500 m time trial performance was also assessed, as was the effectiveness of two cooling methods (Thermoblazer^{TM} ice cooling vest and Med-Eng CardioCool^{TM} water perfused vest. Pre-cooling has been shown to be effective in improving performance in the heat in events lasting 70s (Marsh & Sleivert, 1999) up to one hour (Wilson et al., 2002). However, to date the relative effectiveness of pre-cooling on thermoregulatory and subjective responses has not been investigated in elite athletes or in short duration high intensity events such as a 1500 m time trial. Additionally, there has been no direct comparison of these two cooling methods on subsequent maximal performance. A better understanding of the effectiveness of these two cooling techniques should allow appropriate pre-cooling recommendations for elite athletes competing in hot humid environments.

The present study demonstrated that torso cooling improved elite rowing performance during 1500 m rowing ergometer time trial in the heat and the effects were pronounced. Mean power output was higher and times were faster for all participants in the two cooling trials compared to the control trial. Torso cooling with either method appeared to be equally effective and associated with decreased thermal and psychophysical strain. Furthermore, it appears that thermal and psychophysical strain play an important role in determining pace selection during self-paced exercise in hot humid conditions.

5.1 Measure of body temperature

This experiment depended on accurate measurements of core temperature. Currently the most accurate and widely available techniques for measuring core temperature in humans are T_{re} and T_{oes}. T_{oes} is not ideal because of the discomfort associated with the thermistor insertion into the nasal passage and the need for a doctor to be present for the insertion (Moran and Mendal, 2001). T_{re} is used extensively to estimate core temperature during pre-cooling experiments (Arngrimsson et al., 2004;

Cheung & Robinson, 2004; Hasegawa et al., 2005; Yeargin et al., 2005). Thus, T_{re} was chosen to estimate core body temperature in this experiment as it was the most safe and practical technique to use in our lab. However, there were problems associated with using rectal probes to measure core temperature in athletes rowing on the Concept 2 ergometers. The participants initially found the insertion and the use of the rectal probe awkward. T_{re} requires wire connections between the thermistor and the monitoring device, thus the connecting wire were securely taped in place to minimized movement during exercise. There was some slippage of probes during the experiment. This was evident by a sudden decrease in T_{re} during exercise when core temperature was increasing in all conditions. Because T_{re} was monitored in real time, the athlete was notified immediately of the problem and a brief adjustment period was allowed to reposition the probe. There was no way of determining whether it had been replaced at its original location, other than the return of core temperature toward previous values.

5.2 Torso cooling and strain

5.2.1 Thermal strain

Three participants were unable to complete all three of the experimental trials. Two participants failed to complete the control trial and one participant prematurely terminated the WP trial. The participant that ended the WP trial did so 15 minutes into the warm-up due to feeling faint and as though he was unable to complete the time trial. He reported being particularly tired on this day and had just finished practice prior to coming in for testing. One of the participants was stopped during the warm-up in the control trial as his rectal temperature attained the ethical limit of 39.5ºC. Another participant voluntarily withdrew from the control trial following the warm-up, as he was experiencing breathing difficulty and numbness in his hands and feet, however his rectal temperature only reached 39.16ºC.

There were no significant differences in rectal temperature between conditions from the beginning to the end of the rest period and cooling failed to lower core temperature. The absence of a decrease in rectal temperature during the seated rest period is consistent with previous research. Webster et al. (2005) found that rectal temperature remained relatively stable until the onset of exercise irrespective of the cooling condition. Wearing a cooling vest did not produce any change in rectal temperature during a 30 minute seated rest period (Hasegawa et al., 2005). Thus, it is apparent that torso cooling alone is not sufficient to decrease core temperature at rest in uncompensable heat stress.

During the active warm-up significant time and time X treatment effects were observed for T_{re} ($P < 0.05$). Core temperature increased during exercise for all conditions; however the increase in rectal temperature was attenuated in the two cooling conditions compared to the absence of cooling. T_{re} was lower in the ice vest trial after 25 minutes of exercise and continued to be lower till the end of the warm-up. There were no differences between any of the other conditions. This finding was consistent with previous data where torso cooling attenuated the rise in T_{oes} and T_{re} during exercise (Cotter et al., 2001; Nunneley et al., 1982). Localized cooling has been shown to decrease core temperature in previous research. Ice vests have been shown to blunt the increase in body temperature during a 38 minute active warm-up in the heat while wearing an ice vest as compared to the control condition (Arngrimsson et al., 2003). Hasegawa et al. (2005) found that T_{re} was significantly lower after 45 minutes of exercise during cooling trials with an ice vest with or without water consumption. Similar reductions in core temperature were found after wearing a cooling vest during rest, stretching and warm-up in male and female runners (Webster et al., 2005). Conversely, wearing an ice jacket during 80 minute intermittent sprint performance did not reduce core or mean skin temperature (Duffield et al., 2003). This may the result of an inferior cooling application strategy rather than insufficient cooling power of the ice jacket.

The effects of pre-cooling on core temperature during seated rest and standardized warm-up were evident during the 1500 m time trial. Rectal temperature was significantly lower in both of the cooling conditions at the onset of the time trial and remained lower until the final 500m. The treatment differences were no longer significant by the end of the time trial. Hasegawa et al. (2005) also found that T_{re} was not significantly different between conditions following a run to volitional exhaustion at 80% of VO_{2max}. T_{re} followed a similar trend during a 5km run following cooling with an ice vest (Arngrimsson et al., 2003). Conversely, core temperature remained significantly lower post race following pre-cooling with whole body immersion in cold or ice water (Yeargin et al., 2005). Webster et al. (2005) found that core temperature remained following cooling throughout the 30 min run for two of 3 vest cooling conditions compared to the control.

T_{re} increased during the time trial by 0.14ºC in the control condition and by 0.32ºC, and 0.34ºC in the ice vest and WP vest trials, respectively (Figure 4.1). Arngrimsson and colleagues also found the T_{oes} increase during the 5km run was significantly greater in the vest trial than in the control condition. This increase in heat generation during performance indicates that pre-cooling may have increased the margins of core temperature from the critical thermal maximum during the warm-up, allowing participants to work harder during the subsequent time trial.

Although the application of localized cooling during rest and warm-up did not decrease core temperature it did attenuate its normal rise allowing athletes to maintain thermal homeostasis and begin exercise at a lower core temperature compared to the control condition (Figure 4.1). This in turn delayed the attainment of a critically high core temperature which negatively impacts performance. The cooling vests removed heat from the body either by conduction with the ice vest or by convection with the water perfused vest. This was evident by the significantly lower chest skin temperature throughout the cooling period ($P<0.001$, Figure 4.2). Pre-cooling was also effective at reducing core temperature by cooling peripheral blood before returning to the core. Cold tissue has the ability to act as a heat sink as it can store heat during subsequent exercise. Both the ice vest and the WP vest appear to be effective in relieving thermal strain during the warm-up. It appears that the duration of wearing the vest and the impact of wearing the vest during warm-up are more important in lowering core and skin temperature than the method of cooling.

5.2.2 Technical challenges of torso cooling

Cooling was applied close or directly over the chest thermistors, thus although mean skin temperature was lower during both cooling trials, it was heavily weighted by the chest skin temperature value (Figure 4.2). Chest temperature was significantly reduced from cooling, however when chest temperature was removed from the mean skin temperature calculation there were no significant differences between conditions. However, lowering chest temperature alone may play a role in thermoregulation. It appears from this study that lowering chest temperature was adequate to influence thermal comfort and thermal sensation and therefore behavioural thermoregulation.

Collectively these findings suggest that the decrease in thermal strain and improved performance associated with torso cooling appear to be related to cooling the skin and the associated perception of improved thermal comfort in addition to cooling deeper core tissue.

5.3 Cardiovascular strain

No significant effects of cooling on heart rate were observed in the present experiment during either the ICE or WP conditions throughout seated rest, warm-up or the 1500 m time trial (Figure 4.7). A recent study comparing different ice vests found similar results. The effectiveness of three ice vest cooling techniques was compared and it was found that there were no changes in heart rate associated with pre-cooling (Webster et al., 2005). The present study does not support previous research in which cooling with an ice vest attenuated heart rate by 11 beats per minute during the first 3.2km of a 5km run (Arngrimsson et al., 2003), and ice vest and cold air cooling was effective in limiting heart rate during fixed load exercise (Cotter et al., 2001). Booth et al. (1997) found that heart rate was reduced by 13% following pre-cooling and continued to be lower through 10 minutes of exercise. However, these differences did not persist throughout the 30 min run. Heart rate was not different between trials from 15 minutes to the end of exercise. Another study reported that ice vest cooling significantly reduced heart rate after 15 minute of exercise, but these differences did not persist to the end of exercise (Hasegawa et al., 2005).

It has been proposed that the decrease in heart rate associated with cooling may be explained by low pressure baroreflexes and peripheral vasoconstriction (Olschweski and Bruck, 1988). If exercise in the heat increases the blood flow demand to the skin, thus increasing cardiovascular strain, then cooling the core may decrease the demand for skin blood flow thereby minimizing strain. Furthermore, peripheral vasoconstriction associated with cooling may lead to greater cardiac filling and thus a decreased heart rate. This had been demonstrated following whole body cooling with cold water immersion (Booth et al., 1997; Gonzalez-Alonzo et al., 1999) and ice vests and cold air (Cotter et al., 2001; Sleivert et al., 2001). However, increasing demands of exercise may overshadow this reduction in cardiovascular strain. For example a 13% decrease in heart rate following cold water immersion was offset by increased work output during exercise particularly during the later stages of running performance (Booth et al., 1997). The same may be true for the present study. The work rate during the standardized warm-up was very demanding and may have masked any potential benefits of cooling on cardiovascular strain. However, this does not explain the lack of difference in heart rate during seated rest or the onset of the warm-up. The discrepancy between these studies and this current study may lie in the method of cooling used to lower core temperature, cooling with an ice vest is less aggressive than either whole body immersion or the combination of cold air and ice vests. Booth et al. (1997) were able to lower pre-exercise rectal temperature by 0.7ºC and mean skin temperature by 5.9ºC, while there was no difference in T_{re} following 45 minutes of seated rest in the present study. This method of pre-cooling was much more effective at removing heat from the body and would have caused significantly greater vasoconstriction as the whole body was cooled not just the blood vessels in the torso. Consequently, these methods had larger decreases in core temperature and in sub-maximal heart rate.

5.4 Psychophysical strain

Torso cooling during seated rest decreased psychophysical strain as indicated by cooler ratings of thermal sensation and increased thermal comfort in both the ice vest and WP vest trials (Figure 4.5 & 4.6). Participants began feeling significantly cooler the seated rest period during the ice vest trial and WP vest trial as compared to the control. This improved rating of thermal sensation persisted through the end of the rest period and was maintained throughout the warm-up. Thermal comfort was rated on a scale from 1 being comfortable to 5 being extremely uncomfortable. Both cooling treatments relieved any deterioration in ratings of thermal comfort during the 45 minute rest period. Thermal comfort ranged from 1.3-1.6, whereas it increased steadily to 2.8 in the control trial.

Although the practical implications of a 1 point difference on a perceptual scale may seem minimal it appears that it may play a role in determining pacing strategies (Tucker et al., 2004). During the warm-up metabolic heat production and high ambient heat load limited the benefits of cooling and the athletes became more uncomfortable in all conditions. However, participants were significantly more comfortable in the cooling trials. Physiological strain was reduced at lower exercise intensities but the effects of cooling dissipated during the later stages of the warm-up. The athletes felt cooler throughout the warm-up in the two cooling trials, this did not however, translate into improved ratings of thermal comfort.

Heat stress occurs when an individuals' evaporative cooling requirements exceeds ambient cooling power of the environment, thus they perceive they are getting hotter. It is possible that the perception of heat strain does not match its physiological counterpart during exercise heat stress. Tikuisis et al. (2002) examined T_c and heart rate, secondary determinants of physiological strain associated with heat stress, and matched them to the strain indices. Strain indexes (TC, TS, RPE) are bounded on a scale of zero to maximum in contrast to measure of physiological strain which is usually unbounded. It appears that there is a lower perceived heat tolerance for untrained participants. That is they have a higher perception for the same amount of physiological strain, or trained individuals underestimate physiological strain. Furthermore, fatigue during exertional heat stress in endurance trained subjects is associated with the attainment of core temperature of 39.7 to 40.2ºC. This places them at potentially greater risk of heat strain injury if allowed to continue to exercise in the heat according to their perception.

Skin temperature should not be underestimated in its relative importance in determining thermoregulatory responses. It has been suggested that cold response primarily driven by skin temperature, but in the heat discomfort is mainly driven by core temperature. However, Frank et al. (1999) demonstrated that T_c/T_{sk} contribution ratio is 1:1 for subjective thermal comfort. They proposed that the skin plays a critical role in the body's thermoregulatory response to varying ambient conditions, as it is more sensitive to changes and will allow an individual to make behavioural changes before any change in core temperature occurs. Countering significant changes in core temperature either above or below normal resting temperature requires more energy and time, and is not an efficient process. Thus, it appears that the body is constantly evaluating the external and internal environment and making adjustment in anticipating of any major changes which would disrupt homeostasis.

These results promote the theory of a governor in the central nervous system which detects and integrates afferent signals arising from multiple origins (muscles, peripheral organs, heart and thermoreceptors) and initiates the appropriate response to protect the body during maximal exercise to prevent absolute fatigue and consequent organ damage. The fact that changes in work output are occurring prior to changes in core temperature in different experimental conditions, suggests that the skin plays an important role as afferent feedback for this controller. Tucker et al. (2004) proposed that sensory input from the skin plays a role in mediating a decrease in central recruitments by informing the brain that the capacity for heat dissipation is reduced and thus heat production is decreased to prevent temperature from rising too rapidly. Thus it would seem that skin temperature plays an important role in determining pacing strategies, particularly during uncompensable heat stress.

It would follow that the sensation of thermal comfort would affect the perception of work during exercise in the heat. However this was not the case. Although there was a significant effect of time on RPE during the 30 minute warm-up ($P = 0.001$), there was no treatment effect ($P = 0.392$). Final RPE scores were near maximal in all conditions suggesting that each individual performed to their maximum capacity in each trial. These results are supported by previous research (Arngrimsson, et al., 2004; Cotter et al., 2000; Hasegawa et al., 2005; Tucker et al., 2004). One study did report lower RPE being significantly lower in cooling compared to heating trials at 10 minutes of exercise; however at exhaustion RPE was equally high in all trials (Gonzalez-Alonzo et al. 1999). In each of these studies more work was done for the same perception of effort. Thus, it appears that RPE is not tightly coupled to an individual perception of thermal load or comfort. The mismatch between perceived exercise intensity and output at different temperatures may have some practical significance. If participants perceived that they were working less hard when they were in a hyperthermic state they may increase power output which would lead increased endogenous heat production and homeostatic failure. However, because the perception of effort is the equivalent for all points in the cooling and control conditions, the participants' work rate is such that they will not attain the critical limiting core temperature. This would further support the theory of teleoanticipation and the central governor model.

In the present study, RPE tended to be lower in the cooling trials however there was a large amount of variability, particularly just prior to beginning the time trial. This was because the participants were not actually exercising when they gave their pre time trial RPE score so some participants reported zero scores while others gave RPE a score of 10 because they were still tired from the warm-up. Furthermore the RPE scores reported after 10 minutes into the warm-up were not given during steady state rowing, so it is possible that the rower was completing a piece (high exertion) or he may have been during the one minute rest period (low exertion).

5.6 Torso cooling and performance

The present study demonstrated that torso cooling during seated rest and exercise significantly improved 1500 m time trial performance on a rowing ergometer in an uncompensable hot environment. This supports existing literature which has investigated the possible ergogenic benefits of torso pre-cooling during rest and active warm-up on subsequent endurance performance in the heat (Arngrimsson et al., 2004; Cotter et al., 2000; Hasegawa et al., 2005; Webster et al., 2005). Pre-cooling has not been show effective in improving intermittent sprint performance (Cheung & Robinson, 2004; Duffield et al., 2003) and has even been reported to negatively affect sprint cycling (Sleivert et al., 2001). To our knowledge no studies have specifically examined the effects of torso cooling on performance with elite athletes partaking in high intensity events like the 1500 m time trial which lasts approximately 5 minutes. Thus, the observation that torso pre-cooling improves 1500 m time trial performance in elite rowers is pertinent, and emphasizes the practical significance of localized cooling as an ergogenic aid.

5.7 Placebo effect

There is a possibility of placebo effect from pre-cooling. It was impossible to blind the participants of the cooling conditions, thus a placebo effect cannot be discounted. However, an attempt was made to minimize this effect. The athletes were told prior to beginning that the study attempted to determine whether the pressure from wearing the vest on its own was effective in improving performance, or whether cooling could be detrimental to performance. Furthermore, the combination of thermoregulatory and psychophysical data indicates that the observed performance enhancements were due to reduced body temperature and improved comfort.

5.8 Complication associated with pre-cooling

Complications associated with torso cooling during exercise in the heat are due to several potential mechanisms.

5.8.1 Evaporative cooling

Wearing a cooling vest decreases the ability for evaporative cooling (Webster et al., 2005), which is the main method of heat dissipation in hot environments. Cooling vest in warm environment effectively cooled body and facilitated heat loss. In the present study T_{sk} of the vest and WP trials were lower throughout the warm-up. This result indicates that the ice packs in the cooling vest and cold water in the WP cooled the body effectively. Although the vest inhibited evaporative cooling on the skin's surface the skin was always cooled and non evaporative heat loss increased. Sweat rate, although not significantly different, tended to be lower in the two cooling trials compared to the control. Sweat rate was estimated by body mass loss, corrected for fluid intake. Changes in body mass between conditions may indicate the existence of differences in hydration status between trials as participants were only allowed to consume a fixed amount of water. Such changes may be implicated in the reduced performance in the control trial. Dehydration influences exercise performance through decreased heat storage capacity which is the result of inability to maintain cardiovascular function and hence thermal homeostasis (Kay & Marino, 2000).

In the present study, the difference in body mass from the beginning to the end of the testing protocol was 1.1, 0.85 and 0.81 kg for the control, ice vest and WP vest trials, respectively although the differences were not significant ($P = 0.319$). Previous studies have shown reductions in sweat rates following pre-cooling. Total and evaporative sweat loss were both significantly lower following 60 minutes of cycling at 60% VO_{2max} in cooling and cooling with hydration trials, while sweat efficiency was significantly higher with hydration only compared to all other trials (Hasegawa et al., 2005). Other studies have reported reduced sweat rates following pre-cooling with cold water immersion (Kay et al., 1999; Wilson et al., 2003) and delayed the onset of sweating with cold air exposure (Olshweski & Bruck, 1988; Schmidt & Bruck, 1981). Thus, it would appear that pre-cooling decreases sweat rate and may decrease rate of dehydration in addition to facilitating heat dissipation.

5.8.2 Weight

The benefits of pre-cooling must be weighed against the possibility of increased metabolic demands of carrying the extra weight of the vest. The ice vest and WP vests used in the current study had wearing weights of 2 kg and .99 kg, respectively. This is slightly lighter than the ice vest used by Hasegawa et al. (2005) which weighed 3.3kg. Other studies using ice vest cooling have not reported wearing weights (Arngrimsson et al., 2004; Cotter et al., 2001; Duffield et al., 2003; Webster et al., 2005). The present study did not evaluate whether work load was increased by the additional weight of the cooling garments. However, Hasegawa and colleagues found that oxygen uptake during cycling at 60% VO_{2max} remained similar in cooling and control trials in which the participants were not wearing an ice jacket despite subjects perceiving that they were working harder because of the extra weight. It is possible that the additional weight of the cooling garments does not have a significant impact on non weight bearing sports such as rowing or cycling, however it may be hinder activities like running.

5.8.3 Thermal comfort and exercise intensity

It has been suggested previously that individuals who are cooled during exercise may self-select higher exercise intensity which is inappropriate for the conditions due to enhanced thermal comfort. They perceive they have a lower rate of heat storage from the afferent information coming from the skin, yet their core temperature may be unchanged if the cooling strategy is not aggressive enough. For example at the beginning of the warm-up in the present study participants felt significantly cooler although their core temperature was unchanged. This did not appear to be a problem in the present study.

However, there was no way of determining whether they were working harder at this time because the warm-up was not steady state. We can speculate that the work rates were similar between trial, as there were no differences between conditions for distance covered during the warm-up (P>0.05). A reduction in power output during the time trial would suggest that the athletes did not select a realistic pacing strategy. There was no evidence from performance or thermal strain data to indicate that participants self-selected inappropriate exercise intensity during the 1500 m time trial. Power output was highest during the final 1500 m of the self-paced performance. Participants completed all cooling trials except for one participant. This rower did not complete the WP trial; however he terminated the trial early in the warm-up due to fatigue from previous exercise bouts and was not close to reaching a critical limiting core temperature.

5.8.4 Cooling body surface area

The cooling power of both of the vests was sufficient to induce a relatively large decrease in thermal sensation by the end of the warm-up and core temperature was also significantly reduced despite differences between the amount of body surface area cooled. It appears that the fit and the garment design may play a greater role in the effectiveness of the vest. Loosely fitting vests were less effective in reducing skin temperature. In the present study the ice vest had a more snug fitting design than the WP vest. Consequently, the ice vest had greater heat storage and the lowest mean times for completing the 1500 m time trial. It was observed that the ice packs lasted on average 30 minutes in the conditions of this study. Thus, once the ice was melted the tight fitting neoprene which initially insulated the ice from the heat began to reduce heat dissipation. The duration of cooling with ice packs depends on the closeness of contact to the body, environmental conditions, endogenous heat production and the type of activity being performed. A comparison of three different cooling vests revealed that vests that fit more closely cover a greater surface area and contain more coolant decrease skin temperature more effectively (Webster et al., 2005).

Other methods of pre-cooling appear to be very effective in removing heat from the body. Whole body cold water immersion can provide cooling rates up to 0.35ºC/min depending on the water temperature (Proulx et al., 2003). Yeargin et al. (2005) reduced core temperature by 2.15 and 1.65ºC following a 45 minute run and 12 minutes of whole body immersion in 5 and 13ºC water. Participants in the present study reported that although their core felt cooler, their heads became excessively hot an uncomfortable during cooling trials. Thus, it would appear that the rating of thermal comfort was more representative of the torso than the entire body. Head cooling was not applied in this study, as the effects of torso cooling alone were of interest. However, head cooling has been shown to be an extremely effective method of heat removal as it the blood vessels do not constrict when cold is applied (Nunnely, 1982; Shvartz, 1972). It is likely that the ergogenic effects of torso pre-cooling observed in the present study would be enhanced with the addition of head cooling. Additionally, the cooling conditions were changed partway through the trial by the removal of the cooling vest. So it is possible that any changes observed may have been magnified if cooling was continued through the time trial. Thus, selectively cooling the torso appears to be an effective site for improving comfort and decreasing thermal strain, and is perhaps more practical than the combination of head and torso cooling for many sports.

5.9 Pacing Strategies

5.9.1 Competition and pacing

Competition can influence pacing especially in boat racing; rowers want to put themselves in a position of power even though the pace may not be optimum for time. For example, the competition in a race can affect their pace at the end of the race. Furthermore, there are different boat speeds for a given stroke rate creating pacing within pacing. The present study attempted to create a competitively meaningful simulation of a typical rowing time trial. Rowers were matched and performed the entire experimental protocol in pairs. This was intended to increase motivation and competitiveness during the trial, and to simulate and actual race with the intention of eliciting maximal efforts. Subjects in this experiment selected a higher power output from the onset of time trial in the two cooling conditions compared to the control trial and they remained higher throughout the 1500 m. It is interesting to note that the power output pattern was similar between conditions; however the absolute power output was greater overall for the cooling conditions. So the rowers did not go out fast at the beginning of the control trial and die at the end. Rather, they systematically reduced power output for each 500m of the race. The athletes were not willing or not able to go to harder in the control trial. Perhaps this relatively conservative pace was a protective strategy which prevented thermal failure and catastrophic fatigue due to the attainment of a critical core temperature. This may indicate that the combination of improved perceived comfort and reduced thermal strain due to pre-cooling increased performance.

Pre-cooling improved subsequent time trial performance by reducing the time to complete the 1500 m race. Mean times were 12.2 and 9.6 seconds faster than control in the ice vest and WP trials, respectively. This translates to a difference of 62 m and 48 m at these rowing speeds. This is a significant difference in finishing times in a sport that can come down to photo finishes.

There is evidence to support the role pre-cooling and body temperature on influencing pace selection. Marino (2004) suggested that pacing strategy does not change but systematically increases subconsciously, based on thermal comfort or core temperature. Although pre-cooling was not applied differences in rates of heat storage were compared in two populations of runners in the heat. In this study African runners, who have lower heat storage at a given running speed, out performed Caucasian runners in hot (35ºC) but not cool (15ºC) conditions in an 8km time trial. Differences in running speed were present from the onset of the time trial. Tucker et al. (2004) found that cyclists subconsciously selected a lower power output soon after the start of a 20km time trial in the heat (35ºC) compared to cool (15 ºC) condition. This occurred when T_{re} was still significantly lower than levels shown previously to associated with bodily harm or diminished central drive. It appears that the central governor down regulates activity in advance of thermoregulatory failure.

Tucker et al (2004) noticed that the greatest power output occurred during the final 5% of a 20km cycling time trial when T_c was highest. They also found that power output and iEMG activity during self paced exercise in the heat occurs before any abnormal increase in T_{re}, heart rate or perception of effort. This adaptation may be part of an anticipatory response which adjusts muscle recruitment and power output to reduce heat production. These results support previous research which demonstrated that passive heating decreased central drive (Morrison et al., 2004). In this study motor unit recruitment and MVC force decreased progressively with increasing core temperature. Electrically evoked maximal force remained unchanged. Thus the force generating capacity is unaffected but central fatigue is associated with elevated T_c. Morrison et al. (2004) suggests that hyperthermia diminishes central drive and reduces the ability to activate muscle in the heat, thus precipitating fatigue.

In pre-cooling, the reduction in thermoregulatory strain may not be the only benefit for performance. Based on this model thermal sensation and perception may be equally as important. Change in pacing strategies based on afferent inputs. St. Clair Gibson and colleagues (2003) have suggested a pacing algorithm in which the actual pace is not constant. Rather pace oscillates constantly during non monotonic activity. They propose that pace is affected by multiple factors including interoceptors, which monitor metabolic activity, fuel supply and temperature, exteroceptor, which detect change in the external environment and the output from the motor cortex which codes the motor command to change pace inside the brain itself. Memory of prior events and knowledge of the distance to be covered may also be used to set current pacing strategy.

This is a continuation of the theory of teleoanticipation which includes both feed forward planning and feedback control of afferent changes associated with peripheral metabolic structures and the external environment as well as incorporating knowledge from previous exercise bouts (Noakes et al., 2004). According to the central governor model during self paced exercise the central nervous system continuously modifies pace in a complex non-linear dynamic system. Power output is adjusted continuously on the basis of metabolic calculations taking into consideration prior knowledge from pervious exercise, planned end point, current metabolic rate, essentially creating a continuum adjusting for power output and hence pace during exercise.

5.10 Threshold

The duration of the pre-cooling protocol used in this experiment was long (45 minutes rest and 30 minute warm-up = 75 minutes). Although it did not lower core temperature from pre-exercise values, both methods of pre-cooling were successful in minimizing heat gains during the active warm-up. It is possible that shorter pre-cooling periods may not be as effective (Duffield et al., 2003). Additionally, a key component of this study was that cooling was applied during an active warm-up. If cooling was stopped prior to the warm-up then it is likely that the ergogenic effects of pre-cooling would dissipate.

It is possible that there is a threshold level of cooling necessary to attain in order to induce performance benefits. If this is the case then is more cooling better? Cooling with whole body immersion in either cold (13ºC) or ice (5ºC) water following a 45 minute warm-up and preceding an 8 mile running race was very successful in decreasing core temperature compared to air (Yeargin et al., 2005). Ice water immersion resulted in a significantly lower core temperature than cold water. However, cold water immersion was the only treatment which had statistically significant lower performance times than the mock treatment (no cooling). Ice water was so effective in removing heat that it left subjects feeling stiff and cold after removal thus potentially limiting their psychological and physical performance. Bergh and Ekblom (1979) reported that pre-cooling by swimming in 13 to 15ºC water reduced physical performance in arm and leg exercise to exhaustion. However the pre-exercise oesophageal temperature was 34.9ºC, so further reductions in core temperature would have induced hypothermia, which is also detrimental to performance.

5.11 Effectiveness of cooling methods

Finally this study attempted to determine whether there were any differences between two cooling methods. Both vests cooled skin temperature faster than if a vest was not worn. Rates of heat storage from the beginning to the end of the experiment were higher with both ice vest (43.50 ±11.44 W/m^2) and WP vest (37.40 ± 12.11W/m^2) compared to the control (22.16 ± 6.13 W/m^2, P = 0.008, ?^{2} = 0.544, Power = 0.868). Both cooling methods removed more heat than the control condition. Heat transfer tended to be higher from the ice vest; however, there were no statistically significant differences between the two methods. There were also no differences between conditions for sweat rate, core temperature or any of the psychophysical variables. Furthermore, performance subsequent to both treatments was significantly enhanced compared to the control, but not different between cooling techniques. Thus it would appear that both cooling methods were equally beneficial for performance.

The fit of the vest is critical and appears to affect the effectiveness of cooling and subsequently affects performance. The ice vest slightly outperformed the water perfused vest as an ergogenic aid. This may be because the ice vest was more fitted, which in turn enhanced body cooling. The ice packs in the vest lasted approximately 30 minute after which the water perfused vest outperformed the ice vest, but only until new ice packs were inserted. Perhaps the WP vest would have performed better if it came in smaller sizes with more tapered cut.

The practicality of the two methods of cooling is also a consideration. The ice vest is less expensive than the WP vest and it is also easier to use as it requires only ice packs and a cooler for field use. Conversely, the WP vest requires a cooler and a pump, so it limits the range of use in athletic settings. Athletes are tethered to one place unless they have a personal cooling system, which is costly both in price and metabolic demands (weight approximately 6kg).

5.12 Recommendations

Cooling vests (either ice or water perfused) should be worn for 60 to 70 minutes prior to performing in extremely hot environments to minimise heat stress and improve performance. If using an ice vest the ice packs should be changed every 20 to 30 minutes. Cooling should be applied during the active warm-up if possible, as this is where the majority of cooling appears to take place. The water perfused garments may not be suitable for use during active warm-up and this need to be considered. Perhaps, a strategy involving ice vests available for on water use would be beneficial and the water perfused garments may be used during the hours immediately prior to warm-up and during recovery on land. Regardless of the type of cooling garment used ensure that it fits as tightly as possible. Ideally, each athlete should be given the opportunity to train with the cooling garment prior to any competitions, to determine a strategy that works best for them.

5.13 Conclusions

Selectively cooling the torso with either an ice or water perfused vest during seated rest and active warm-up reduced the rate of heat storage and widened the margin before a body temperature at which heat exhaustion occurs. This allowed rowers to complete a 1500 m ergometer time trial with a higher power output and lower mean times.

Thus, it appears that pre-cooling prior to exercise will reduce the risk of heat injury and improves performance in high intensity short duration exercise in elite athletes by delaying a gain in core temperature, and reducing psychophysical strain.

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TABLE OF APPENDICES

Appendix A- Literature Review Table - Summary of research investigating the effects of pre-cooling on thermoregulatory and performance variables.

Table 1. Summary of research investigating the effects of pre-cooling on thermoregulatory and performance variables.

Study	**Participants**	**Pre-Cooling Method**	**Exercise Protocol**	**Environmental Conditions**	**Physiological Response**	**Performance Effect**
Arngrimsson et al. 2003	8 female &	ice vest 9 male trained runners	38 min warm-	32ºC, 50%rh up & 5 km run on treadmill	?Tsk, ?Tre, ?Tes ?HR, ?RPE, ?TC	? 5 km run time by 1.1%
Bolster et al. 1999	6 endurance Trained tri-athletes, male	cold water immersion	15min swim 45min cycle	26.6ºC, 60%rh	?Tre - 0.5ºC ? heat storage	not tested
Booth et al. 1997	5 male & 3 female comp. runners	cold water immersion	30 min self-paced treadmill run	32ºC, 60%rh	?Tsk, ?Tb ? HR, ? TC ?Blood lactate	?distance run by 304 m (4%)
Booth et al. 2001	7 males	cold water immersion	35 min cycling 60% peak VO2	35ºC, 46%rh	?Tm, ?Tes, ?TS ?*fc* ,	not tested
Cotter et al. 2000	9 males low fitness	ice vests with & without thigh cooling, & cold air	20 min cycling @ 65% VO2 peak, 15 min self-paced	35ºC, 60%rh	?Tb, ?TS, ?TC, ?HR ?FBF, ?O2 pulse	?power output, (17%)
Duffield et al. 2003	7 male hockey players	ice jackets	80 min interm-ittent sprint cycling	30ºC, 60%rh	no change in Tc, HR, lactate, RPE	no change in work done or power output
Gonzalez-Alonzo et al. 1999	7 male cyclists	cold water immersion	cycling at 60% VO_{2max} to exhaustion	40ºC, 19%rh	?Tes, ?HR, ?FBF, ?RPE no change in blood lactate	? time to exhaustion by 17 min (27%)
Kay et al. 1999	7 moderately trained males	cold water immersion	30 min self-paced cycling	31ºC, 60%rh	?Tsk, ?sweating ?heat storage,	?distance cycled by 900m (10%)

? = decrease, ? = increase, rh = relative humidity, Tre = rectal temperature, Tsk = skin temperature, Tb = body temperature, Tes = esophageal temperature, HR = heart rate, TC = thermal comfort, TS = thermal strain, *fc* = cardiac frequency, FBF = forearm blood flow, RPE = rate of percived exertion, LCG = Liquid Conditioning Garment

Table 1. **Continued**

Study	**Participants**	**Pre-Cooling Method**	**Exercise Protocol**	**Environmental Conditions**	**Physiological Response**	**Performance Effect**
Lee & Hames 1995	14 male runners	cold air 5ºC	running at 82% VO2max to exhaustion	24ºC, 51%rh	?Tre, ?Tsk, ?Tb, ?HR ? heat storage	? exercise endurance by 8.5%
Marsh & Sleivert 1999	13 elite male cyclists	ice jackets & cold air test	70 s sprint cycling power	29ºC, 80%rh blood lactate	?Tc, ?Tsk, no change in HR or	? mean 70 s cycling power by 22 W (3.3%)
Nunneley et al. 1982	5 males 1 female 60 rpm, 1.5kpm	LCG with 8ºC water	manikin task 8 min cycling	30ºC	?Tsk, ?Tre, ?Tes ?HR, ?TC, ?TS	trend toward ? reaction time ? errors
Olshewski & Bruck, 1988	7 males	double cold exposure to 0ºC air	cycling with ? work load to exhaustion	18ºC, 50%rh	?Tsk, ?Tre, ?Tes ? heat content, ?HR ? heat storage	? mean endurance time to exhaustion and work performed
Schmidt & Bruck, 1981	3 female & 9 male trained rowers	double cold exposure to 0ºC air	cycling with ? work load to exhaustion	18ºC	?Tb (1ºC), ?HR no change in VO2 delayed sweating onset	?mean endurance time to exhaustion & work performed
Sleivert et al. 2001	9 active Males	ice vests & 0ºC air w & w/o thigh cooling	high intensity 45 s cycling	33ºC, 60%rh	?Tc, ?Tsk, ?HR ?FBF	? mean and peak power detrimental effects removed with warm up
Wilson et al. 2002	8 males	cold water immersion	60 min cycling @ 60% VO_{2max}	30ºC, 32%rh	?Tre, ?Tsk, ?Tb, ?HR, ?TC ?sweat rate, ?heat storage	not tested
White et al. 2003	11 males immersion	cold water @ 60% VO_{2max}	30 min cycling	30ºC, 32%rh	?Tre, ?Tsk, ?Tb	not tested & no control

? = decrease, ? = increase, rh = relative humidity, Tre = rectal temperature, Tsk = skin temperature, Tb = body temperature, Tes = esophageal temperature, HR = heart rate, TC = thermal comfort, TS = thermal strain, FBF = forearm blood flow, RPE = rate of percvied exertion

Appendix B- Information Sheet for Participants- This information sheet was presented to each participant prior to agreeing to take part in the study.

Information Sheet For Participants

"Thermoregulatory and Psychophysical Responses of Pre-cooling the Torso During Steady State and Self-Paced Rowing Performance"

Thank you for showing an interest in this project. Please read this information sheet carefully before deciding whether or not to participate. If you have any questions, please, do not hesitate to ask. If you decide to participate we thank you. If you decide not to take part there will be no disadvantage to you of any kind and we thank you for considering our request.

What is the aim of this study?
This project is being undertaken as part of the requirements for a Masters degree at the School of Physical Education, University of Victoria. This research is being funded by the Natural Science and Engineering Research Counsel (NSERC), the Michael Smith Foundation for Health Research (MSFHR) and the University of Victoria.

This study is investigating the changes that occur in core temperature, perception and performance when you are exercising in excessively hot humid conditions. Normally, when the body becomes too hot, the brain activates defence mechanisms in an attempt to keep cool. Examples of this include an increase in sweat rate, change in exercise intensity or cessation of exercise.
Exercising in a thermo-stressful environment is a challenged regularly faced by athletes. A prime example is the upcoming Summer Olympics in Athens, Greece, where daily high temperatures are between 36°C and 40°C and humidity can be anywhere from 22 to 57%. One potential method of dealing with the increase in heat strain is by lowering core body temperature prior to exercise though pre-cooling.
Pre-cooling has been shown to improve performance by decreasing thermal and cardiovascular strain as measured by a decrease in core temperature, cardiac frequency and skin temperature. However, the practical application of pre-cooling is yet to be fully assessed and definite strategies have not been established. In addition, there is also the possibility that pre-cooling may have a negative effect on performance because you are cooling the active muscles.

The aim of this project is to determine the thermoregulatory and psychophysical effect of selectively cooling the torso during steady state rowing. The effects of torso cooling on pace selection and performance will also assessed during a 1500 m time trial on a rowing ergometer.

What type of Participants are being sought?
We are seeking male and female national team rowers (aged between 18 and 40).You are being asked to participate in this study because you are a member of the National Rowing Team's elite pool.

Should you agree to take part in this project, you will be asked to....

Participate in an initial screening session which will include
Determining your height, weight, body composition through skin-fold protocol, heart rate and blood pressure.

Performing a sub-maximal exercise test on a rowing ergometer to determine lactate threshold. This is a progressive incremental submaximal test. Each stage is five minutes long, followed by 1 minute rest. Wattages are increased each stage. Wattages used are determined by your category and gender (i.e. lightweight or heavyweight, male or female). Lactate samples are taken from the finger tip after each stage and 3 minutes following the end of the test. Blood samples will be obtained via finger prick under sterile conditions during the recovery period and analyzed for blood lactate (1 hour).
Completing a familiarisation session to become accommodated to rowing on the ergometer while wearing the thermoregulatory equipment. This session will involve rowing at easy pace on an ergometer for at least 10 min.

Be available for three testing sessions (3 hours each), each separated by one week.

Each testing session will involve a rest period where you remain seated for 45 minutes, followed by a 30 min row on the ergometer at an easy pace. Immediately upon completing the 30 minutes row you will be instructed to complete as a 1500 m time trial as fast as possible. You will be required to adjust the stroke rate and power yourself, but will have to rely on subjective pace judgment, as the display screen of the ergometer will be covered.
The three sessions will be identical in nature except for the manner in which the torso is cooled. The three conditions are as follows:
a) No pre cooling of the torso during the 45 minute rest period or during exercise.
b) Pre cooling the torso using an ice vest during the 45 minute rest period during 30 minutes of steady state exercise.
c) Pre cooling the torso using a CardioCool vest and 5ºC water during the 45 minute rest period during 30 minutes of steady state exercise.

Pre-cooling will involve selectively cooling the torso during the 45 minute rest period and steady state row, but not during the 1500 m self-paced trial. Cooling is achieved via ice or cold water flowing through a specially designed vest.

During each session heart rate, sweat rate, core temperature, skin temperature, thermal comfort, thermal strain and rate of perceived exertion will be determined.

During all sessions (except the lactate threshold test, which will be carried out under standard laboratory conditions) the temperature and relative humidity of the environmental chamber will be set at 35ºC and 55% respectively. The temperature and relative humidity of the environmental chamber will be monitored continuously.

Risks and Benefits

Although unlikely, there is a small chance of minor infection due to the finger prick protocol during the lactate threshold testing. However, this is remote since sterile techniques will be adhered to throughout testing.
When exercising in a hot environment there is a risk of heat injury. It is important that we continuously monitor your core temperature to ensure you don't overheat. The test will be stopped immediately if any core temperature measurement exceeds 39.5ºC. Core temperature will be monitored using a rectal thermistor inserted in the anal canal to a depth of 10 cm. You will be required to insert the rectal thermistor yourself and then remove it at the end of the session. The rectal thermistor is a standard procedure for measuring core temperature. The thermistors are sterile and disposable and are not shared between participants. There may be some discomfort associated with the use of the thermistors but feel free to ask any questions related to their use.

Please be aware that you may decide not to take part in the project without any disadvantage to yourself of any kind.

Your participation in this research is expanding the pool of knowledge in the area of thermoregulation. The results of this study will be used in preparation for the coaches and rowers attending the upcoming Summer Olympic Games in Athens, Greece, and in future competitions that take place in hot humid environments.

What Data or Information will be Collected and What Use will be Made of it?

Name, address, and phone number: For contact reasons.
Age and training history: For statistical purposes.
Body weight: Before and after exercise body weight will be recorded to determine fluid losses during the testing session.
Heart rate, core temperature, skin temperature, sweat rate, thermal comfort, and oxygen consumption will be recorded to determine if aerobic fitness affects muscle function
Anonymity and Confidentiality
Your anonymity in this project is only partial since the investigators and other participants will know of your participation. All data obtained will be used solely for the purpose of analysing the group effects pre-cooling during exercise in the heat.
Results of this project may be published, but any data included will not be linked to a specific participant. Your data will be assigned a personal identification number to ensure anonymity in both the analysis and documentation of results. The data collected and the coded identifications will be securely stored in separate locked cabinets in such a way that only the principle investigators will be able to gain access to it. The data obtained in this study will only be available to Elizabeth Johnson, Dr Howie Wenger and Dr Gordon Sleivert. The results of this study will be used by the National Rowing Team coaches in preparation for the upcoming Summer Olympics in Athens, Greece.
At the end of the project any personal information will be destroyed immediately except that, as required by the University of Victoria's research policy, any raw data on which the results of this project depend will be retained in secure storage for five years, after which it will be destroyed.

Can Participants Change their Mind and Withdraw from the Project?

Your participation in this research is completely voluntary. If you do decide to participate, you may withdraw at any time without any consequences or any explanation. If you do withdraw from the study your data will be excluded from the analysis.

What if Participants have questions?

This study is being conducted by Elizabeth Johnson, under the supervision of Dr. Howie Wenger, and Dr. Gordon Sleivert. Please feel free to contact us at any time with questions and concerns you may have about participating in this research study.

Elizabeth Johnson
Master of Science Candidate
School of Physical Education
University email: earj@uvic.ca

or

Dr Gordon Sleivert
Director of Sport and Medical Research
PacificSport, Victoria
Email: gsleivert@pacificsport.com

Dr Howie Wenger
School of Physical Education
University of Victoria
Email: hwenger@uvic.ca

If you wish to contact an independent person regarding any aspect of your participation in this study please contact:
Dr. Doug Nichols, Director, School of Physical Education, UVic
Phone: 721-8376 or email dnichols@uvic.ca

Or you may verify the ethical approval of this study, or raise any concerns you might have, by contacting the Associate Vice-President, Research (250)-472-4362

Appendix C- Informed Consent Form- this sheet was completed by each participant prior to beginning the study to ensure that each individual understood their personal rights when participating in the study.

"Thermoregulatory and Psychophysical Effects of Pre-cooling the Torso during Steady State and Self-Paced Rowing Performance"

I have read the Information Sheet concerning this project and understand what it is about. All my questions have been answered to my satisfaction. I understand that I am free to request further information at any stage.

I know that:

1. my participation in the project is entirely voluntary;
2. I am free to withdraw from the project at any time without any disadvantage;
3. the data will be destroyed at the conclusion of the project but any raw data on which the results of the project depend will be retained in secure storage for five years, after which it will be destroyed;
4. there are risks associated with my participation in the study. All my questions regarding the risks have been answered to my satisfaction.
5. the results of the project may be published but my anonymity will be preserved.

I agree to take part in this project.

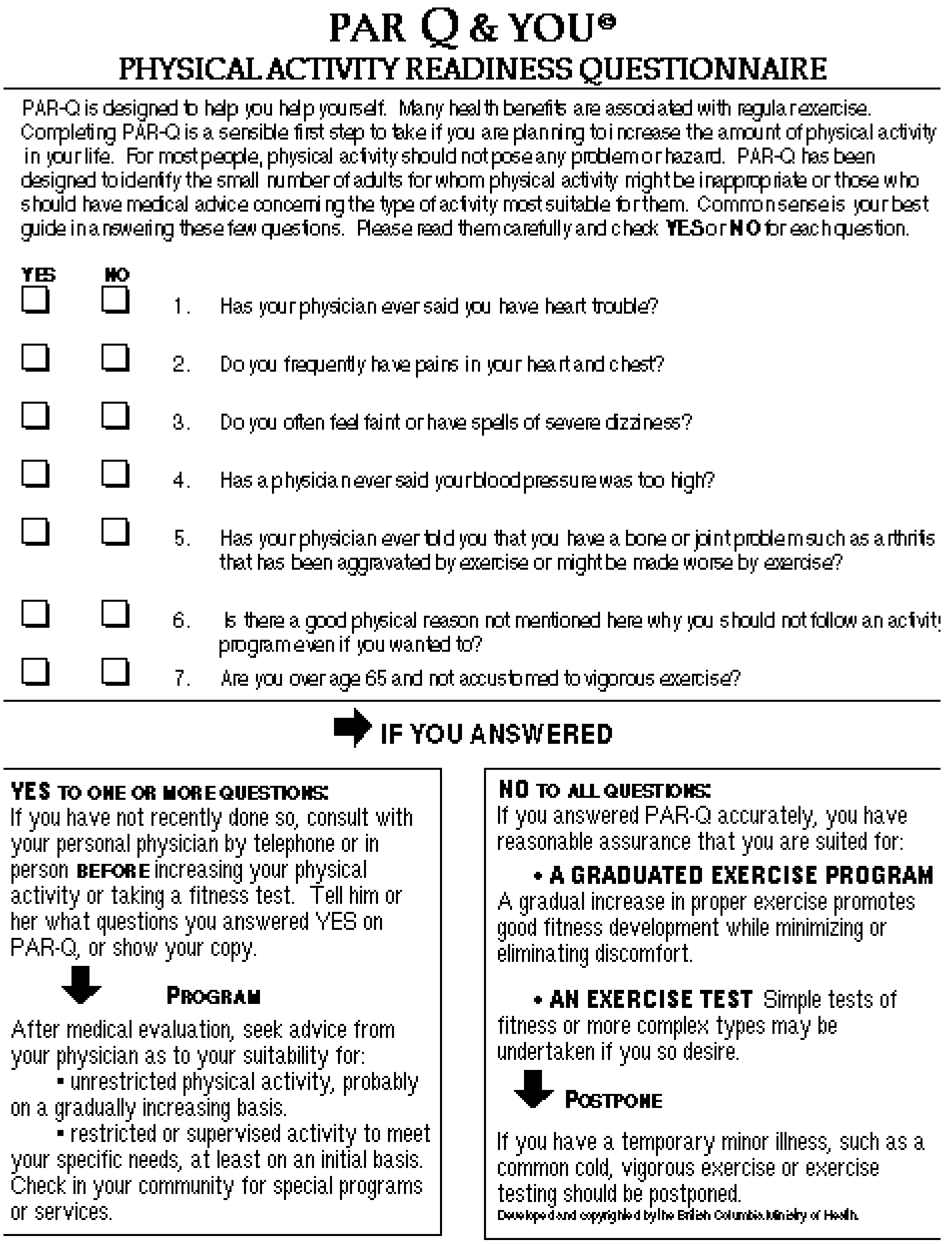
....
(Signature of participant) (Date)

....
(Witness) (Date)

This project has been reviewed and approved by the Ethics Committee of the University of Victoria

University of Victoria
British Columbia • Canada

Appendix D- Physical Activity Readiness Questionnaire (PAR-Q) - used determine whether an individual is able to participate in vigorous exercise, or a physically demanding experiment.



PAR Q & YOU©

PHYSICAL ACTIVITY READINESS QUESTIONNAIRE

PAR-Q is designed to help you help yourself. Many health benefits are associated with regular exercise. Completing PAR-Q is a sensible first step to take if you are planning to increase the amount of physical activity in your life. For most people, physical activity should not pose any problem or hazard. PAR-Q has been designed to identify the small number of adults for whom physical activity might be inappropriate or those who should have medical advice concerning the type of activity most suitable for them. Common sense is your best guide in answering these few questions. Please read them carefully and check **YES** or **NO** for each question.

YES **NO**

☐ ☐ 1. Has your physician ever said you have heart trouble?

☐ ☐ 2. Do you frequently have pains in your heart and chest?

☐ ☐ 3. Do you often feel faint or have spells of severe dizziness?

☐ ☐ 4. Has a physician ever said your blood pressure was too high?

☐ ☐ 5. Has your physician ever told you that you have a bone or joint problem such as arthritis that has been aggravated by exercise or might be made worse by exercise?

☐ ☐ 6. Is there a good physical reason not mentioned here why you should not follow an activit program even if you wanted to?

☐ ☐ 7. Are you over age 65 and not accustomed to vigorous exercise?

➡ IF YOU ANSWERED

YES TO ONE OR MORE QUESTIONS:
If you have not recently done so, consult with your personal physician by telephone or in person **BEFORE** increasing your physical activity or taking a fitness test. Tell him or her what questions you answered YES on PAR-Q, or show your copy.

⬇ **PROGRAM**

After medical evaluation, seek advice from your physician as to your suitability for:

- unrestricted physical activity, probably on a gradually increasing basis.
- restricted or supervised activity to meet your specific needs, at least on an initial basis. Check in your community for special programs or services.

NO TO ALL QUESTIONS:
If you answered PAR-Q accurately, you have reasonable assurance that you are suited for:

- **A GRADUATED EXERCISE PROGRAM** A gradual increase in proper exercise promotes good fitness development while minimizing or eliminating discomfort.
- **AN EXERCISE TEST** Simple tests of fitness or more complex types may be undertaken if you so desire.

⬇ **POSTPONE**

If you have a temporary minor illness, such as a common cold, vigorous exercise or exercise testing should be postponed.

Developed and copyrighted by the British Columbia Ministry of Health.

Appendix E- Rating of Perceived Exertion Scale- a psychophysical tool used to give an indication about how hard a participant is working at a given point throughout the experimental protocol.

Ratings of Perceived Exertion

0	Nothing at all
0.5	Very, very weak
1	Very weak
2	Weak
3	Moderate
4	Somewhat difficult
5	Strong
6	
7	Very difficult
8	
9	
10	Very, very difficult (maximal)

From (Borg, 1982)

Appendix F- Rating of Thermal Sensation Scale- a psychophysical tool used to give an indication about how a subject is feeling at a given point throughout the experimental protocol. This tool emphasizes *the feeling/sensation* one is experiencing in the thermal environment.

Thermal Sensation

0	Unbearably cold
1	Very cold
2	Cold
3	Cool
4	Slightly cool
5	Neutral
6	Slightly warm
7	Warm
8	Hot
9	Very Hot

From Gagge et al., (1967)

Appendix G- Rating of Thermal Comfort Scale- a psychophysical tool used to give an indication about how a subject is feeling at a given point throughout the experimental protocol. This tool emphasizes *how comfortable* one feels in the thermal environment.

Thermal Comfort Scale

1	Comfortable
1.5	
2	Slightly Uncomfortable
2.5	
3	Uncomfortable
3.5	
4	Very Uncomfortable
4.5	
5	Extremely Uncomfortable

From Gagge et al., (1967)

Appendix H - Letter to participants for lactate testing

Hello ________,

Just wanted to remind you about your upcoming testing session on ________.

There are a few things that you should know before you come in. The training and nutritional regimens in the two days immediately prior to the testing session can have an impact on your results.

- Please follow the following suggestions.
    - **Maintain a high carbohydrate diet.** Try to emphasize such things as pasta, rice, bread, and potatoes in your meals.
    - **Do not consume caffeinated beverages** in the 90 minute period before your test. If you have a morning test and need a cup of coffee make sure you are awake early enough to have it. Avoid higher intensity training
    - **Avoid hard workouts and strength training** the day before and the day of the testing. Both use carbohydrates as their major fuel source. Please come to the testing session well rested and ready to give your best performance.
    - **Avoid alcohol.** Alcohol interferes with glycogen storage, so do not drink the evening before the test.
    - **Come well hydrated**. Your hydration level has a large effect on your ability to perform in the heat. Please drink at least 500ml (2cups) of water the evening before the test and another 500ml in the morning when you get up.
    - **If you could keep a brief record of what you ate and drank the day before the test as well as what training you did it would be very helpful so we could replicate it for the future two trials**.

    - Please bring a small towel for sweat.
    - Please wear shorts and a cotton t-shirt

If you have any other questions please do not hesitate to e-mail me and I will get back to you as soon as I can.

One final thing, Pacific Sport would like to come in during your testing session to take some photos/video for an in house informational thing. Would this be ok with you? Please let me know if you have any problems with it.

The results of your lactate tests will be available when you come in for testing.

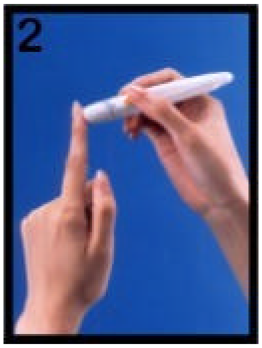
Thanks for you help and I hope you have a great weekend out in the sunshine!

Cheers,
Liz

Appendix I - Protocol and wattages for lactate testing

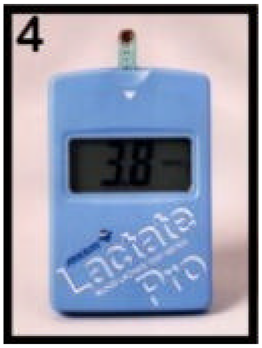
Stage	LW men	LW women	HW men	HW women
Drag factor	160	140	180	150
Warm-up	180	140	250	160
1	190	(140)	260	(160)
2	230	170	295	190
3	270	200	330	220
4	310	230	365	250
5	350	260	400	280

Insert the test strip into the strip inlet of the meter.



Collection of the blood.

Blood is automatically aspirated and measurement begins.



The measurement result is displayed in 60 seconds.

Appendix J – Warm-up protocol

Warm-up protocol

Drag factor = 120

10 minutes steady state @ 40 watts below lactate threshold

10 strokes @ 24 stroke rate

1 min rest

10 strokes @ 26 stroke rate

1 min rest

10 strokes @ 28 stroke rate

1 min rest

15 strokes @ race pace

1 min rest

15 strokes @ race pace

1 min rest

10 strokes @ over pace

1 min rest

1 min start piece

Remainder steady state @ 40 watts below lactate threshold

Appendix K – Raw Data

Heart rate – control condition (HRC) during rest (R), warm-up (W) and time trial (TT) in beats per minute. Numbers indicate time (minutes) when data was collected.

subject #	HRCR0	HRCR2	HRCR5	HRCR10	HRCR15	HRCR20	HRCR30	HRCR40	HRCR45
1	75	72	60	60	58	62	68	65	71
2	87	59	43	56	57	70	51	68	56
3	73	81	72	74	72	74	80	79	80
4	83	74	69	73	75	78	76	82	78
5	73	48	60	59	57	57	50	53	53
6	59	57	52	56	51	57	49	46	50
7	80	71	63	66	70	65	70	70	62
8	92	70	77	73	83	81	79	81	83
mean	77.75	66.5	62	64.625	65.375	68	65.375	68	66.625
sd	10.18051	10.81005	10.9805	7.854707	11.14755	9.227289	13.37308	13.13664	13.04867

HRCW2	HRCW5	HRCW10	HRCW25	HRCW30	HRCTT0	HRCTT500	HRCTT1000	HRCTT1500
101	164	175	179	189	136	187	200	204
157	163	169	174	185	126	192	200	200
136	150	157	158	173	135	182	188	192
151	135	179	164.71429	176.33333	138	196	199	200
142	150	158	169	175				
129	131	142	155	166	119	184	191	199
134	146	159	158					
146	154	160	160	170	131	169	180	188
137	149.125	162.375	164.71429	176.33333	130.8333	185	193	197.1666667
17.204651	11.813279	11.710038	8.5809471	8.1171971	7.194906	9.38083152	8.148619515	5.946988033

Heart rate – vest condition (HRV) during rest (R), warm-up (W) and time trial (TT) in beats per minute. Numbers indicate time (minutes) when data was collected.

subject #	HRVR0	HRVR2	HRVR5	HRVR10	HRVR15	HRVR20	HRVR30	HRVR40	HRVR45
1	73	84	69	73	69	71	71	68	75
2	77	66	60	59	77	62	64	70	72
3	65	71	67	61	58	66	68	63	63
4	71	69	70	75	78	70	68	74	74
5	62	56	51	57	50	49	47	53	57
6	72	54	54	52	65	59	53	62	70
7	77	63	62	62	65	63	60	57	64
8	85	67	72	76	74	71	73	62	61
mean	72.75	66.25	63.125	64.375	67	63.875	63	63.625	67
sd	7.225945	9.346504	7.717096	9.070163	9.651055	7.491662	9.10259	6.864765	6.63325

HRVW2	HRVW5	HRVW10	HRVW25	HRVW30	HRVTT0	HRVTT500	HRVTT1000	HRVTT1500
140	138	163	175	181	126	195	200	205
149	170	178	164	179	121	191	204	208
139	145	159			115	188	193	196
149	157	171	165	181	130	191	196	201
143	144	146	155	158	112	181	187	191
137	137	147	157	166	117	186	193	198
120	137	144	138	156	109	166	177	186
145	154	159	164	169	132	176	185	188
140.25	147.75	158.375	159.71429	170	120.25	184.25	191.875	196.625
9.3005376	11.756457	12.281665	11.542881	10.645813	8.447316	9.5281538	8.65922299	7.92712342

Heart rate – LCG condition (HRL) during rest (R), warm-up (W) and time trial (TT) in beats per minute. Numbers indicate time (minutes) when data was collected.

subject #	**HRLR0**	**HRLR2**	**HRLR5**	**HRLR10**	**HRLR15**	**HRLR20**	**HRLR30**	**HRLR40**	**HRLR45**
1	82	65	70	71	65	63	66	66	72
2	70	59	57	59	52	62	60	51	81
3	71	76	75	68	74	73	74	63	79
4	90	78	70	74	75	73	67	65	70
5	80	57	52	56	54	51	49	54	61
6	57	63	57	61	49	42	47	43	50
7	79	74	73	74	74	75	79	69	73
8	75	67	71	69	71	66	55	69	62
	75.5	67.375	65.625	66.5	64.25	63.125	62.125	60	68.5
	9.841603	7.872874	8.814558	6.948792	10.95119	11.58123	11.46968	9.546877	10.29563

HRLW2	**HRLW5**	**HRLW10**	**HRLW25**	**HRLW30**	**HRLTT0**	**HRLTT500**	**HRLTT1000**	**HRLTT1500**
149	154	164	174	181	129	194	203	205
159	167	176	179	185	134	194	199	204
138	146		156	165	113	182	190	196
134	151	166	173	180	110	184	195	203
141	142	148	159	162	115	180	187	192
129	134	142	148	156	98	185	190	195
142	154	163	157	168	113	168	180	186
138	144	151						
141.25	149	158.57143	163.71429	171	116	183.85714	192	197.285714
9.2543426	9.8994949	11.914377	11.542881	11.015141	12.05543	8.914942	7.70281334	7.06433025

Bicep temperature – control condition (BTC) during rest (R), warm-up (W) and time trial (TT) in degrees Celsius. Numbers indicate time (minutes) when data was collected.

subject #	BTCR0	BTCR2	BTCR5	BTCR10	BTCR15	BTCR20	BTCR30	BTCR40	BTCR45
1	34.21	35.24	35.62	35.97	36.19	36.37	36.7	36.9	36.9
2	33.55	34.97	35.42	35.64	35.64	35.84	36.15	36.1	36.1
3	33.31	34.53	35.05	35.49	35.84	35.99	36.04	36.42	36.44
4	35.22	37.62	37.72	37.98	38.19	37.83	38.27	38.29	38.29
5	34.99	35.82	36.17	36.6	36.62	36.65	36.8	36.44	36.65
6	34.7	35.52	35.77	36.3	36.4	36.62	37.57	37.59	37.59
7	34.89	36.24	36.39	36.7	36.77	36.85	36.9	37.03	36.95
8	35.09			36.2	36.32	36.45	36.73	36.88	37.16
	34.495	35.70571	36.02	36.36	36.49625	36.575	36.895	36.95625	37.01
	0.727147	1.011432	0.873002	0.779579	0.779834	0.609262	0.727677	0.705305	0.686149

BTCW2	BTCW5	BTCW10	BTCW15	BTCW25	BTCW30	BTCTT0	BTCTT500	BTCTT1000	BTCTT1500
37.41	39.98	37.67	38.13	39.18	39.47	41.58	40.14	40.3	40.76
36.2	36.3	36.17	36.65	37.39	38.08	37.65	37.34	37.59	38.01
36.22	35.74	35.39	35.42	35.44	36.29	37.05	38.97	39.15	39.13
37.88	38.1	38.27	38.24	37.52	38.55	39.13	38.55	38.89	38.89
36.37	35.79	36.29	36.47	36.98	37.36				
37.62	37.65	38.03	37.18	38.4	39	38.66	38.87	38.84	38.84
37.16	36.82	37.56	37	37.26	38	38.05			
37.72	37.72	38.14	38.71	38.27	38.79	39.24	38.58	38.66	38.66
37.0725	37.2625	37.19	37.225	37.555	38.1925	38.76571	38.741667	38.905	39.0483333
0.7044907	1.4169459	1.0844485	1.0866594	1.1202806	1.0093244	1.471381	0.9001648	0.87175111	0.92020469

Biceps temperature –vest condition (BTV) during rest (R), warm-up (W) and time trial (TT) in degrees Celsius. Numbers indicate time (minutes) when data was collected.

subject #	**BTVR0**	**BTVR2**	**BTVR5**	**BTVR10**	**BTVR15**	**BTVR20**	**BTVR30**	**BTVR40**	**BTVR45**
1	31.8	33.34	33.77	34.36	34.75	35.1	35.84	36.29	36.62
2	34.43	35.6	36.02	36.25	36.42	36.55	36.85	36.88	36.75
3	34.16	36.5	36.55	36.55	36.65	36.57	37	37.1	37.26
4	33.67	34.21	34.8	35.32	35.74	35.87	35.99	36.3	36.4
5	37	36.57	36.82	37.31	37.18	37.41	37.69	37.74	37.85
6	34.55	36.95	36.95	36.25	36.8	36.5	37.06	36.95	37.47
7	34.79	35.94	36.24	36.42	36.7	37	37	37.05	37.08
8	33.82	35.25	35.69	36.37	36.22	36.55	36.9	37.16	37.26
mean	34.2775	35.545	35.855	36.10375	36.3075	36.44375	36.79125	36.93375	37.08625
sd	1.439362	1.24367	1.087343	0.88824	0.760014	0.698937	0.601105	0.472318	0.476953

BTVW2	**BTVW5**	**BTVW10**	**BTVW15**	**VTVW25**	**BTVW30**	**BTVTT0**	**BTVTT500**	**BTVTT1000**	**BTVTT1500**
37.02			37.07	37.46	37.38	37.05	37.49	37.39	37.77
36.98	36.95	36.78	36.5	36.47	37.06	38.55	37.39	38.01	38.61
38.5	39.98	39.82	39.07	38.81	39.84	40.14	38.55	38.52	36.8
36.57	36.35	36.75	36.9	37.49	37.62	37.77	37.36	37.44	37.47
38.13	36.6	36.12	36.02	36.24	36.5	37.21	35.97	36.17	36.65
38.29	37.11	36.52	36.85	37.03	37.85	38.14	37.52	37.77	37.88
37.26	37.28	37.23	37	36.85	37.21	36.67	36.29	36.5	36.39
37.47	36.95	36.9	37.67	37.98	38.27	38.37	38.32	38.55	38.63
37.5275	37.317143	37.16	37.135	37.29125	37.71625	37.9875	37.36125	37.54375	37.525
0.7009331	1.2147937	1.2214609	0.9130639	0.835933	1.0087749	1.094516	0.8830214	0.86562838	0.85913578

Biceps temperature –LCG condition (BTL) during rest (R), warm-up (W) and time trial (TT) in degrees Celsius. Numbers indicate time (minutes) when data was collected.

subject #	**BTLR0**	**BTLR2**	**BTLR5**	**BTLR10**	**BTLR15**	**BTLR20**	**BTLR30**	**BTLR40**	**BTLR45**
1	32.11	34.31	34.85	35.39	35.74	36.04	36.44	36.55	36.75
2	34.26	35.15	35.4	35.64	35.77	36.12	36.4	36.59	36.64
3	33.67	35.61	35.61	35.84	35.94	36.14	36.17	35.92	36.42
4	33.6	34.9	34.92	35.64	35.5	35.92	36.17	36.68	36.62
5	39.81	41.97	41.88	42.08	41.22	39.82	38.21	38.05	38.08
6	34.94	36.1	36.25	36.15	36.15	36.4	36.8	36.85	36.57
7	35.86		41.94	39.84	38.18	37.69	37.72	37.87	37.77
8	34.53	35.35	35.32	35.89	36.1	36.45	36.62	36.7	36.78
mean	34.8475	36.19857	37.02125	37.05875	36.825	36.8225	36.81625	36.90125	36.95375
sd	2.284818	2.605702	3.048191	2.491009	1.962593	1.333146	0.751017	0.710461	0.615094

BTLW2	**BTLW5**	**BTLW10**	**BTLW15**	**BTLW25**	**BTLW30**	**BTLTT0**	**BTLTT500**	**BTLTT1000**	**BTLTT1500**
37.31	37.82	37.41	36.9	36.95	37.31	37.46			
36.77	37.1	37.67	37.03	38.39	38.7	39.02	38.66	39.1	38.95
37.03	37.1	36.19	35.07	36.44	36.37	36.04	34.63	34.55	35.29
37.36	36.95	39.08	35.74	35.35	36.27	36.8	37.67	37.93	38.11
44.03	42.27	40.98	40.49	40.19	40.76	41.55	41.52	41.83	41.61
37.34	37.21	36.98	36.47	37.11	37.57	37.24	37.77	37.88	38.53
42.1	44.73	42.36	41	39.6	40.84	39.34	39.84	40.41	40.49
36.9	36.8	36.75	36.78						
38.605	38.7475	38.4275	37.435	37.718571	38.26	38.20714	38.348333	38.6166667	38.83
2.8088584	3.0207556	2.2016341	2.1487205	1.7466389	1.9153242	1.883655	2.3238883	2.50308343	2.17432288

Chest temperature – control condition (CTC) during rest (R), warm-up (W) and time trial (TT) in degrees Celsius. Numbers indicate time (minutes) when data was collected.

subject #	CTCR0	CTCR2	CTCR5	CTCR10	CTCR15	CTCR20	CTCR30	CTCR40	CTCR45
1	33.14	33.36	33.82	34.46	34.97	35.37	36.05	36.52	36.73
2	33.24	34.24	34.7	35.4	35.77	36.02	36.37	36.42	36.5
3	33.62	34.21	34.65	35.1	35.42	35.77	36.1	36.32	36.37
4	33.31	33.99	34.41	35	35.25	35.45	36.12	36.15	36.22
5	34.7	34.53	34.56	34.9	35.15	35.37	35.64	36.1	36.17
6	34.11	33.78	33.92	34.31	35	35.45	36.15	36.3	36.3
7	34.82	35.82	36.17	36.37	36.5	36.57	36.68	36.73	36.85
8	33.7			35.02	35.4	35.52	35.77	35.89	35.97
mean	33.83	34.27571	34.60429	35.07	35.4325	35.69	36.11	36.30375	36.38875
sd	0.651482	0.77685	0.773064	0.63085	0.502671	0.420646	0.323905	0.261476	0.293133

CTCW2	CTCW5	CTCW10	CTCW15	CTCW25	CTCW30	CTCTT0	CTCTT500	CTCTT1000	CTCTT1500
36.93	36.95	37.21	37.26	37.16	37.54	37.57	36.17	36	35.87
36.07	36.62	37.06	37.39	37.67	38.06	38.06	36.47	36.45	36.35
36.37	34.12	35	36.05	36.65	36.9	39.47	32.57	36.68	36.62
35.97	36.5	36.6	36.35	36.2	34.75	37.01	36.8	36.57	36.4
36.55	36.95	37.36	38.32	38.24	38.5				
36.22	36.57	36.98	37.06	37.88	38.14	38.14	37.18	37.44	36.95
36.78	37.47	37.98	38.03	38.29	38.39	38.29			
36.1	36.35	37.21	37.72	37.85	38.01	38.42	37.36	37.21	37.16
36.37375	36.44125	36.925	37.2725	37.4925	37.53625	38.13714	36.091667	36.725	36.5583333
0.350385	1.0017476	0.8699097	0.7815689	0.7554705	1.2357177	0.761352	1.7802406	0.524166	0.46075662

Chest temperature – vest condition (CTV) during rest (R), warm-up (W) and time trial (TT) in degrees Celsius. Numbers indicate time (minutes) when data was collected.

subject #	**CTVR0**	**CTVR2**	**CTVR5**	**CTVR10**	**CTVR15**	**CTVR20**	**CTVR30**	**CTVR40**	**CVR45**
1	32.33	31.29	30.42	25.39	22	18.72	18.91	18.86	22.77
2	34.04	32.02	30.96	30.73	30.03	28.23	27.48	26.11	26.29
3	34.28	26.6	24.08	20.88	19.5	20.4	21.34	22.14	23.21
4	34.7	31.43	31.76	31.81	32.09	32.52	32.71	26.51	28.48
5	35.22	32.4	31.67	31.05	29.84	28.21	27.32	27.1	27.35
6	35.32	32.33	30.21	27.44	27.66	28.26	26.33	24.1	26.24
7	34.4	27.12	28.42	27.37	26.87	24.1	18.23	22.86	22.73
8	32.71	22.27	24.1	25.46	20.6	23.92	24.23	23.83	24.63
mean	34.125	29.4325	28.9525	27.51625	26.07375	25.545	24.56875	23.93875	25.2125
sd	1.08817	3.703457	3.175877	3.665827	4.765255	4.599901	4.901421	2.713719	2.201952

subject #	**CTVW2**	**CTVW5**	**CTVW10**	**CTVW15**	**CTVW25**	**CTVW30**	**CTVTT0**	**CTVTT500**	**CTVTT1000**	**CTVTT1500**
1	22.28	22.57	23.28	23.72	26.1	27.5	44.68	39.39	39.18	39.55
2	26.83	26.94	28.39	32.07	31.83	31.38	36.55	29.75	30.75	35.5
3	27.1	25.1	26.51	28.74	31.17	31.5	36.15	34.53	33.7	33.56
4	28.76	29.29	34.93	34.8	35.02	36.37	37.41	37.11	37.49	37.62
5	30.31	30.07	31.45	33.03	34.07	35.79	36.9	37.83	36.62	36.65
6	28.39	28.53	31.86	32.55	34.65	33.82	36.5	36.55	36.55	36.1
7	20.75	20.75	20.69	29.8	31.17	32.98	35.92	35.22	34.04	33.05
8	24.59	25.57	28.14	30.21	30.94	32.05	34.04	36.57	36.52	36.68
mean	26.12625	26.1025	28.15625	30.615	31.86875	32.67375	37.26875	35.86875	35.60625	36.08875
sd	3.3180499	3.271342	4.6711575	3.4036241	2.8693027	2.802784	3.15517	2.8882641	2.63881974	2.10322499

Chest temperature – LCG condition (CTL) during rest (R), warm-up (W) and time trial (TT) in degrees Celsius. Numbers indicate time (minutes) when data was collected.

subject #	**CTLR0**	**CTLR2**	**CTLR5**	**CTLR10**	**CTLR15**	**CTLR20**	**CTLR30**	**CTLR40**	**CTLR45**
1	32.83	32.81	32.24	31.55	31.2	30.91	30.63	30.49	30.31
2	32.85	31.76	30.89	31.15	30.8	30.26	29.98	29.03	28.68
3	33.43	34.02	34.01	31.79	31.41	30.54	27.05	25.88	25.79
4	32.71	30.12	29.47	26.78	25.17	26.29	21.85	23.7	22.03
5	35.89	34.26	33.46	32.64	32.48	32.14	31.83	31.95	30.87
6	34.36	33.19	31.27	28.69	28.12	28.44	28.14	26.6	25.97
7	35.27		34.51	33.36	32.43	31.93	31.01	30.56	29.91
8	31.71	31.62	28.28	26.11	25.66	25.17	23.77	22.71	22.91
mean	33.63125	32.54	31.76625	30.25875	29.65875	29.46	28.0325	27.615	27.05875
sd	1.421834	1.469433	2.207021	2.722113	2.949351	2.582513	3.609419	3.405034	3.404826

CTLW2	**CTLW5**	**CTLW10**	**CTLW15**	**CTLW25**	**CTLW30**	**CTLTT0**	**CTLTT500**	**CTLTT1000**	**CTLTT1500**
30.42	30.45	30.4	32.14	33.41	33.48	35.6	36.42	36.45	35.84
25.32	24.94	26.3	29.14	31.26	31.66	35.92	35.4	35.02	32.88
25.48	25.1	27.82	31.53	33.56	34.16	34.31	33.34	33.15	32.88
22.58	22.47	23.39	25.81	27.19	28.3	26.24	34.02	34.12	35.87
30.49	31.36	32.98	33.99	35.1	36.6	39.34	39.29	39.82	39.82
26.94	26.65	28.46	29.98	31.69	31.86	31.9	34.9	34.97	34.53
30.31	31.5	33.7	35.15	35.35	35.92	36.35	36.83	37.11	36.95
23.17	25.12	27.32	29.68						
26.83875	27.19875	28.79625	30.9275	32.508571	33.14	34.23714	35.742857	35.8057143	35.5385714
3.2506326	3.440878	3.4398253	2.949081	2.8054556	2.8316779	4.175615	1.9913372	2.21513624	2.43846556

Thigh temperature – control condition (TTC) during rest (R), warm-up (W) and time trial (TT) in degrees Celsius. Numbers indicate time (minutes) when data was collected.

subject #	**TTCR0**	**TTCR2**	**TTCR5**	**TTCR10**	**TTCR15**	**TTCR20**	**TTCR30**	**TTCR40**	**TTCR45**
1	32	33.99	34.46	35.12	35.45	35.55	36.05	36.35	36.25
2	31.03	32.09	32.64	33.68	34.26	35	35.1	35.55	35.74
3	32.85	33.44	34.21	34.73	35.45	35.62	35.25	35.64	35.92
4	33.79	34.41	34.8	35	35.4	35.45	36.07	35.74	36.05
5	35.09	36.12	36.6	36.93	37.16	37.24	37.36	37.41	37.59
6	33.62	35.3	35.74	36.2	36.1	36.35	36.42	36.52	36.55
7	33.09	34.7	35.35	36.12	36.3	36.6	36.78	36.93	36.95
8	33.07			35.99	36.25	36.3	36.57	36.75	36.85
mean	33.0675	34.29286	34.82857	35.47125	35.79625	36.01375	36.2	36.36125	36.4875
sd	1.210463	1.304092	1.261592	1.031814	0.859284	0.732704	0.757741	0.672319	0.620294

TTCW2	**TTCW5**	**TTCW10**	**TTCW15**	**TTCW25**	**TTCW30**	**TTCTT0**	**TTCTT500**	**TTCTT1000**	**TTCTT1500**
36.37	36.35	36.2	36.2	36.22	36.5	38.29	36.47	36.32	36.27
35.4	35.4	35.74	36.42	35.55	35.05	37.16	35.87	35.32	35.35
35.32	34.75	35.22	35.77	35.42	35.69	37.31	35.3	34.58	34.53
35.1	35.99	36.65	36.5	35.35	37.01	36.8	35.37	35.69	35.92
37.41	37.49	38.11	38.4	38.84	37.01				
36.1	36.3	36.85	37.18	37.62	37.98	37.47	37.18	37.31	36.02
36.7	36.8	36.37	35.52	36.57	36.62	36.7			
36.65	37.06	37.62	37.88	36.9	35.45	37.03	35.89	34.95	35.62
36.13125	36.2675	36.595	36.73375	36.55875	36.41375	37.25143	36.013333	35.695	35.6183333
0.8055245	0.8901324	0.9443214	1.0091996	1.2152065	0.9655929	0.531521	0.7110743	0.9937555	0.62184939

Thigh temperature – vest condition (TTV) during rest (R), warm-up (W) and time trial (TT) in degrees Celsius. Numbers indicate time (minutes) when data was collected.

subject #	**TTVR2**	**TTVR5**	**TTVR10**	**TTVR15**	**TTVR20**	**TTVR30**	**TTVR40**	**TTVR45**
1	33.87	34.41	34.95	35.35	35.47	36.2	36.44	36.39
2	33.92	34.41	34.95	35.27	35.5	35.92	36.17	36.2
3	34.93	35.2	35.5	35.77	35.84	36.32	36.65	36.85
4	34.12	34.8	35.12	35.6	35.74	36.02	36.15	36.3
5	36.02	36.37	37.11	37.29	37.54	37.57	37.7	37.88
6	35.55	36.02	36.65	36.83	36.93	37.13	37.31	37.49
7	34.14	34.8	35.77	35.74	36.15	36.5	36.75	36.9
8	32.43	33.56	34.53	34.93	35.1	35.82	35.82	36.12
mean	34.3725	34.94625	35.5725	35.8475	36.03375	36.435	36.62375	36.76625
sd	1.118669	0.909002	0.897278	0.806026	0.81801	0.616395	0.627465	0.642138

TTVW2	**TTVW5**	**TTVW10**	**TTVW15**	**TTVW25**	**TTVW30**	**TTVTT0**	**TTVTT500**	**TTVTT1000**	**TTVTT1500**
36.04	35.98	36.14	35.89	35.64	35.64	37.44	35.32	35.25	34.53
34.95	33.82	33.78	34.88	35.17	33.87	36.75	35.25	35.02	34.95
34.8	34.24	34.95	34.8	33.63	35.4	37.06	34.51	33.97	33.68
36.2	36.32	36.8	36.35	35.52	36.45	36.4	35.97	35.52	35.47
37.88	37.54	37.47	37.18	37.59	37.39	38.5	38.4	38.5	38.37
37.11	36.9	36.93	37.06	37.16	37.47	37.06	37.41	37.34	36.83
36.62	36.65	35.55	36.32	35.77	36.45	36.3	36.1	36.4	35.4
36.25	36.05	35.92	36.25	35.25	35.72	36.9	35.87	35.2	35
36.23125	35.9375	35.9425	36.09125	35.71625	36.04875	37.05125	36.10375	35.9	35.52875
1.0260665	1.2833077	1.1891624	0.8818234	1.2253738	1.1700969	0.692025	1.249845	1.44616735	1.4548386

Thigh temperature – LCG condition (TTL) during rest (R), warm-up (W) and time trial (TT) in degrees Celsius. Numbers indicate time (minutes) when data was collected.

subject #	**TTLR2**	**TTLR5**	**TTLR10**	**TTLR15**	**TTLR20**	**TTLR30**	**TTLR40**	**TTLR45**
1	33.87	34.56	35.45	35.77	36.15	36.6	36.9	36.88
2	33.82	34.29	34.78	35.22	35.4	35.87	36.04	36.14
3	35.35	35.34	36.4	36.55	36.7	36.88	37.16	36.35
4	34.04	33.92	34.51	34.83	35.57	36.52	36.85	36.9
5	35.45	35.74	35.82	36.25	36.5	36.15	37.06	37.13
6	35.69	36.22	36.45	36.3	36.83	36.95	37.39	37.49
7		36.52	36.98	37.21	37.29	37.47	37.57	37.7
8	33.68	33.7	33.75	34.31	34.8	35.17	35.64	35.77
mean	34.55714	35.03625	35.5175	35.805	36.155	36.45125	36.82625	36.795
sd	0.890837	1.069418	1.106239	0.963713	0.83736	0.713891	0.662073	0.666569

TTLW2	**TTLW5**	**TTLW10**	**TTLW15**	**TTLW25**	**TTLW30**	**TTLTT0**	**TTLTT500**	**TTLTT1000**	**TTLTT1500**
36.75	36.93	36.8	36.4	35.35	35.79	37.21	36	35.67	35.62
35.29	35.17	36.49	36.54	36.12	36.57	37.41	35.5	35.17	35.02
36.22	35.74	35.35	35.02	34.16	35.45	36.27	33.7	33.51	33.41
35.42	34.95	34.02	35.17	33.22	32.88	30	33.75	33.58	33.44
36.8	36.85	36.85	37.01	37.85	37.7	38.4	36.85	36.83	37.13
36.8	36.55	37.03	37.11	37.31	37.8	37.8	37.65	37.67	37.2
37.34	37.36	37.65	37.83	37.03	37.54	37.18	36.7	37.41	37.95
35.35	35.37	35.99	35.3						
36.24625	36.115	36.2725	36.2975	35.862857	36.247143	36.32429	35.735714	35.6914286	35.6814286
0.7986048	0.917263	1.1423628	1.0339902	1.7136094	1.7549902	2.863022	1.5301727	1.71530783	1.83373416

Calf temperature – control condition (CAC) during rest (R), warm-up (W) and time trial (TT) in degrees Celsius. Numbers indicate time (minutes) when data was collected.

subject #	**CACR0**	**CACR2**	**CACR5**	**CACR10**	**CACR15**	**CACR20**	**CACR30**	**CACR40**	**CACR45**
1	31	33.24	33.58	33.75	33.6	33.26	33.34	33.68	33.72
2	32.37	33.19	33.48	34.14	34.26	34.31	34.9	35	35
3	32.95	33.92	34.48	34.73	35.05	34.9	35.44	36.5	36.6
4	32.74857	33.835	34.24167	34.87429	35.03	35.06714	35.35571	35.71714	35.85714
5	34.01	34.55	35.05	35.34	35.64	36.14	36.5	37.03	37.33
6	33.65	34.43	34.8	35.12	35.45	35.69	35.79	35.84	35.89
7	31.68	33.68	34.06	35.62	35.79	35.77	36.12	36.62	37.21
8	33.58			35.42	35.42	35.4	35.4	35.35	35.25
	32.74857	33.835	34.24167	34.87429	35.03	35.06714	35.35571	35.71714	35.85714
	1.033599	0.527028	0.587776	0.649744	0.747988	0.926649	0.953338	1.066754	1.20849

CACW2	**CACW5**	**CACW10**	**CACW15**	**CACW25**	**CACW30**	**CACTT0**	**CACTT500**	**CACTT1000**	**CACTT1500**
34.55	38.71	38.31	37.18	37.36	37.16	39.44	36.8	36.37	36.6
34.8	34.7	34.7	33.92	34.21	35.02	35.35	35.22	34.9	34.65
36.19	35.94	35.82	36.22	36.5	35.89	38.26	35.27	32.16	34.14
35.411429	35.908571	35.752857	35.677143	35.937143	36.151429	37.24333	35.82	34.82	34.392
37.28	36.19	35.54	36.29	36.57	36.93				
33.34	33.53	33.92	34.26	35.12	35.64	36.4	35.94	35.37	34.9
36.37	36.42	37.08	36.57	36.7	37	37.13			
35.35	35.87	34.9	35.3	35.1	35.42	36.88	35.87	35.3	31.67
35.411429	35.908571	35.752857	35.677143	35.937143	36.151429	37.24333	35.82	34.82	34.392
1.220485	1.4788744	1.3910604	1.1316324	1.0471282	0.8007573	1.310199	0.5726779	1.41544339	1.59202261

Calf temperature –vest condition (CAV) during rest (R), warm-up (W) and time trial (TT) in degrees Celsius. Numbers indicate time (minutes) when data was collected.

subject #	CAVR2	CAVR5	CAVR10	CAVR15	CAVR20	CAVR30	CAVR40	CAVR45
1	34.14	34.8	35.42	35.05	34.8	34.78	35.07	35.54
2	33.19	33.63	33.9	33.95	34.21	34.43	34.61	34.78
3	32.45	32.52	32.78	32.81	32.76	33.65	34.53	34.43
4	33.17	33.63	34.02	34.46	34.26	34.46	34.58	34.95
5	34.55	34.78	35.05	35.24	35.57	36.04	36.5	36.7
6	34.8	34.9	35.15	35.3	35.35	35.37	35.5	35.55
7	34.11	34.24	35	35.02	35.29	35.42	35.59	35.69
8	33.85	34.34	34.95	35.1	35.17	35.45	35.94	35.97
	33.7825	34.105	34.53375	34.61625	34.67625	34.95	35.29	35.45125
	0.789733	0.811313	0.891515	0.859617	0.922046	0.762027	0.718451	0.721891

CAVW2	CAVW5	CAVW10	CAVW15	CAVW25	CAVW30	CAVTT0	CAVTT500	CAVTT1000	CAVTT1500
35.81	36.44	36.69	35.56	35.49	36.09	37.93	35.29	35.02	34.5
34.88	34.8	35.3	35	34.07	34.26	36.65	37.34	36.98	36.45
35.84	37.08	36.75	36.75	36.7	37.05	38.08	37.33	37	36.7
35.05	34.65	33.56	33.78	34.07	34.38	35.32	33.95	33.32	33.32
37.26	38.05	36.09	35.94	36.65	37.1	37.64	36.7	36.04	36.04
35.84	34.85	33.24	33.56	34.38	34.36	35.79	35.57	35.15	34.58
36.5	36.82	37.41	35.84	35.15	35.59	36.29	34.65	34.38	34.85
36.1	36.32	36.32	36.17	35.62	35.87	36.4	36.32	36.3	36.45
35.91	36.12625	35.67	35.325	35.26625	35.5875	36.7625	35.89375	35.52375	35.36125
0.7584759	1.2418182	1.5272384	1.1371141	1.056043	1.164103	1.018595	1.2410012	1.29433863	1.21912659

Calf temperature – LCG condition (CAL) during rest (R), warm-up (W) and time trial (TT) in degrees Celsius. Numbers indicate time (minutes) when data was collected.

subject #	CALR2	CALR5	CALR10	CALR15	CALR20	CALR30	CALR40	CALR45
1	33.85	34.48	35.1	35.32	35.37	35.49	35.72	35.92
2	33.7	34.04	34.26	34.38	34.46	35	35.14	35.27
3	35.12	35.14	34.9	34.9	35.05	34.82	35.12	35.12
4	33.92	33.99	34.51	34.7	34.9	35.12	35.69	35.69
5	35.74	36.04	36.62	36.95	37.05	37.1	37.36	37.46
6	35.27	35.64	35.94	36.2	36.37	36.5	36.32	36.45
7		34.78	35.87	36.27	36.27	37.26	37.31	37.44
8	34.36	34.31	34.21	33.8	33.95	33.92	33.87	34.16
	34.56571	34.8025	35.17625	35.315	35.4275	35.65125	35.81625	35.93875
	0.806554	0.749795	0.88222	1.074935	1.05382	1.184898	1.172506	1.144745

CALW2	CALW5	CALW10	CALW15	CALW25	CALW30	CALTT0	CALTT500	CALTT1000	CALTT1500
35.77	35.79	34.46	34.11	34.75	34.97	36.55	35.44	34.78	34.33
35.42	35.54	35.84	35.52	34.11	34.4	35.02	34.46	34.09	33.65
35.74	35.92	36.29	35.62	35.89	36.37	37	35.15	34.92	34.04
35.77	35.72	33.58	33.58	33.85	34.51	35.25	33.63	33.34	32.93
38.16	38.63	37.72	37.72	38.39	39.07	40.19	39.15	38.39	38
35.64	35.22	33.95	33.68	33.99	34.73	35.52	34.46	34.34	34.41
37.98	38.11	38.37	37.67	37.77	37.93	37.46	37.16	37.26	37.33
34.78	35.55	35.92	35.1						
36.1575	36.31	35.76625	35.375	35.535714	35.997143	36.71286	35.635714	35.3028571	34.9557143
1.2256398	1.2956851	1.7190025	1.630863	1.8772929	1.8592356	1.788218	1.9033029	1.82719014	1.92532125

Rectal temperature – control condition (RTC) during rest (R), warm-up (W) and time trial (TT) in degrees Celsius. Numbers indicate time (minutes) when data was collected.

subject #	RTCR0	RTCR2	RTCR5	RTCR10	RTCR15	RTCR20	RTCR30	RTCR40	RTCR45
1	36.69	36.81	36.86	36.86	36.86	36.86	36.92	36.98	37.03
2	37.09	36.98	36.86	36.81	36.75	36.86	36.98	37.03	37.03
3	37.09	37.15	37.09	37.03	36.98	36.36	36.92	36.92	36.98
4	37.37	37.38	37.38	37.26	37.21	37.15	37.09	37.09	37.09
5	37.37	37.49	37.49	37.44	37.44	37.44	37.44	37.44	37.44
6	37.66	37.67	37.61	37.61	37.55	37.49	37.49	37.49	37.49
7	37.32	37.38	37.38	37.26	37.21	37.21	37.26	37.44	37.38
8	37.26	37.26	37.38	37.38	37.38	37.38	37.32	37.26	37.32
	37.23125	37.265	37.25625	37.20625	37.1725	37.09375	37.1775	37.20625	37.22
	0.283823	0.278414	0.284702	0.283243	0.286144	0.382321	0.230822	0.230027	0.208258

RTCW2	RTCW5	RTCW10	RTCW15	RTCW25	RTCW30	RTCTT0	RTCTT500	RTCTT1000	RTCTT1500
37.03	37.21	37.61	38.02	37.96	38.32	38.8	38.5	38.5	38.38
37.21	37.44	37.96	38.2	38.92	39.35	39.35	39.35	39.54	39.79
36.98	37.15	37.38	37.49	37.73	38.2	38.32	38.38	38.5	38.62
37.15	36.75	35.17	36.64	38.08	38.26	38.32	38.38	38.56	38.56
37.49	37.61	37.84	38.2	39.1	39.6				
37.44	37.61	37.78	38.08	38.62	38.86	39.04	39.29	39.29	39.47
37.49	37.61	37.96	38.32	38.92	39.16	39.16			
37.38	37.44	37.73	38.08	38.74	38.74	39.29	39.29	39.29	39.35
37.27125	37.3525	37.42875	37.87875	38.50875	38.81125	38.89714	38.865	38.9466667	39.0283333
0.206151	0.3020289	0.9323463	0.559041	0.5134043	0.5291891	0.432925	0.4899286	0.47672494	0.58053137

Rectal temperature – vest condition (RTV) during rest (R), warm-up (W) and time trial (TT) in degrees Celsius. Numbers indicate time (minutes) when data was collected.

RTVR0	**RTVR2**	**RTVR5**	**RTVR10**	**RTVR15**	**RTVR20**	**RTVR30**	**RTVR40**	**RTVR45**
37.43	37.38	37.32	37.15	37.03	37.15	37.09	37.09	37.14
37.37	37.38	37.38	37.38	37.38	37.32	37.26	37.26	37.26
37.37	37.15	37.09	37.26	37.26	37.21	37.21	37.09	37.09
37.26	37.21	37.21	37.15	37.09	37.03	36.92	36.86	36.86
37.14	37.32	37.32	37.32	37.32	37.32	37.32	37.26	37.26
37.72	37.9	37.9	37.9	37.9	37.84	37.73	37.61	37.61
37.55	37.44	37.38	37.32	37.15	37.15	37.15	37.15	37.15
37.26	37.32	37.32	37.32	37.32	37.38	37.32	37.26	37.26
37.3875	37.3875	37.365	37.35	37.30625	37.3	37.25	37.1975	37.20375
0.182502	0.22758	0.236764	0.237306	0.269388	0.246345	0.234947	0.214193	0.211318

RTVW2	**RTVW5**	**RTVW10**	**RTVW15**	**RTVW25**	**RTVW30**	**RTVTT0**	**RTVTT500**	**RTVTT1000**	**RTVTT1500**
37.2	37.26	37.37	37.32	37.32	37.66	38.5	38.68	38.68	38.32
37.32	37.38	37.78	38.2	38.5	38.62	38.8	38.8	39	39.2
37.2	37.4	37.6	37.84	37.67	37.84	37.9	37.9	37.96	38.14
36.81	36.98	37.32	37.44	37.84	38.02	38.08	38.14	38.2	38.26
37.38	37.49	37.78	37.9	38.38	38.68	38.74	38.8	38.86	38.98
37.67	37.73	37.96	38.26	38.8	39.04	39.29	39.16	39.2	39.3
37.21	36.92	35.76	36.7	38.08	38.32	38.38	38.44	38.56	38.74
37.26	37.26	37.49	37.78	38.32	38.56	38.74	38.8	38.86	38.92
37.25625	37.3025	37.3825	37.68	38.11375	38.3425	38.55375	38.59	38.665	38.7325
0.2385035	0.2638587	0.691267	0.512473	0.4835268	0.4701899	0.44029	0.4082016	0.41386678	0.444257

Rectal temperature –LCG condition (RTL) during rest (R), warm-up (W) and time trial (TT) in degrees Celsius. Numbers indicate time (minutes) when data was collected.

RTLR0	**RTLR2**	**RTLR5**	**RTLR10**	**RTLR15**	**RTLR20**	**RTLR30**	**RTLR40**	**RTLR45**
37.6	37.49	37.44	37.32	37.32	37.26	37.21	37.26	37.26
37.26	37.15	37.15	37.03	37.09	37.15	37.21	37.14	37.03
37.09	37.15	37.14	37.09	37.09	37.04	37.03	37.03	36.98
36.8	36.81	36.8	36.75	36.7	36.7	36.81	36.86	36.86
37.49	37.49	37.49	37.49	37.49	37.44	37.38	37.38	37.38
37.66	37.67	37.67	37.61	37.55	37.55	37.55	37.49	37.44
37.49	37.49	37.49	37.38	37.38	37.38	37.44	37.32	37.32
36.06	36.92	36.92	36.92	36.92	36.98	36.92	36.86	36.86
37.18125	37.27125	37.2625	37.19875	37.1925	37.1875	37.19375	37.1675	37.14125
0.536162	0.308935	0.307048	0.297822	0.294121	0.278093	0.259612	0.235963	0.235702

RTLW2	**RTLW5**	**RTLW10**	**RTLW15**	**RTLW25**	**RTLW30**	**RTLTT0**	**RTLTT500**	**RTLTT1000**	**RTLTT1500**
37.21	37.32	37.61	37.78	38.26	38.38	38.44	38.44	38.5	38.56
37.14	37.2	37.6	37.6	37.6	38.01	38.92	39	39.2	39.47
37.03	37.21	37.3	37.5	37.7	37.9	37.9	37.96	38.08	38.14
36.86	37.03	37.38	37.55	37.84	38.08	38.14	38.02	38.08	38.26
37.49	37.49	37.73	37.9	38.44	38.7	39.1	39.1	39.16	39.35
37.49	37.49	37.67	37.84	38.32	38.74	38.68	38.77	39	39.1
37.5	37.8	38.2	38.45	38.92	39.35	39.4	39.5	39.5	39.6
36.92	36.98	37.15	37.32						
37.205	37.315	37.58	37.7425	38.154286	38.451429	38.65429	38.684286	38.7885714	38.9257143
0.2631132	0.2710298	0.3206244	0.344539	0.4688588	0.5155071	0.533131	0.573116	0.56942745	0.59938461

Skin temperature – control condition (SKTC) during rest (R), warm-up (W) and time trial (TT) in degrees Celsius. Numbers indicate time (minutes) when data was collected.

subject #	SKTCR0	SKTCR2	SKTCR5	SKTCR10	SKTCR15	SKTCR20	SKTCR30	SKTCR40	SKTCR45
1	32.805	34.026	34.44	34.903	35.158	35.284	35.703	36.032	36.083
2	0	0	0	0	0	0	0	0	0
3	33.239	34.094	34.648	35.069	35.478	35.632	35.78	36.25	36.347
4	35.195	36.405	36.611	36.874	37.054	36.984	38.117	38.482	38.731
5	0	0	0	0	0	0	0	0	0
6	0	0	0	0	0	0	0	0	0
7	33.867	35.294	35.65	36.269	36.399	36.5	36.654	36.838	36.972
8	33.967	0	0	35.648	35.85	35.931	36.144	36.251	36.359
mean	33.8146	34.95475	35.33725	35.7526	35.9878	36.0662	36.4796	36.7706	36.8984
sd	1.228863	1.486698	1.352093	1.094151	0.998027	0.923817	1.196077	1.303804	1.35599

SKTCW2	SKTCW5	SKTCW10	SKTCW15	SKTCW25	SKTCW30	SKTCTT0	SKTCTT500	SKTCTT1000	SKTCTT1500
36.486	38.091	37.366	37.293	#VALUE!	37.835	39.291	37.547	37.428	37.563
0	0	0	0	0	0	0	0	0	0
36.079	35.096	35.325	35.839	36.011	36.273	38.07	35.576	36.097	36.459
38.077	38.716	39.117	#VALUE!	0	38.724	39.576	38.817	38.902	38.921
0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0
36.796	36.931	37.352	36.927	37.319	37.641	37.668	0	0	0
36.546	36.807	37.109	37.565	37.236	37.214	38.08	37.134	36.811	36.204
36.7968	37.1282	37.2538	37.3001	36.918333	37.5374	38.537	37.2685	37.3095	37.28675
1.282217	1.873187	1.7979529	1.7998703	1.0304095	1.8548187	1.7398581	1.95886132	1.680860094	1.82561291

Skin temperature –vest condition (SKTV) during rest (R), warm-up (W) and time trial (TT) in degrees Celsius. Numbers indicate time (minutes) when data was collected.

subject #	TSKVR0	TSKVR2	TSKVR5	TSKVR10	TSKVR15	TSKVR20	TSKVR30	TSKVR40	TSKVR45	TSKVW2	TSKVW5	TSKVW10	TSKVW15	TSKVW25	TSKVW30	TSKVTT0	TSKVTT500	TSKVTT1000	TSKVTT1500
1	32.183	32.991	33.099	31.999	31.105	30.2	30.621	30.847	32.203	32.16	21.255	21.55	32.527	33.294	33.81	39.593	37.186	37.025	37.002
2	33.387	33.708	33.702	33.864	33.779	33.376	33.369	33.053	33.108	33.109	32.891	33.367	34.547	34.338	34.158	37.21	34.66	35.028	36.513
3	33.406	32.406	31.733	30.885	30.561	30.811	31.496	32.008	32.397	33.808	33.788	34.239	34.653	0	35.892	37.915	36.292	35.86	35.184
4	33.815	33.15	33.654	33.967	34.361	34.517	34.706	32.989	33.714	33.849	33.886	35.576	35.536	35.671	36.363	36.898	36.325	36.247	36.285
5	35.316	34.805	34.777	34.94	34.612	34.308	34.225	34.292	34.476	35.56	35.119	34.983	35.339	35.941	36.585	37.461	37.16	36.745	36.872
6	34.659	34.854	34.332	33.467	33.764	33.884	33.517	32.877	33.721	34.594	34.042	34.548	34.944	35.812	35.867	36.962	36.817	36.794	36.476
7	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
8	32.853	30.512	31.517	32.445	31.052	32.195	32.593	32.649	32.985	33.088	33.23	33.96	34.848	34.85	35.414	36.383	36.905	36.821	36.883
	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	33.65986	33.20371	33.25914	33.081	32.74771	32.75586	32.93243	32.67357	33.22914	33.73829	33.62971	34.19536	34.62771	34.98433	35.44129	37.48886	36.4778571	36.36	36.45928571
	1.220253	1.969893	1.74627	1.853844	2.137639	2.061198	1.839459	1.308295	1.082502	1.411708	1.726013	2.104375	1.824007	1.623679	1.729216	1.667399	1.69655713	1.645596783	1.362375598

Skin temperature –LCG condition (SKTL) during rest (R), warm-up (W) and time trial (TT) in degrees Celsius. Numbers indicate time (minutes) when data was collected.

subject #	**TSKLR0**	**TSKLR2**	**TSKLR5**	**TSKLR10**	**TSKLR15**	**TSKLR20**	**TSKLR30**	**TSKLR40**	**TSKLR45**
1	32.332	33.68	33.935	34.192	34.3	34.389	34.539	34.636	34.678
2	33.007	33.577	33.553	33.845	33.891	33.886	34.088	33.922	33.878
3	33.374	34.983	34.982	34.549	34.495	34.354	33.306	32.996	32.957
4	32.747	33.098	32.899	32.53	32.107	32.757	31.734	32.622	32.113
5	36.57	37.107	36.958	36.904	36.75	36.298	35.662	35.884	35.603
6	34.42	34.979	34.628	33.93	33.781	34.092	34.172	33.777	33.55
7	34.649	0	37.195	36.53	35.879	35.598	35.565	35.505	35.332
8	32.904	33.699	32.682	32.192	32.15	32.236	31.935	31.725	31.893
	0	0	0	0	0	0	0	0	0
	33.75038	34.44614	34.604	34.334	34.16913	34.20125	33.87513	33.88338	33.7505
	1.528551	1.562018	1.940406	1.961628	1.881313	1.552933	1.687889	1.601564	1.568239

TSKLW2	**TSKLW5**	**TSKLW10**	**TSKLW15**	**TSKLW25**	**TSKLW30**	**TSKLTT0**	**TSKLTT500**	**TSKLTT1000**	**TSKLTT1500**
34.823	35.025	34.595	34.814	35.128	35.389	36.67	25.214	25.025	24.742
32.769	32.754	33.657	34.263	34.941	35.302	36.968	36.21	36.088	35.283
33.145	32.992	33.531	34.108	35.01	35.523	35.759	34.161	33.996	33.941
32.22	31.96	32.261	32.215	32.176	32.849	31.962	34.983	34.999	35.468
37.348	37.185	37.102	37.29	37.835	38.562	39.985	39.443	39.539	39.455
33.772	33.512	33.828	34.093	34.9	35.335	35.406	36.223	36.257	36.24
36.787	37.963	38.022	37.945	37.445	38.122	37.635	37.773	38.19	38.288
32.047	32.76	33.603	34.018	0	0	0	0	0	0
0	0	0	0	0	0	0	#VALUE!	0	0
34.11388	34.26888	34.57488	34.84325	35.34786	35.86886	36.34071	36.50164286	36.52557143	36.438
2.222696	2.38108	2.264711	2.062311	2.083809	2.146946	2.748029	1.981262761	2.123965496	2.135647613

Body temperature –control condition (TBC) during rest (R), warm-up (W) and time trial (TT) in degrees Celsius. Numbers indicate time (minutes) when data was collected.

subject #	**TBCR2**	**TBCR5**	**TBCR10**	**TBCR15**	**TBCR20**	**TBCR30**	**TBCR40**	**TBCR45**
1	35.8356	36.013	36.17505	36.2643	36.3084	36.49405	36.6482	36.69855
2	0	0	0	0	0	0	0	0
3	36.0804	36.2353	36.34365	36.4543	36.1052	36.521	36.6855	35.78995
4	37.03875	37.11085	37.1249	37.1554	37.0919	37.44945	37.5772	37.66435
5	0	0	0	0	0	0	0	0
6	0	0	0	0	0	0	0	0
7	36.6499	36.7745	36.91315	36.92615	36.9615	37.0479	37.2293	37.2372
8	0	0	36.7738	36.8445	36.87285	36.9084	36.90685	36.98365
	0	0	0	0	0	0	0	0
mean	36.40116	36.53341	36.66611	36.72893	36.66797	36.88416	37.00941	36.87474
sd	0.695483	0.637017	0.519019	0.483578	0.583312	0.539743	0.594554	0.982334

TBCW2	**TBCW5**	**TBCW10**	**TBCW15**	**TBCW25**	**TBCW30**	**TBCTT0**	**TBCTT500**	**TBCTT1000**	**TBCTT1500**
36.8396	37.51835	37.5246	37.76555	#VALUE!	38.15025	38.97185	38.16645	38.1248	38.09405
0	0	0	0	0	0	0	0	0	0
36.66465	36.4311	36.66075	36.91215	37.12835	37.52555	38.2325	37.3986	37.65895	37.86365
37.47445	37.4381	36.55145	#VALUE!	0	38.4224	38.7596	38.53295	38.6797	38.68635
0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0
37.2471	37.37235	37.7472	37.83245	38.35965	38.62835	38.6378	0	0	0
37.0881	37.21845	37.51265	37.89975	38.2136	38.2059	38.8665	38.5354	38.42235	38.2489
0	0	0	0	0	0	0	0	0	0
37.06278	37.19567	37.19933	37.56654	37.81874	38.18649	38.69365	38.15835	38.22145	38.2232375
0.592704	0.867659	1.368642	1.065794	0.732814	0.914559	0.904697	0.97073224	0.83922545	0.91673972

Body temperature –vest condition (TBV) during rest (R), warm-up (W) and time trial (TT) in degrees Celsius. Numbers indicate time (minutes) when data was collected.

subject #	**TBVR0**	**TBVR2**	**TBVR5**	**TBVR10**	**TBVR15**	**TBVR20**	**TBVR30**	**TBVR40**	**TBVR45**
1	35.59355	35.84385	35.84265	35.34715	34.95625	34.7175	34.82585	34.90495	35.41205
2	35.97595	36.0948	36.0927	36.1494	36.11965	35.9396	35.89815	35.78755	35.8068
3	35.9826	35.4896	35.21505	35.02875	34.91535	34.97035	35.2101	35.3113	35.44745
4	36.05425	35.789	35.9654	36.03595	36.13485	36.15045	36.1451	35.50515	35.7589
5	36.5016	36.43975	36.42995	36.487	36.3722	36.2658	36.23675	36.2212	36.2856
6	36.64865	36.8339	36.6512	36.34845	36.4524	36.4554	36.25545	35.95345	36.24885
7	0	0	0	0	0	0	0	0	0
8	35.71755	34.9372	35.28895	35.61375	35.1262	35.56525	35.66555	35.64615	35.76375
	0	0	0	0	0	0	0	0	0
	36.06774	35.9183	35.92656	35.85864	35.72527	35.72348	35.74814	35.61854	35.81763
	0.54664	0.848546	0.777367	0.815236	0.932038	0.889057	0.806305	0.607679	0.526452

TBVW2	**TBVW5**	**TBVW10**	**TBVW15**	**TBVW25**	**TBVW30**	**TBVTT0**	**TBVTT500**	**TBVTT1000**	**TBVTT1500**
35.436	31.65825	31.833	34.83645	35.9109	36.3125	38.88255	38.1571	38.10075	37.8587
35.84615	35.80885	36.23545	36.92145	37.0433	37.0583	38.2435	36.6555	35.5038	35.64005
35.5383	34.4783	34.23315	36.72455	0	37.1582	37.90525	37.3372	37.225	37.1054
35.77365	35.8971	36.7096	36.7736	37.08085	37.44005	37.6663	37.50475	37.51645	37.56875
36.743	36.66015	36.80105	37.00365	37.52635	37.94675	38.29235	38.226	38.11975	38.2422
36.5934	36.4392	36.7658	37.0994	37.7542	37.92945	38.4752	38.33995	37.6689	36.4721
0	0	0	0	0	0	0	0	0	0
35.7998	35.8495	36.2545	36.7538	37.1055	37.4589	37.91505	38.13675	38.14635	38.20705
0	0	0	0	0	0	0	0	0	0
35.96147	35.81576	36.10473	36.58756	37.07018	37.32916	38.19717	37.7653214	37.46871429	37.2991786
0.751961	1.236263	1.582662	1.120363	0.912301	0.935275	0.888754	0.94165996	1.277546054	1.39275833

Body temperature –LCG condition (TBL) during rest (R), warm-up (W) and time trial (TT) in degrees Celsius. Numbers indicate time (minutes) when data was collected.

subject #	**TBLR0**	**TBLR2**	**TBLR5**	**TBLR10**	**TBLR15**	**TBLR20**	**TBLR30**	**TBLR40**	**TBLR45**
1	11.3162	11.788	11.87725	11.9672	12.005	12.03615	12.08865	12.1226	12.1373
2	35.77145	35.89945	35.89105	35.91525	35.97035	36.0076	36.1173	36.0137	35.9268
3	11.6809	12.24405	12.2437	12.09215	12.07325	12.0239	11.6571	11.5486	11.53495
4	11.46145	11.5843	11.51465	11.3855	11.23745	11.46495	11.1069	11.4177	11.23955
5	37.168	37.35595	37.3038	37.2849	37.231	37.0403	36.7787	36.8564	36.75805
6	36.526	36.72815	36.6053	36.322	36.23085	36.3397	36.3677	36.19045	36.0785
7	36.49565	0	37.38675	37.0825	36.85465	36.7563	36.78375	36.68475	36.6242
8	11.5164	11.79465	11.4387	11.2672	11.2525	11.2826	11.17725	11.10375	11.16255
mean	36.17138	36.38998	36.4539	36.31228	36.25457	36.26744	36.16304	36.12531	36.0528
sd	0.641733	0.718352	0.820358	0.849059	0.79118	0.653195	0.683067	0.65569	0.667007

TBLW2	**TBLW5**	**TBLW10**	**TBLW15**	**TBLW25**	**TBLW30**	**TBLTT0**	**TBLTT500**	**TBLTT1000**	**TBLTT1500**
12.18805	12.25875	12.10825	12.1849	12.2948	12.38615	12.8345	8.8249	8.75875	8.6597
35.61015	35.6439	36.21995	34.74205	36.66935	37.0622	38.2368	37.5035	35.8033	38.00455
11.60075	11.5472	11.73585	11.9378	12.2535	12.43305	12.51565	11.95635	11.8986	11.87935
11.277	11.186	11.29135	11.27525	11.2616	11.49715	11.1867	12.24405	12.24965	12.4138
37.4403	37.38325	37.5102	37.6865	38.22825	37.2737	39.40975	39.22005	39.29265	39.38675
36.1887	36.0977	36.3253	36.52855	37.123	37.54825	37.5341	37.87855	37.32495	37.0525
36.29495	36.66755	36.9417	37.20725	38.40375	38.9202	38.78225	38.36255	37.6635	37.6978
11.21645	11.466	11.76105	11.9063	0	0	0	0	0	0
36.01423	36.06848	36.37221	36.17201	37.27975	37.3646	38.0855	37.92245	37.173575	37.727925
1.227506	1.304419	1.218717	1.601999	1.083926	1.526995	1.159072	0.935103015	1.68909325	1.48990785

Thermal sensation – control condition (TSC) during rest (R), warm-up (W) and pre and post time trial (TT). Numbers indicate time (minutes) when data was collected.

subject #	TSCR0	TSCR2	TSCR5	TSCR10	TSCR15	TSCR20	TSCR30	TSCR40	TSCR45
1	5	7	7	7	7	7.5	7	7	7
2	5	6	5	6	6	6	7	7	7
3		6	6	6	7	7	7.5	8	8
4	6	6	6	6	6	6	6	6	6
5	5	6	6	7	7	7	7	7	8
6	6	7	7	7.5	7.5	7.5	7.5	7.5	7.5
7	6	7	7	7	7	7	7	7	7
8	6	8	8	8	8	8	9	9	8
	5.571429	6.625	6.5	6.8125	6.9375	7	7.25	7.3125	7.3125
	0.534522	0.744024	0.92582	0.75297	0.678101	0.707107	0.845154	0.883883	0.703943

TSCW2	TSCW5	TSCW10	TSCW25	TSCW30	TSCTTPRE	TSCTTPOST
7.5	8	7.5	9	9	9	9
7	7	7	9	9	9	
8	9	9	9	9	9	9
7	8	9			9	
8	8	8	8	9		
8	8	9	9	9	9	9
7	8	8	9			
9	9	9	9	9	9	
7.6875	8.125	8.3125	8.8571429	9	9	9
0.703943	0.6408699	0.7989949	0.3779645	0	0	0

Thermal sensation – vest condition (TSV) during rest (R), warm-up (W) and pre and post time trial (TT). Numbers indicate time (minutes) when data was collected.

subject #	TSVR2	TSVR5	TSVR10	TSVR15	TSVR20	TSVR30	TSVR40	TSVR45
1	1	1	1	1	1	3	3	4
2	2	2	3	3	3	4	5	5
3	3	3	4	4	5	6	6	6
4	2	1	2	2	2	2	2	2
5	4	4	5	5	5	5	6	6
6	6	6	6	6	6	6	7	7
7	3	3	3	3	3	3	4	4
8	5	5	6	5	5	6	6	6
	3.25	3.125	3.75	3.625	3.75	4.375	4.875	5
	1.669046	1.807722	1.832251	1.685018	1.752549	1.59799	1.726888	1.603567

TSVW2	TSVW5	TSVW10	TSVW25	TSVW30	TSVTTPRE	TSVTTPOST
3	6	6	7	7	6	8
6	7	8	8	9	9	9
8	8	8			9	9
6	7	7	8	8	8	9
6	7	7	8	9	8	9
7	8	9	9	9	9	9
4	4	6	6	7	6	9
7	7	8	8	9	8	10
5.875	6.75	7.375	7.7142857	8.2857143	7.875	9
1.6420806	1.2817399	1.0606602	0.9511897	0.9511897	1.246423455	0.534522

Thermal sensation –LCG condition (TSL) during rest (R), warm-up (W) and pre and post time trial (TT). Numbers indicate time (minutes) when data was collected.

subject #	**TSLR2**	**TSLR5**	**TSLR10**	**TSLR15**	**TSLR20**	**TSLR30**	**TSLR40**	**TSLR45**
1	3	2	2	2	2	2	2	2
2	4	3	3	3	3	3	3	3
3	5	4	3	3	4	4	4	5
4	4	3	3	3	3	3	4	2
5	5	4	5	6	6	6	6	6
6	7	7	7	7	7	7	7	7
7	4	4	3	3	4	3	3	3
8	5	6	6	6	6	6	4	5
	4.625	4.125	4	4.125	4.375	4.25	4.125	4.125
	1.187735	1.642081	1.772811	1.885092	1.767767	1.832251	1.642081	1.885092

TSLW2	**TSLW5**	**TSLW10**	**TSLW25**	**TSLW30**	**TSLTTPRE**	**TSLTTPOST**
6	6	6	7	8	7	9
5	6	6	7	8	8	9
5	7	7	7	7	7	9
7	7	8	8	8	7	9
7	7	8	9	9	9	9
7	8	8	9	9	9	9
5	7	8	9	9	8	
7	7	8				
6.125	6.875	7.375	8	8.2857143	7.85714286	9
0.9910312	0.6408699	0.9161254	1	0.7559289	0.89973541	0

Thermal comfort – control condition (TCC) during rest (R), warm-up (W) and pre and post time trial (TT). Numbers indicate time (minutes) when data was collected.

subject #	**TCCR0**	**TCCR2**	**TCCR5**	**TCCR10**	**TCCR15**	**TCCR20**	**TCCR30**	**TCCR40**	**TCCR45**
1	1	2	2	3	3	3.5	3.5	3	3.5
2	1	1	1	2	2	2	2	2	2
3		1	1.5	1.5	2	2	2	3	3.5
4	1.5	1.5	1.5	1.5	2	2	2	2	2
5	1	2	2	2	2.5	2.5	3	3	3
6	1	2	2	2	2.5	2	2.5	2.5	2.5
7	1	2	2	1.5	1.5	2	2	1.5	2
8	2.5	3.5	4	3.5	3.5	3.5	4	4	4.5
mean	1.285714	1.875	2	2.125	2.375	2.4375	2.625	2.625	2.875
sd	0.566947	0.790569	0.886405	0.744024	0.64087	0.678101	0.790569	0.790569	0.916125

TCCW2	**TCCW5**	**TCCW10**	**TCCW25**	**TCCW30**	**TCCTTPRE**	**TCCTTPOST**
3.5	4	4	4	4.5	5	5
3.5	3.5	4	5	5	5	
4	4	5	5	5	5	5
3	4	4.5			5	
3.5	3.5	3.5	4.5	5		
3	3.5	4	5	5	5	5
2	3	3	5			
4	5	5	5	5	5	5
3.3125	3.8125	4.125	4.7857143	4.9166667	5	5
0.6512351	0.5938675	0.6943651	0.3933979	0.2041241	0	0

Thermal comfort – vest condition (TCV) during rest (R), warm-up (W) and pre and post time trial (TT). Numbers indicate time (minutes) when data was collected.

subject #	**TCVR2**	**TCVR5**	**TCVR10**	**TCVR15**	**TCVR20**	**TCVR30**	**TCVR40**	**TCVR45**
1	2	2	1.5	2	2	2	2	2
2	2	2	2	1	1	2	1	1
3	2	1.5	1.5	1.5	2	2	2	2
4	1	1	1	1	1	1	1	1
5	1.5	1.5	2	2	2	2	2	2
6	1	1	1	1	1	2	2	2
7	1	1	1	1	1	1	1	1
8	1	1	1.5	1.5	1.5	2	1.5	2
mean	1.4375	1.375	1.4375	1.375	1.4375	1.75	1.5625	1.625
sd	0.495516	0.443203	0.417261	0.443203	0.495516	0.46291	0.495516	0.517549

TCVW2	**TCVW5**	**TCVW10**	**TCVW25**	**TCVW30**	**TCVTTPRE**	**TCVTTPOST**
1.5	2.5	2.5	3	3.5	3.5	5
3	3	4	4.5	4.5	5	5
3	3.5	4.5			5	5
2	2	2	4	4.5	4	5
2.5	3	3	3.5	4	3	5
2.5	3	4	5	5	5	5
1.5	2	2	2.5	2.5	1.5	4
3.5	3	4	3.5	3.5	4	4.5
2.4375	2.75	3.25	3.7142857	3.9285714	3.875	4.8125
0.728869	0.5345225	1	0.8591247	0.8380817	1.2174329	0.372011905

Thermal comfort – LCG condition (TCL) during rest (R), warm-up (W) and pre and post time trial (TT). Numbers indicate time (minutes) when data was collected.

subject #	**TCLR2**	**TCLR5**	**TCLR10**	**TCLR15**	**TCLR20**	**TCLR30**	**TCLR40**	**TCLR45**
1	1.5	1	1.5	1	1	1	1	1
2	1	1	1	1	1	1	1	1
3	1	1	1	1	1	1	1	1.5
4	1	1	1	1	1	1	1.5	1
5	1.5	1.5	2	2	2	2	2	2
6	1.5	1.5	1.5	1.5	1.5	2	1.5	1.5
7	1	1	1	1	1	1	1	1
8	1	1.5	1.5	2	2	1.5	1.5	1.5
mean	1.1875	1.1875	1.3125	1.3125	1.3125	1.3125	1.3125	1.3125
sd	0.258775	0.258775	0.372012	0.458063	0.458063	0.458063	0.372012	0.372012

TCLW2	**TCLW5**	**TCLW10**	**TCLW25**	**TCLW30**	**TCLTTPRE**	**TCLTTPOST**
2	3	3.5	4	4	3	5
2	3	3	4	4.5	3.5	5
1.5	3.5	3.5	3.5	3.5	3.5	4.5
2.5	3	4	3.5	4	4	5
2.5	2.5	3	4.5	5	5	5
2	2.5	3	4	4.5	4	5
2	3	3.5	4	4.5	3.5	
2.5	3	3				
2.125	2.9375	3.3125	3.9285714	4.2857143	3.78571429	4.916666667
0.3535534	0.320435	0.3720119	0.3450328	0.48795	0.63620901	0.204124145

Rate of perceived exertion – control condition (RPC) during rest (R), warm-up (W) and pre and post time trial (TT). Numbers indicate time (minutes) when data was collected.

subject #	**RPCR0**	**RPCR2**	**RPCR5**	**RPCR10**	**RPCR15**	**RPCR20**	**RPCR30**	**RPCR40**	**RPCR45**
1	0	0.5	0.5	0.5	0.5	1	0.5	0.5	0.5
2	0	0	0	0	0	0	0	0	0
3	0	0	0	0	0	0	0	0	0
4	0	0	0	0	0	0	0	0	0
5	0	0	0	0	0	0	0	0	0
6	0	0	0	0	0	0	0	0	0
7	0	0	0	0	0	0	0	0	0
8	0	0	0	0	0	0	0	0	0
mean	0	0.0625	0.0625	0.0625	0.0625	0.125	0.0625	0.0625	0.0625
sd	0	0.176777	0.176777	0.176777	0.176777	0.353553	0.176777	0.176777	0.176777

RPCW2	**RPCW5**	**RPCW10**	**RPCW25**	**RPCW30**	**RPCTTPRE**	**RPCTTPOST**
3	4	5	8	9	10	10
3	4	6	8	10	10	10
3	3.5	5	7	10	10	10
4	4	5			7	10
3	4	5	9	9		
3	3	3	3	4	0	10
4	5	5	10			
3	4	6	7	9	0	10
3.25	3.9375	5	7.4285714	8.5	6.166666667	10
0.46291	0.5629958	0.9258201	2.2253946	2.258318	4.915960401	0

Rate of perceived exertion –vest condition (RPV) during rest (R), warm-up (W) and pre and post time trial (TT). Numbers indicate time (minutes) when data was collected.

subject #	**RPVR2**	**RPVR5**	**RPVR10**	**RPVR15**	**RPVR20**	**RPVR30**	**RPVR40**	**RPVR45**
1	0	0	0	0	0	0.5	0.5	0.5
2	0	0	0	0	0	0	0	0
3	0	0	0	0	0	0	0	0
4	0	0	0	0	0	0	0	0
5	0	0	0	0	0	0	0	0
6	0	0	0	0	0	0	0	0
7	0	0	0	0	0	0	0	0
8	0	0	0	0	0	0	0	0
mean	0	0	0	0	0	0.0625	0.0625	0.0625
sd	0	0	0	0	0	0.176777	0.176777	0.176777

RPVW2	**RPVW5**	**RPVW10**	**RPVW25**	**RPVW30**	**RPVTTPRE**	**RPVTTPOST**
1	3	3	3	5	2	9.5
3	3	4	7	9	10	10
3	3.5	4			7	10
3	3	3.5	7	7	4	10
3	4	5	6	8	0	10
3	3	3	6	8	0	10
4	4	5	6	7	1	9
3	3	3	4	4	0	9
2.875	3.3125	3.8125	5.5714286	6.8571429	3	9.6875
0.834523	0.4580627	0.842509	1.5118579	1.7728105	3.741657387	0.4580627

Rate of perceived exertion – LCG condition (RPL) during rest (R), warm-up (W) and pre and post time trial (TT). Numbers indicate time (minutes) when data was collected.

subject #	**RPLR2**	**RPLR5**	**RPLR10**	**RPLR15**	**RPLR20**	**RPLR30**	**RPLR40**	**RPLR45**
1	0	0	0	0	0	0	0	0
2	0	0	0	0	0	0	0	0
3	0	0	0	0	0	0	0	0
4	0	0	0	0	0	0	0	0
5	0	0	0	0	0	0	0	0
6	0	0	0	0	0	0	0	0
7	0	0	0	0	0	0	0	0
8	0	0	0	0	0	0	0	0
mean	0	0	0	0	0	0	0	0
sd	0	0	0	0	0	0	0	0

RPLW2	**RPLW5**	**RPLW10**	**RPLW25**	**RPLW30**	**RPLTTPRE**	**RPLTTPOST**
3	5	4	6	7	3	10
3	3.5	4	7	8	0	10
6	7	7	7	8	0	10
4	4	4	6	4	3	10
0.5	2	3	8	9	10	10
1	3	3	4	4	0	10
3	5	6	7	10	7	
4	4	5				
3.0625	4.1875	4.5	6.4285714	7.1428571	3.28571429	10
1.7410485	1.5103807	1.4142136	1.272418	2.3401262	3.90360029	0

500m split times – control condition (STC) at 500, 1000 and 1500 m and the average (AVG) during the 1500 m time trial.

SUBJECT	**STC500**	**stc1000**	**STC1500**	**STCAVG**
1.0	100.6	103.5	99.6	101.2
2.0	104.3	106.1	103.1	104.5
3.0	96.6	100.3	97.8	98.2
4.0	101.4	106.8	107.9	105.4
5.0				
6.0	99.8	99.1	96.7	98.5
7.0				
8.0	107.0	107.2	104.5	106.2
MEAN	101.62	103.83	101.60	102.33
SD	3.63	3.47	4.31	3.52

500m split times –vest condition (STV) at 500, 1000 and 1500 m and the average (AVG) during the 1500 m time trial.

SUBJECT	**STV500**	**STV1000**	**STV1500**	**STVAVG**
1.0	98.5	98.3	96.6	97.8
2.0	100.9	102.0	100.0	101.1
3.0	90.7	93.0	93.0	92.4
4.0	100.8	105.1	103.3	103.1
5.0	96.9	97.1	94.4	96.1
6.0	97.8	97.6	95.2	96.9
7.0	97.1	98.9	98.7	98.2
8.0	99.0	102.8	102.6	101.5
MEAN	97.71	99.35	97.98	98.39
SD	3.21	3.81	3.81	3.44

500m split times (seconds) – LCG condition (STL) at 500, 1000 and 1500 m and the average (AVG) during the 1500 m time trial.

SUBJECT	**STL500**	**STL1000**	**STL1500**	**STLAVG**
1.0	99.5	98.2	98.0	98.6
2.0	99.3	102.0	100.3	100.5
3.0				92.4
4.0	102.7	101.9	98.7	101.1
5.0	100.3	101.2	96.9	99.5
6.0	96.2	96.1	94.4	95.6
7.0	107.4	110.8	104.0	107.4
8.0				101.5
MEAN	100.90	101.70	98.72	99.58

SD	3.81	5.04	3.25	4.41

Stroke rate (strokes/minute) – control condition (SRC) at 500, 1000 and 1500 m and the average (AVG) during the 1500 m time trial.

subject #	**SRC500**	**SRC1000**	**SRC1500**	**SRCAVG**
1	30	28	31	29
2	35	32	33	33
3	30	29	29	29
4	36	33	32	34
5				
6	33	31	32	32
7				
8	29	28	30	29
	32.16667	30.16667	31.16667	31
	2.926887	2.136976	1.47196	2.280351

Stroke rate (strokes/minute) –vest condition (SRV) at 500, 1000 and 1500 m and the average (AVG) during the 1500 m time trial.

subject #	**SRV500**	**SRV1000**	**SRV1500**	**SRVAVG**
1	32	31	32	32
2	32	31	32	32
3	32	30	31	31
4	36	33	33	34
5	34	32	33	33
6	33	33	33	33
7	33	33	34	34
8	31	29	30	30
	32.875	31.5	32.25	32.375
	1.552648	1.511858	1.28174	1.407886

Stroke rate (strokes/minute) – LCG condition (SRC) at 500, 1000 and 1500 m and the average (AVG) during the 1500 m time trial.

subject #	**SRL500**	**SRL1000**	**SRL1500**	**SRLAVG**
1	33	32	32	32
2	34	32	33	33
3	28	30	31	30
4	34	32	34	33
5	32	28	28	29
6	34	33	33	33
7	31	30	31	31
8				
	32.28571	31	31.71429	31.57143

	2.21467	1.732051	1.976047	1.618347

Power output (Watts) – control condition (POC) at 500, 1000 and 1500 m and the average (AVG) during the 1500 m time trial.

subject #	**POC500**	**POC1000**	**POC1500**	**POCAVG**
1	343.9	316	354	337.5
2	308.1	293.1	319.5	306.6
3	388.4	347.3	373.7	369.3
4	336.1	287.5	278.4	299.3
5				
6	351.8	360.1	387.1	365.9
7				
8	285.6	284	306.9	291.9
mean	335.65	314.6667	336.6	328.4167
sd	35.708976	32.4792	41.93128	34.10621

Power output (Watts) – vest condition (POV) at 500, 1000 and 1500 m and the average (AVG) during the 1500 m time trial.

subject #	**POV500**	**POV1000**	**POV1500**	**POVAVG**
1	366.7	368.8	387.8	374.3
2	340.5	326.1	349.8	338.6
3	369.2	430.4	343.8	444.3
4	341.8	301.7	317.1	319.7
5	385.2	382.4	416	394.1
6	374.5	376.6	405.5	385.2
7	381.9	361.7	364.5	369.2
8	360.3	322.5	324.1	335
mean	365.0125	358.775	363.575	370.05
sd	16.75457	40.9811	36.63097	39.80757

Power output (Watts) – LCG condition (POL) at 500, 1000 and 1500 m and the average (AVG) during the 1500 m time trial.

subject #	**POL500**	**POL1000**	**POL1500**	**POLAVG**
1	355.2	370	371.4	365.4
2	357.9	330.31	346.8	344.7
3				390
4	323.2	330.8	364.5	338.9
5	346.5	337.7	385	355.6
6	392.6	395	415.7	400.9
7	282.3	257	311.4	282.4
8				
mean	342.95	336.8017	365.8	353.9857
sd	37.20155	46.76847	35.24787	38.87842

Total distance covered during 1500 m time trial (meters) – control condition

subject #	DISTCWTOT
1	6880
2	7154
3	5577
4	
5	7032
6	6833
7	5950
8	6494
mean	6560
sd	590.9447

Total distance covered during 1500 m time trial (meters) – vest condition

subject #	DISTVWTOT
1	
2	6717
3	
4	6716
5	6937
6	7100
7	5954
8	7191
mean	6769.1667
sd	443.98352

Total distance covered during 1500 m time trial (meters) – LCG condition

subject #	DISTLWTOT
1	7075
2	
3	6063
4	6593
5	7298
6	6905
7	6546
8	
mean	6746.667
sd	440.0276

Appendix K – Vita

Vita

Surname: Johnson Given Names: Elizabeth Anne Rebecca

Place of Birth: Fredericton, New Brunswick, Canada

Educational Institutions Attended:

2003-present	University of Victoria School of Physical Education	Victoria, BC
2001-2002	University of New Brunswick Faculty of Kinesiology	Fredericton, NB
1998-2000	University of Victoria Faculty of Microbiology and Biochemistry	Victoria, BC

Degrees Awarded:

B.Sc. Kinesiology (Honours)	University of New Brunswick	2002

Awards:

Michael Smith Foundation for Health Science grant, March 2004
University of Victoria’s President’s Research Award, January 2004
National Science and Engineering Research Council Post Graduate Scholarship – PGS-A (2003-2005)
Lieutenant Governors Silver Medal, University of New Brunswick, May 2002
Canadian Society for Exercise Physiology Award, May 2002
Duke of Edingburgh Bronze Award

Publications:

Johnson, E. & Sleivert, G. (2002). The influence of muscle pre-activation on concentric only and stretch-shorten cycle jumping power. Canadian Journal of Applied Physiology, 27 (Suppl), S25.

Johnson, E., Nason, D., Albert, W., & Sleivert, G. (2002). Muscle recruitment patterns in four back health exercises. Canadian Journal of Applied Physiology, 27 (Suppl), S25.

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Morrison, S., Sleivert, G.G., Johnson, E., Bernhardt, T., Cheung, S., & Neary, P.J. (2005). Cerebral oxygenation, central drive and force output during passive heating and cooling. Medicine & Science in Sports and Exercise, 37 (5 Suppl), S195.

Bernhardt, T.A. Neary, P.J., Morrison, S.A., Johnson, E., Sleivert, G.G., & Cheung, S.S. (2005). Medicine & Science in Sports and Exercise, 37(5 Suppl), S196.

Abstract

Pre-Cooling During Steady-State Rowing Decreases Physiological Strain and Enhances Self-Paced Rowing Performance in Elite Rowers

E. Johnson,[1] G.G. Sleivert,[2] S.S. Cheung,[3] & H. Wenger[1]

1 University of Victoria, Victoria, BC, 2 PacificSport Canadian Sport Centre Victoria, Victoria, BC, 3 Dalhousie University, Halifax, NS

Exercise in hot humid conditions is associated with rising core temperature and adverse psycho-physiological and performance responses. Evidence suggests pre-cooling enhances performance in events lasting several minutes to an hour, but little research exists on short duration events with elite athletes, or the effectiveness of different cooling methods.

Purpose: To examine the thermoregulatory and psychophysical effects of cooling the torso using an ice (ICE) or water-perfused (WP) vest during rest and a steady-state rowing warm-up on subsequent performance in a 1500 m self-paced ergometer time trial in the heat.

Methods: 8 lightweight male rowers (23 ± 4 y) participated in 3 experimental rowing sessions on a Concept 2 ergometer in an environmental chamber (38ºC, 47% RH) 1 week apart in counterbalanced order. Pre-cooling was applied in 2 of the trials using an ICE or WP vest. In the control condition (CON) the participants wore a WP vest not perfused with water. Vests were worn during a 45 min rest period and 30 min warm-up, but removed for a 1500 m time trial. Rectal temperature (T_{re}), skin temperature (T_{sk}), heart rate (HR), ratings of perceived exertions (RPE), thermal comfort (TC) and sensation (TS) were monitored throughout the trials.

Results: There were no significant differences among conditions for HR, T_{re}, RPE or TS following the warm-up. TC and T_{sk} were significantly different between CON and both WP and ICE following the warm-up ($P<.05$). The reduction in psychophysical strain translated into enhanced time trial performance. This was reflected in a significant increase in power output during the self-paced trial in the ICE and WP conditions compared to CON (11±1.2 % and 9.6±1.1% respectively, $P>0.05$), with the differences evident from the onset of the time trial (500 m).

Conclusions: Pre-cooling with an ice-vest or a water perfused vest enhanced performance in a 1500 m rowing time trial. Rowers chose a higher power output from the onset of the time trial following pre-cooling, consistent with the teleo-anticipation model of fatigue.

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Author:____________________________________

Elizabeth Anne Rebecca Johnson

Signed: August 13, 2005