Performing successfully in the heat at the 2004 Olympic Games in Athens: Which active cooling strategies represent best practice for endurance athletes

Marc Quod
Edith Cowan University

Edith Cowan University

Copyright Warning

You may print or download ONE copy of this document for the purpose of your own research or study.

The University does not authorize you to copy, communicate or otherwise make available electronically to any other person any copyright material contained on this site.

You are reminded of the following:

- Copyright owners are entitled to take legal action against persons who infringe their copyright.

- A reproduction of material that is protected by copyright may be a copyright infringement. Where the reproduction of such material is done without attribution of authorship, with false attribution of authorship or the authorship is treated in a derogatory manner, this may be a breach of the author's moral rights contained in Part IX of the Copyright Act 1968 (Cth).

- Courts have the power to impose a wide range of civil and criminal sanctions for infringement of copyright, infringement of moral rights and other offences under the Copyright Act 1968 (Cth). Higher penalties may apply, and higher damages may be awarded, for offences and infringements involving the conversion of material into digital or electronic form.

EDITH COWAN UNIVERSITY

School of Exercise, Biomedical and Health Sciences

Performing Successfully in the Heat at the 2004 Olympic Games in
Athens: Which Active Cooling Strategies Represent "Best Practice"
for Endurance Athletes?

HONOURS THESIS

Student Name: Marc Quod

Student Number: ████████

Degree: Bachelor of Science (Sport Science) Honours

Principal Supervisor: Dr. Paul B. Laursen

Secondary Supervisor: Dr. David T. Martin

Date of Submission: January 18, 2005

USE OF THESIS

The Use of Thesis statement is not included in this version of the thesis.

Declaration

I certify that this thesis does not, to the best of my knowledge and belief:

i.   incorporate without acknowledgement any material previously submitted for a degree or diploma in any institution of higher education;

ii.   contain any material previously published or written by another person except where due reference is made in the text; or

iii.   contain any defamatory material

Signature: _____

Date: 05/04/2005

Acknowledgements

Abstract

Previous research using athletes has documented that precooling can improve endurance performance, especially in warm conditions. However, research comparing performance following different cooling techniques which are incorporated into a pre-race routine is rare. **Purpose:** The purpose of this study was to compare the effects of two precooling techniques on cycling time trial performance in warm conditions. **Methods:** Six endurance trained, regionally competitive cyclists completed one maximal graded exercise test ($\dot{V}O_{2peak}$ 71.4 $\pm$3.2 ml·kg^{-1}·min^{-1}) and four ~40 min laboratory cycling time trials in a heat chamber (34.3 $\pm$1.1°C; 41.2 $\pm$3.0% relative humidity (rh)) using a fixed power-variable power format. After familiarisation, cyclists prepared for the time trial using two different precooling strategies and a control condition administered in a counterbalanced order. The three trials included: 1) no cooling (Control), 2) cooling jacket for 40 min (Jacket) or 3) 30 min water immersion (29°C to 24°C at a rate of 0.2°C·min^{-1}) followed by cooling jacket for 40 min (Combination). Comparisons were made using a two-way ANOVA with repeated measures and Student's paired t-tests where appropriate. **Results:** Rectal temperature (T_{re}) prior to the time trial was 37.8 $\pm$0.1°C in Control, similar in Jacket (37.8 $\pm$0.3°C) and significantly lower in Combination (37.1 $\pm$0.2°C, p < 0.01). Blood lactate during each treatment was similar except for the final readings (Control = 15.8 $\pm$4.4 mM, Jacket = 19.8 $\pm$4.3 mM and Combination = 17.5 $\pm$4.0 mM, p < 0.005). Heart rate was similar throughout the time trial for each treatment. Compared to the Control trial, performance time was similar for Jacket (-16 $\pm$36s, -1.5%; p = 0.34) but faster for Combination (-42 $\pm$25s, -3.8%; p = 0.01). The pacing strategy for Control and Combination were similar (gradually reducing split times) but unique for Jacket (started with a fast split time followed by a temporary increase in split times). **Conclusions:** A combination precooling strategy incorporating immersion in cool water followed by the use of a cooling jacket can: 1) produce decreases in T_{re} that persist throughout a warm up and 2) improve laboratory cycling time trial performance. The effects of a cooling jacket alone on T_{re} are subtle and do not appear to persist throughout a warm up. Further research is required to understand the influence of cooling jackets on pacing strategy during time trials performed in the heat.

Table of Contents

List of Tables

List of Figures

List of Equations

Chapter 1   Introduction

1.1 Background

It has been well established in the literature that endurance performance is compromised when conducted in hot conditions (Galloway and Maughan 1997; Tatterson, Hahn et al. 2000; Marino 2002) and the investigation of methods to combat the detrimental effects of heat on athletic and occupational performance has been a topic of interest for researchers since the 1930's (Bazett, Scott et al. 1937). Prior to the Atlanta Olympic Games, which occurred in warm conditions, research was undertaken by the Australian Institute of Sport investigating the influence of ambient temperature on time trial performance. Australian professional road cyclists performed two maximal laboratory-based 30 min time trials in both "warm" (32°C) and "normal" (23°C) ambient conditions (Tatterson, Hahn et al. 2000). Results of this investigation showed a 6% reduction in mean power output when riding in "warm" conditions. In addition, as the rate of rise in core temperature (T_{core}) and peak T_{core} (~39.5°C) were similar between the "warm" and "normal" conditions, it is possible that the reduction in power output might be related to the starting T_{core}. Indeed, subjects in this study began their "warm" trial with a starting T_{core} that was ~0.25°C higher than the "normal" condition (Tatterson, Hahn et al. 2000).

Similarly, the 2004 Athens Olympic Games will take place in late summer (14th - 28th of August) and it is likely that these Games will occur in hot conditions. Weather records during August from 1994-2002 have been analysed and indicate that the ambient temperature is frequently greater than 32°C and can be as high as 42°C with a relative humidity typically ~40% (personal communications – Matt Brearley, Northern Territory Institute of Sport and Dr. D.T. Martin, Australian Institute of Sport; AIS). The women's time trial at the Athens Olympic Games will take place between 1 and 3 pm, and as illustrated in Figure 1, the mean temperature at this time of day for the period 1994 to 2002 was ~ 31°C with a range of 28 to 38°C. The men's time trial will take place between 3 and 7 pm. The average temperature for this time of day was ~ 30°C with a range of 26 to 38.5°C. In addition, the ambient temperature between 1 and 3 pm

was greater than 32°C 28% of the time and between the hours of 3 and 7 pm, the ambient temperature was greater than 32°C 30% of the time during 1994-2002 (Figures 2a and 2b). While it is not certain that it will be hot on race day in 2004, history indicates that temperatures greater than 30°C could be observed.
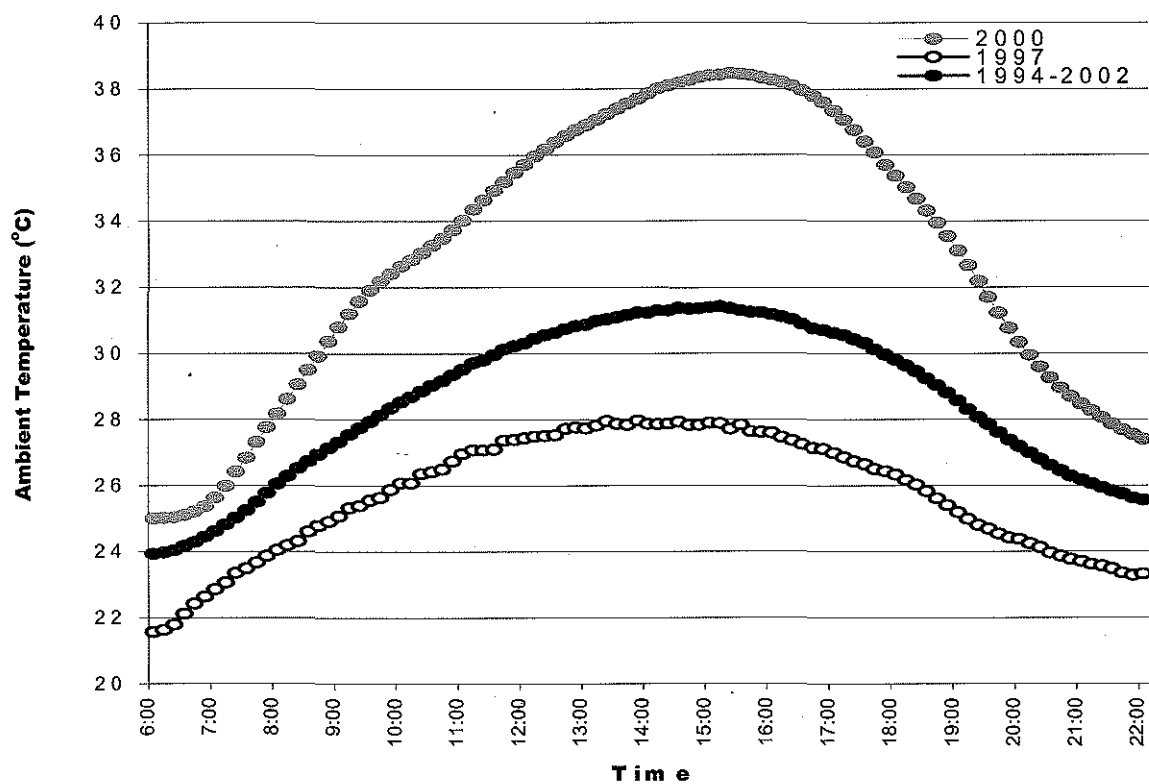
Figure 1. Mean ambient temperatures (°C) for the city of Athens, Greece in 1997, 2000 and the period from 1994-2002 (Unpublished data; Dr D.T. Martin, AIS).
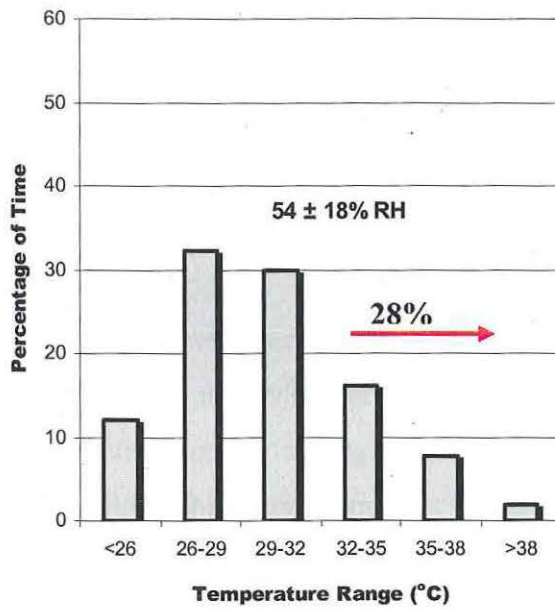
2a. Women's Time Trial (1-3 pm)
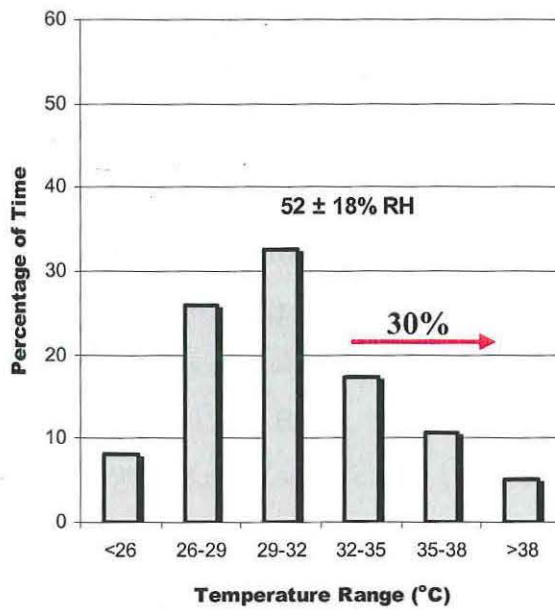
2b. Men's Time Trial (3-7 pm)

Figure 2a and 2b. Amount of time spent in different temperature bands between 1994 and 2002 (August 14 – 28) in Athens, Greece from 1-3 pm (Figure 2a) and 3-7 pm (Figure 2b). (Unpublished data; Dr D.T. Martin, AIS).

During August 2003, potential Australian Olympic Team cyclists had an opportunity to familiarise themselves with the Olympic time trial circuit in Athens. During this familiarisation, Dr D.T. Martin collected T_{core} data using an ingestible pill telemetry system (CorTemp^{TM}) from one of Australia's best time trialists completing a warm up and a practice lap of the time trial circuit. As illustrated in Figure 3, T_{core} rose from 36.7 to 38.1°C during a 45 min warm up and then rose at a rate of 1°C every 20 min during the practice lap peaking at ~39°C (Dr. D.T. Martin, unpublished data). During exercise in the heat, it is generally recognised that athletes rarely exceed a T_{core} of 39.5 – 40.5°C (Fuller, Carter et al. 1998; Marino 2002; Cheung and Sleivert 2004) and research suggests that active cooling strategies before endurance competition can improve performance by enabling the body to increase the amount of heat stored prior to reaching a critically high T_{core} (Schmidt and Bruck 1981; Hessemer, Langusch et al. 1984; Marino 1996; Booth, Marino et al. 1997; Kay, Taaffe et al. 1999; Marino 2002). As the Olympic men's time trial will likely be performed under hot conditions and the rate of rise in T_{core} may potentially be greater than what was observed in the practice trial outlined previously, due to a higher power output and possibly warmer ambient temperatures, it may be desirable for this athlete to begin competition with a T_{core} less than 37.5°C for optimal performance.

Numerous researchers have studied the effects of active cooling prior to a performance task in both neutral (~20°C) and warm (~32°C) environments (Schmidt and Bruck 1981; Hessemer, Langusch et al. 1984; Olschewski and Bruck 1988; Myler, Hahn et al. 1989; Lee and Haymes 1995; Booth, Marino et al. 1997; Smith, Yates et al. 1997; Martin, Hahn et al. 1998; Kay, Taaffe et al. 1999; Marsh and Sleivert 1999; Cotter, Sleivert et al. 2001; Sleivert, Cotter et al. 2001) In nearly all published cases, application of cool water, air or ice prior to a maximal sustained effort (1 to 60 min) appears to be beneficial. While many of these precooling manoeuvres have proven beneficial in a laboratory setting, very few have been tested in a competitive environment. In addition, many precooling techniques utilised in laboratory based cooling research are impractical for use in the field and can be uncomfortable for the athlete. Often in the field situation, access to power, ice and staff are limited and athletes often have pre-race commitments that interfere with precooling methods.
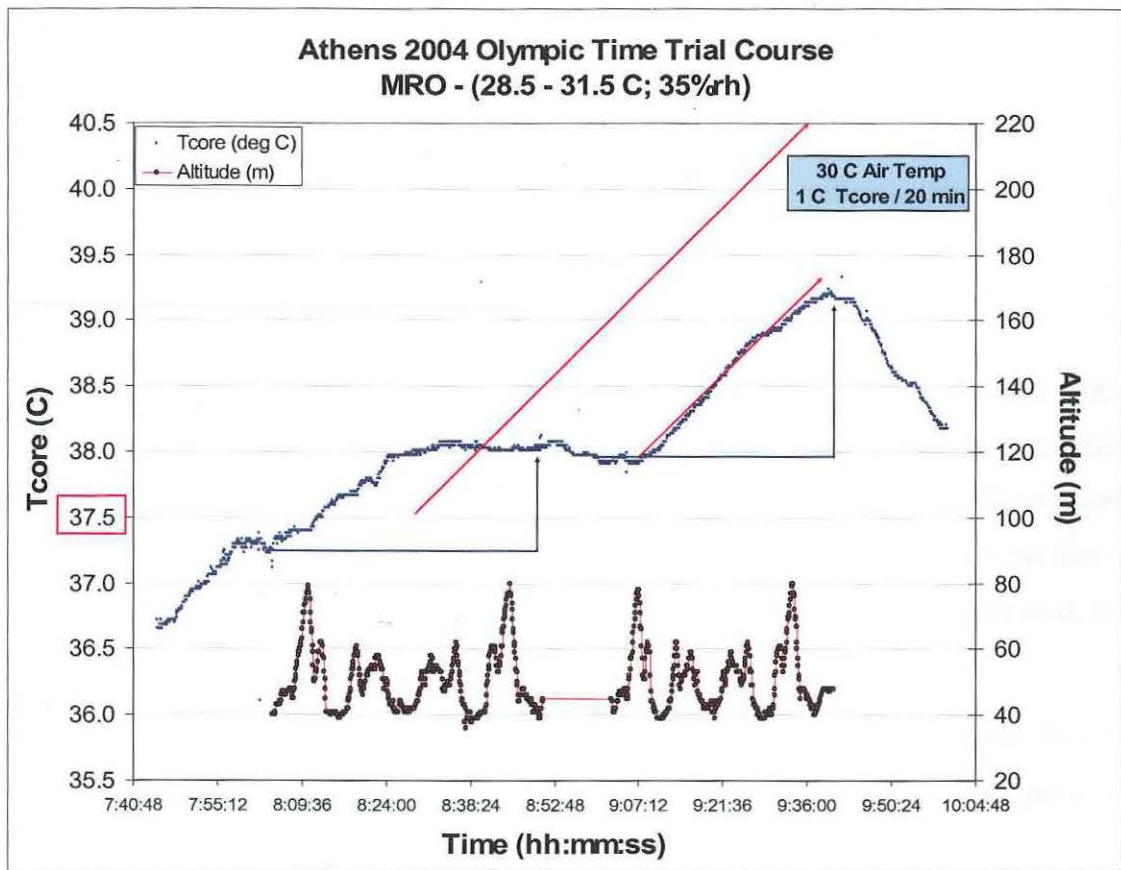
Figure 3. T_{core} data (CorTemp™) collected from a cyclist during a warm up (Time 8:00:00 – 8:52:48) and practice lap (Time 9:02:00 – 9:36:00) of the Olympic Time Trial circuit (Unpublished data; Dr. D.T. Martin, AIS).

There are currently a number of precooling strategies available for use by athletes. Some of the more popular precooling strategies include: 1) ice jackets or cooling jackets that use novel coolants such as a "Phase Change Material" (PCM), 2) fans that produce an ice mist, 3) plunge pools and cold showers, 4) ingestion of cold water/breathing cold air, 5) use of cold intra-venous drips, 6) portable tents with air-conditioning units that produce a cool micro-climate and 7) immersion of limbs in cool water or the use of a rapid thermal exchange device such as AVAcore's Core Control™. Some of these strategies cool the shell (skin), others cool the core or cool both, and each may have different physiological and performance effects. Despite substantial literature supporting the benefits of precooling, a comparative study is yet to be completed. In addition, very little research, if any, has been conducted utilising these precooling methods in the field.

As a result of insufficient information in the literature, in December 2003, experts in thermal regulation and precooling, as well as Olympic cycling coaches, support staff and sport scientists gathered at the AIS to determine which of the available precooling methods would benefit the performance of Australian time trial cyclists at the Athens Olympic Games. A variety of potential cooling methods were discussed, and the following important issues were identified:

- The method must have the capacity to reduce T_{core} as it was thought that the greater the reduction in T_{core}, the greater the potential performance benefit.

- To be able to incorporate the precooling manoeuvre into the athletes existing pre-race routine.

- The precooling manoeuvre must not be "uncomfortable" for the athlete.

- The precooling manoeuvre must be conducted within the confines of the race location. Therefore, issues such as staffing and access to power, ice and water need to be considered.

The precooling manoeuvre should be completed prior to the start of the warm up to ensure minimal disturbance to the athlete. This would allow the athlete to focus solely on the event and potentially avoid any problems with pacing.

A number of potential cooling methods were short-listed and pilot trials were conducted. The changes in rectal temperature (T_{re}) from a number of the pilot trials are presented in Figure 4. During the Control trial of the pilot study, T_{re} remained stable until the warm up was commenced where thereafter it rose 0.75°C above baseline. When wearing a cooling jacket (Jacket), T_{re} was reduced by 0.4°C at the start of the warm up but was similar to Control at the conclusion of the warm up. During the Plunge only trial, the subject started the warm up 0.6°C cooler than the Control and finished the warm up 0.5°C cooler than the Control and Jacket trial. However, by far the most effective precooling manoeuvre (with regard to a reduction in T_{re}) was the Combination strategy (plunge and cooling jacket). T_{re} using the Combination trial was 1.5°C lower than the Control trial at the start of the warm up, and this difference persisted to the end of the warm up. Consequently, a powerful precooling method had been discovered that: 1) substantially reduced T_{re}, 2) was comfortable for the athlete and 3) could be incorporated into the athlete's pre-race routine. It was envisaged that the plunge component of the manoeuvre could be conducted in the athletes' hotel; the athlete would then wear a cooling jacket while travelling to the race start and once the athlete was ready to warm up, the cooling jacket would be removed. However, the impact on performance of this particular protocol still needed to be established.

Two precooling methods were therefore chosen for further investigation. The first of these was the use of a PCM cooling jacket as this was the simplest cooling strategy and one that is widely employed. The second precooling method was the use of a combination strategy (cool water plunge + PCM cooling jacket) as it appeared to be the most powerful strategy with regard to reducing T_{re}. In addition, as these two cooling methods differed in their ability to lower T_{re}, a comparison of the performance effects of each method may provide some insight as to whether a greater reduction in T_{re} does in fact produce a greater performance benefit.
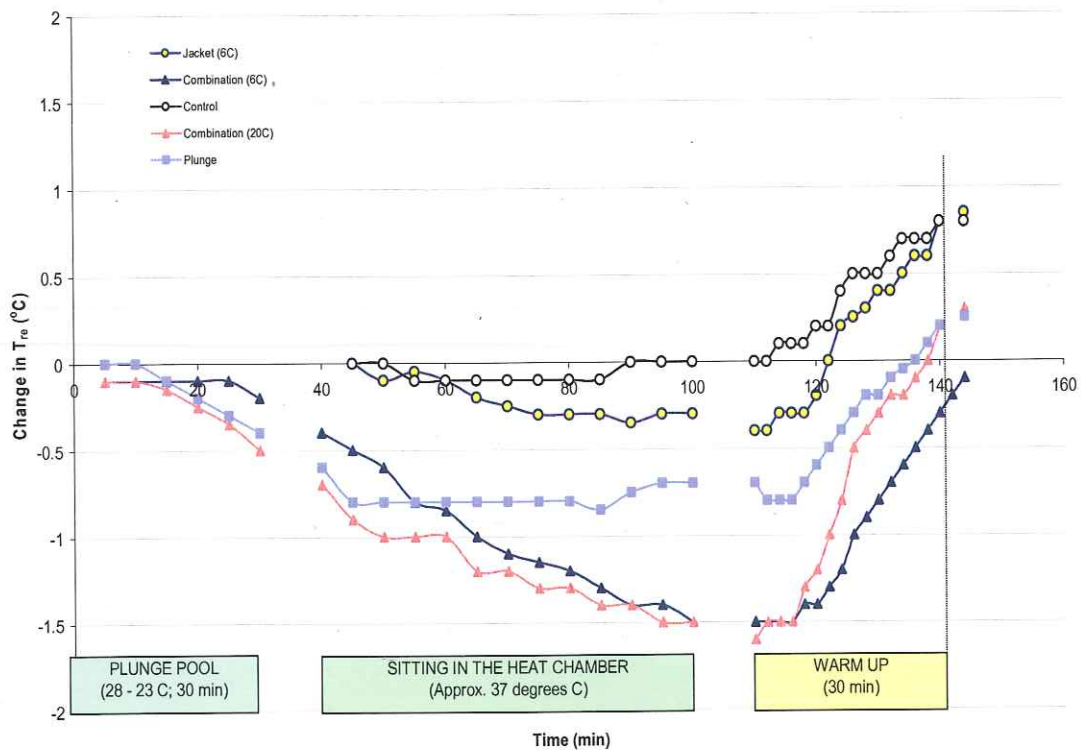
Figure 4. Change in rectal temperature (T_{re}) after different precooling methods (n = 1). Plunge pool – immersed in water for 30 min (water temp reduced from 28°C to 24°C); Sitting in the heat chamber – subjects sat for 60 min in a heat chamber (~37°C) for 60 min; Warm up – 6 min at 100 W, 7 min at 200 W, 2 min at 250 W, completed twice.

1.2 Purpose of the Study

The purpose of this research was to compare the effect of two practical precooling strategies on subsequent cycling time trial performance. In addition, by investigating the relationship between changes in performance following different precooling methods in combination with thermoregulatory, metabolic, cardiovascular and endocrine variables, some of the potential mechanisms for performance changes may be examined.

It should be acknowledged that this was the first of a series of studies that were designed to determine the most appropriate method for Australian cyclists to precool prior to the Olympic time trial in Athens. To limit the impact on pacing, this study fixed the pace for the first half of the time trial. The second study, which utilised AIS under-23 scholarship cyclists, used a 30 min time trial without a fixed component to further investigate the impact on pacing. The final study in this series used field trials at the Australian National Cycling Championships and the Tour Down Under cycle race to establish the ecological validity of the precooling technique. Only the first of these three studies will be presented in this thesis.

1.3 Significance of the Study

Despite substantial research establishing a performance benefit following a precooling manoeuvre, very little research has examined methods that are appropriate in the field and few studies have compared different cooling techniques. In addition, the impact of precooling on pacing strategy has previously been ignored by researchers. A comparative study investigating the performance impact of two cooling methods with potential for use in the competitive setting will provide valuable information for applied sport scientists and coaches when making recommendations to athletes for optimal preparation for endurance events in warm ambient conditions. In addition, examining some of the potential mechanisms by which precooling enhances performance will provide further insight into the role of thermoregulatory factors in exercise-induced fatigue. This study is unique in comparison to other precooling research as the cooling

methods under investigation are easily applied in the field, the effects of precooling on pacing will be considered and two different precooling methods will be compared.

1.4 Research Questions

i.   What effects do two different precooling manoeuvres have on cycling time trial performance?

ii. Is pacing during a cycling time trial influenced by a precooling manoeuvre?

iii. Are changes in performance following a precooling manoeuvre related to changes in thermal capacity, metabolism, cardiovascular and/or endocrine variables?

1.5 Hypotheses

i.   Cycling performance will be significantly improved by both precooling manoeuvres with the greatest improvement following the Combination treatment.

ii. Pacing strategy will not be significantly altered by either of the two precooling manoeuvres.

iii. A lower starting T_{re} will be related to a significantly improved cycling time trial performance (i.e. reduced performance time).

iv. Improved performance (reduced performance time) will be related to lower levels of endocrine disturbance (significantly lower levels of prolactin, creatine kinase, C-reactive protein and cortisol).

1.6 Limitations

Although this study had a number of advantages compared to previous precooling research, some limitations did exist. These are: .

i.   The target population for this study was elite level cyclists and it was assumed that the subjects tested were representative of this

target population. To minimise the impact of this particular limitation, the best cyclists within the Ballarat community were selected as subjects. In addition, the follow-up study utilised AIS scholarship holders which were elite level cyclists.

ii.   The performance trial in this study was designed to reduce any precooling effect on the subjects' pacing strategy. While this protocol will contribute to the understanding of the mechanisms associated with the performance effect of a precooling technique, it is not indicative of race conditions. However, the time trial in the second of this series of experiments did not include a fixed component; hence, was representative of a competition time trial.

iii.   As a result of some subjects withdrawing and others unable to complete all of the trials in this study, the subject numbers were reduced to six. This also created an experimental design that was not ideally balanced in terms of the condition order effect. However, it should be remembered that subjects completed all three trials therefore acting as their own control.

1.7 Delimitations

i.   Subjects in this study were aged between 23 and 35 with a mean $\dot{V}O_{2peak}$ of 71.4 ±3.2 ml·kg^{-1}·min^{-1}. The data arising from this study are therefore representative of that group.

ii.   Ambient conditions in this study were ~34°C and 40% rh, which were considered to be representative of the temperature that would be experienced in Athens during the Olympic cycling time trial. The data from this study are therefore representative of those ambient conditions.

1.8 Definition of Selected Terms

T_{re}:   Rectal Temperature

$\overline{T}_{sk}$:   Mean Skin Temperature

$\overline{T}_{b}$:   Mean Body Temperature

$\dot{V}O_2$:   Oxygen consumption

$\dot{V}O_{2peak}$:   Peak Oxygen Consumption

$\dot{V}O_{2max}$:   Maximal Oxygen Consumption

MAP: Maximal Aerobic Power

RPE: Rating of Perceived Exertion

YTS: Young's Thermal Sensation Scale

TT: Time Trial

Chapter 2   Review of the Literature

This literature review was accepted for publication (pending acceptance of revisions) in Sports Medicine on December 2, 2004.

2.1 Introduction

Scientists have been investigating the effects of extreme ambient conditions on human performance and fatigue in both the industrial and athletic settings for many years. Recently, methods that improve athletic performance in the heat have received an increase in research attention, particularly in the lead up to the relatively hot Olympic games of 1996 in Atlanta, USA and 2004 in Athens, Greece. This issue of endurance performance in the heat is likely to receive more attention as athletes begin to prepare for what is likely to be a hot and humid Olympic games in Beijing, China in 2008.

Precooling the body is potentially an effective and legal means of improving athletic performance in the heat. The use of a precooling manoeuvre prior to competition is based on the concept that starting a contest with a cooler body will enable an athlete to increase their heat storage and perform more work prior to reaching a critical core body temperature and therefore delaying the point of fatigue. However, the mechanisms underlying the performance effects associated with precooling are not yet completely understood. More importantly for athletes, the optimal precooling methods for use in the competition environment have not been determined.

The purpose of this review, therefore, is to examine the results of previous precooling research and to provide evidence supporting the use of a precooling manoeuvre prior to endurance exercise performance in the heat. The potential underlying mechanisms potentially responsible for the improved endurance performance generally witnessed following precooling, as well as the practical issues associated with the use of a precooling manoeuvre for elite athletes will be addressed.

2.2 Precooling History

The effect of ambient temperature on physiological variables has interested scientists for many years, with body cooling playing a major role in these investigations. As early as the 1930's, researchers have been examining the human body's response to water baths of various temperatures (Bazett, Scott et al. 1937). Much of the early research on the topic of body temperature and exercise performance was conducted in the military and industrial occupation settings (Bell and Provins 1962; Gold and Zornitzer 1968; Vaughan, Higgins et al. 1968; Webb and Annis 1968; Falls and Humphrey 1970; Falls and Humphrey 1971; Grether 1973; Shvartz and Magazanik 1973; Shvartz, Saar et al. 1973; Shvartz, Saar et al. 1973). Today, the military continues to invest significant resources into methods that enable personnel to maintain or improve their performance in hot working conditions. The practical application of these methods to elite sport; however, is limited.

With the general acceptance that high ambient temperature and humidity have a detrimental effect on performance, the topic of whole body cooling and sport performance began to receive attention during the 1980's (Hartung, Myhre et al. 1980; Schmidt and Bruck 1981; Hessemer, Langusch et al. 1984; Patton and Vogel 1984; Geladas and Banister 1988; Olschewski and Bruck 1988; Livingstone, Nolan et al. 1989). These investigators examined the effects of a range of cooling techniques on a series of physiological variables, and this research resulted in the use of precooling manoeuvrers by elite athletes before competition in warm conditions.

Prior to the 1996 Olympic Games in Atlanta, Australian sport scientists documented that in professional cyclists, the maximal rectal temperature attained following a 30-min time trial in warm (32°C) and moderate (23°C) conditions was similar (~39.5°C), despite a 6% reduction in average power output in the warm condition (Tatterson, Hahn et al. 2000). As a result of these findings, and the apparent advantages of precooling described by earlier research, scientists at the Australian Institute of Sport (AIS) focussed on developing a practical method for implementing precooling with athletes in competition. A collaborative University – Commonwealth Scientific and Industrial Research Organisation (CSIRO) - AIS research team developed

a Neoprene ice jacket which was utilised by a number of Australian Olympians competing in the 1996 Atlanta Olympic Games (Martin, Hahn et al. 1998).

Since 1996, a number of publications have continued to address the topic of precooling and these papers have been carefully reviewed in a recent publication by Marino (2002). After reviewing the available literature, Marino (2002) concluded that "whole body precooling is able to increase the capacity for prolonged exercise at various ambient temperatures." However, Marino (2002) also indicated, that "further work must be completed using more practical performance protocols before firm conclusions can be drawn about the benefits of precooling for exercise performance". In particular, before recommendations can be made to coaches and athletes, research investigating precooling methods that can be used within the constraints of elite competition is required.

2.3 Precooling Methods

There are a number of ways that researchers have been able to artificially lower core body temperature (T_{core}) prior to exercise with the most common methods reported in the literature being exposure to cold air (Schmidt and Bruck 1981; Hessemer, Langusch et al. 1984; Olschewski and Bruck 1988; Lee and Haymes 1995; Mitchell, McFarlin et al. 2003) and cold water immersion (Bergh, Hartley et al. 1979; Booth, Marino et al. 1997; Gonzalez-Alonso, Teller et al. 1999; Kay, Taaffe et al. 1999; Marsh and Sleivert 1999; Booth, Wilsmore et al. 2001). A characteristic of precooling with cold air is that there is typically a rise in T_{core} during the precooling manoeuvre, which is likely a result of warmer peripheral blood being shunted to the core as a consequence of cold-induced vasoconstriction in the periphery (Lee and Haymes 1995; Marino 2002). The reduction in core temperature then occurs after exercise has begun, "presumably owing to an increased return of cooled venous blood with increasing skin blood flow" (Schmidt and Bruck 1981). This post precooling reduction in T_{core} is typically referred to as "the after drop" (Schmidt and Bruck 1981; Hessemer, Langusch et al. 1984; Marino 2002). However, despite the apparent effectiveness of precooling with cold air, it does present some difficulties. Firstly, the time required to achieve a physiologically significant reduction in T_{core} (>0.3°C) can be considerable, taking up to

130 min and often requiring transient rewarming periods to reduce subject shivering and to blunt the metabolic response to the sudden change in ambient conditions (Schmidt and Bruck 1981; Hessemer, Langusch et al. 1984; Olschewski and Bruck 1988; Marino 2002). In addition, this type of precooling manoeuvre can be quite uncomfortable for the subject and therefore may not lend itself for use by elite athletes prior to competition.

As reported by Marino (2002), the use of cold water immersion can avoid the abrupt cold stress response associated with exposure to cool air. This is achieved by gradually dropping the temperature of a water bath from ~29°C to ~22°C over a 60 min period (Marino and Booth 1998). Although the use of water immersion avoids some of the discomfort associated with cold air exposure, the time required to achieve a reduction in T_{core} is still considerable (30-60 min), and while effective in the laboratory setting, imposes considerable logistical problems for use in the field. More recently, the use of practical precooling methods such as cooling jackets have been utilised. These cooling garments have been shown not only to be practical in the field, but sufficiently powerful to blunt the rise in T_{core} during a warm up and enhance performance (Cotter, Sleivert et al. 2001; Arngrimsson, Petitt et al. 2004).

Different precooling methods influence the body in different ways; some methods reduce only skin temperature (i.e. jackets, mist fans, cool air), others reduce skin temperature as well as core temperature (i.e. water bath, cold room, combination treatment), while others reduce core temperature without an effect on skin temperature (i.e. ingestion of cold water, breathing cool air, cold intravenous saline, Ava-core™). Previously, it was thought that a reduction in T_{core} was an important aspect associated with the reduced thermal strain and performance improvement following precooling. However, Kay and colleagues (1999) recently reported "skin precooling in the absence of a reduced rectal temperature is effective in reducing thermal strain and increasing the distance cycled" in a 30 min self-paced cycling time trial. While improvements in performance may be apparent when skin temperature is reduced without a concomitant reduction in T_{core}, it is yet to be established which is more effective at improving

performance or, if a greater reduction in T_{core} results in a greater improvement in performance.

Today there are a number of commercially available cooling products that can be used by athletes. These products include ice jackets, cooling jackets using novel fabrics and coolants, a rapid thermal exchange device, fans that produce an ice mist, plunge pools, cold showers and portable tents with air-conditioning units that produce a cool micro-climate. However, the effect on performance of a number of these commercially available products is yet to be independently tested. In addition, each of these precooling techniques differs greatly in regards to cooling power, athlete comfort and physiological effects. Further, when examining precooling techniques for use in competition, a number of practicality issues need to be considered, including transport, cost, ease of application, access to power, water, refrigerators, staffing of the precooling method, athlete comfort and pre-event routine, consumption of pre-event meals, registration and other pre-event commitments an athlete may have. Further, very few precooling studies account for the significant effect of an athletes' warm up prior to performance. Often an elite athlete, in particular an elite cyclist, can warm up for periods of greater than one hour and at exercise intensities that considerably increase T_{core}. Studies comparing the effectiveness of each of the different types of precooling methods are yet to be completed, and very few studies published to date have taken into consideration the practicalities of using these methods in the field during actual competition.

2.4 Precooling and Performance

As depicted in Table 1, studies investigating the performance effects of a precooling manoeuvre have utilised a range of exercise protocols. Bergh & Ekblom (1979) used an arm and leg exercise to exhaustion protocol (exhaustion within 5-8 min) after cold water immersion (13-15°C) and reported a significant reduction in physical performance and Crowley et al. (1991) reported that cooling the legs resulted in a reduced peak and average power during a standard Wingate test. In contrast, Marsh & Sleivert (1999) reported a 2.7% improvement in mean 70 s power output following 30 min of water immersion (18-14°C). Other authors have examined the effects of

precooling on intermittent exercise performance, with Drust et al. (2000) reporting no performance effect of lowering T_{core} (0.6°C) with a cool shower prior to a simulated soccer game (2 x 45 min periods separated by 15 min). In addition, Bolster et al. (1999) showed no significant thermoregulatory advantage after investigating the impact of water immersion (~25°C) on triathlon performance. Despite the contradictory findings associated with precooling and short term exercise, and the apparent lack of effect on intermittent exercise performance, there is considerable support for the use of a precooling manoeuvre with more prolonged endurance exercise. Lee & Haymes (1995) showed that exposure to cold air reduced T_{core} by 0.37°C and improved run time to exhaustion at 82% $\dot{V}O_{2max}$. Similarly, Booth et al. (1997) reported that runners were able to travel 4% further in 30 min after cool water immersion (23-24°C). Similar results have been observed for cycling, with Schmidt & Bruck (1981) and Olschewski & Bruck (1988) reporting increased time to exhaustion after cold air exposure (0°C), and Hessemer et al. (1984) recorded an increase in work rate during a 60 min cycling test after cold air exposure (0°C). While all of these studies have shown a favourable effect of precooling, it must be noted that all performance tests in these studies were conducted in cool ambient conditions (18 - 22°C), thus limiting the ability to translate the findings to use in warm field conditions.

The small number of laboratory studies examining the influence of whole body cooling prior to exercise performance in hot conditions appears promising. González-Alonso et al. (1999) showed that cyclists can increase their ride time to exhaustion at 60% $\dot{V}O_{2max}$ in ambient conditions of ~40°C and 19% relative humidity (rh) after 30 min of water immersion, while Kay et al. (1999) showed that cold water immersion increased distance cycled in 30 min by almost 1 km in ambient conditions of 31.4°C and 60.2% rh.

Although there is considerable literature available purporting performance improvements associated with precooling, apart from a recent study by Arngrimsson et al. (2004) who reported an improved 5-km run time after the use of a cooling jacket during warm up, the "benefits for exercise performance can only be inferred given that most studies have not used performance-based exercise protocols" (Marino 2002). In

addition, interpretation is made more difficult by the various ambient conditions utilised for different studies.

It is apparent from the published literature that the use of a precooling manoeuvre can influence exercise performance. However, the nature of this impact on performance is affected by several factors including the extent of body cooling (method, duration and intensity), the type of exercise (duration, mode and intensity), ambient environmental conditions, and the training status and heat tolerance of the individual.

Further research is required to determine which cooling methods are most effective for particular types of exercise and this research needs to consider some of the important practical applications for elite athletes in competition, particularly the potentially confounding effect of an athlete's warm up.

Table 1. Summary of precooling studies and associated performance outcomes

Study	Method of Cooling	Change in T_{core}	Exercise Protocol	Ambient Conditions	Conclusion
Bergh & Ekblom (1979)	Water immersion (13-15°C)	Not reported	Arm & leg exercise to exhaustion (5-8 min)	20 - 22°C	Performance reduced (from 6.08 min to 4.36 min) after precooling
Sleivert et al (2001)	Torso only cooling (ice jacket) and whole body cooling (ice jacket +water perfused cuffs around the legs)	Not reported	45 s performance test	33°C 60% rh	Whole body cooling resulted in a ~7% reduction in both mean and peak power, whereas torso only cooling had no effect on power production
Marsh & Sleivert (1999)	30 min water immersion, torso only (18 – 14 °C)	0.3°C reduction in rectal temperature	70 s cycling power test	29°C 80% rh	Following precooling, mean 70s power output was increased by 2.7%
Drust et al. (2000)	Cool shower (26°C) for 60 min	0.6°C reduction in rectal temperature	2 x 45 min intermittent exercise periods on a non-motorised treadmill (separated by 15 min)	20°C	No change in physiological variables after precooling
Booth et al. (1997)	Water immersion (28-24°C)	0.7°C reduction in rectal temperature	Maximum distance run on a treadmill in 30 min	31.6°C 60% rh	Increased distance run by 4% after precooling
Crowley et al. (1991)	Water immersion, legs only (11.5°C)	0.4°C reduction in rectal temperature	Wingate anaerobic power test	Not reported	Cooling reduced peak power, average power, and cumulated work
Kay et al. (1999)	Water immersion (24°C)	No change in rectal temperature	30 min cycling time trial	31.4°C 60.2% rh	0.9km (6%) increase in distance cycled following precooling
Lee & Haymes (1995)	Cold air exposure (5°C)	0.37°C reduction in rectal temperature	Running to exhaustion at 82% of VO_{2max}	24°C 51-52 % rh	Improved rate of heat storage and increased time to exhaustion (121%) with precooling

Mitchell et al. (2003)	Cold air exposure (22°C) with fan and mist cooling	0.17°C reduction in oesophageal temperature	Running to exhaustion at 100% of maximal aerobic power	38°C 40 % rh	Time to exhaustion was reduced by 30 s after precooling
Hessemer et al. (1984)	Cold air exposure (0°C)	0.4°C reduction in oesophageal temperature	60 min work rate test	18°C	6.8% increase in mean 1-h work rate after precooling
Schmidt & Bruck (1981)	Cold air exposure (0°C)	1.0°C reduction in oesophageal temperature	Cycling with increasing workload to exhaustion	18°C	No significant increase in time to exhaustion
Olschewski & Bruck (1988)	Cold air exposure (0°C)	0.2°C reduction in core temperature	Cycling at 80% of VO_{2max} to exhaustion	18°C 50% rh	Time to exhaustion was increased by 12% following precooling
Yates et al. (1996)	Cooling vest worn during warm up	Not reported	1000 m rowing ergometer test	33°C 60% rh	3s (1.3%) improvement in 1000m rowing performance following precooling
Arngrimsson et al. (2004)	Cooling vest worn during warm up	0.21°C reduction in rectal temperature	5 km run on a treadmill	32°C 50% rh	5km run time was improved (1.1%) following precooling
Cotter et al. (2001)	Ice vest + cold air exposure (3°C)	0.5°C reduction in rectal temperature	15 min work performance test	32°C	16% improvement in mean power out put after precooling

2.5 Proposed Mechanisms

2.5.1 Critical Core Body Temperature

Continuous exercise results in an increase in body temperature that is proportional to the metabolic rate, and steady state levels of exercise can be maintained when heat production is matched by heat loss (Marino 2002). In warm ambient conditions, due the decreased temperature gradient between the body and the environment and the subsequent reduced ability of the body to maintain heat loss, the rise in T_{core} while exercising is exaggerated. In these conditions, it has been suggested that the body will intuitively adopt a pacing strategy or adjust the workload to ensure a critical T_{core} is not exceeded (Gonzalez-Alonso, Teller et al. 1999; Marino 2002; Marino, Lambert et al. 2004). This concept is supported by Tatterson et al. (2000), who found that T_{core} at the conclusion of a 30 min cycling time trial was similar despite a 6% reduction in power output in ambient conditions of 32°C compared to 23°C and this concept of a critical core temperature (~40°C) that limits exercise performance has been widely reported (Falls and Humphrey 1971; Schmidt and Bruck 1981; Hessemer, Langusch et al. 1984; Patton and Vogel 1984; Geladas and Banister 1988; Olschewski and Bruck 1988; Lee and Haymes 1995; Febbraio, Murton et al. 1996; Marino 1996; Yates; Booth, Marino et al. 1997; Galloway and Maughan 1997; Smith, Yates et al. 1997; Wimer, Lamb et al. 1997; Fuller, Carter et al. 1998; Marino and Booth 1998; Martin, Hahn et al. 1998; Gonzalez-Alonso, Teller et al. 1999; Kay, Taaffe et al. 1999; Marsh and Sleivert 1999; Drust, Cable et al. 2000; Kay and Marino 2000; Cotter, Sleivert et al. 2001; Gandevia 2001; Marino and Booth 2001; Sleivert, Cotter et al. 2001; Marino 2002; Cheuvront, Kolka et al. 2003; Mitchell, McFarlin et al. 2003; Marino, Lambert et al. 2004). This behavioural response, that is observed across a number of species, reduces metabolic heat production when a critical T_{core} is reached, and may be a mechanism that protects physiological integrity at times of high endogenous and/or exogenous heat load (Fuller, Carter et al. 1998; Cheung and Sleivert 2004). Further, the concept that a critical T_{core} limits exercise is supported by reports that individuals tend to stop exercise at a similar T_{core} irrespective of hydration status, glucose availability (Febbraio, Murton et al. 1996) or starting T_{core} (Gonzalez-Alonso, Teller et al. 1999). However, the notion that fatigue ensues once the critical T_{core} is

reached has recently been challenged. It has been proposed that fatigue doesn't set in once a critical temperature is reached, but rather, the rate of heat storage is sensed by the body, which then anticipatorily adjusts the work rate to ensure the exercise task can be completed within the homeostatic limits of the body (Kayser 2003; St Clair Gibson, Baden et al. 2003; Marino, Lambert et al. 2004; Noakes and St Clair Gibson 2004; Lambert, St Clair Gibson et al. 2005). This antipatory concept is supported by the findings of a recent study by Tucker et al. (2004). In this study, subjects were required to complete two 20 km self paced cycling time trials, one at 35°C (Hot) and one at 15°C (Cool). In the Hot time trial, subjects reduced their pace after only 30% of the time trial was completed, in the absence of any thermal stress. Tucker et al. (2004) proposed that this early reduction in power output in the heat is a part of an anticipatory response that ensures the reduction of heat production and therefore the maintenance of thermal homeostasis.

As suggested by Cheung & Sleivert (2004), there are two potential areas that may contribute to a reduced ability to exercise in the heat. Thermal strain and the associated increase in brain temperature may directly contribute to fatigue by impairing central arousal and/or the voluntary activation of muscle. As well, the considerable degree of cardiovascular strain and impaired blood flow to the brain and splanchnic tissues may enhance fatigue in hyperthermic conditions. It is possible that the use of a precooling manoeuvre may enhance performance by increasing the time taken for an athlete to reach this critical T_{core} or rather provide a greater capacity to store heat; however, the influence of precooling on the potential underlying fatigue mechanisms while exercising in hyperthermic conditions are not yet completely understood.

2.5.2 Potential Central Mechanisms of Fatigue

There is growing support for the notion that a reduced central nervous system (CNS) drive may play a significant role in the development of fatigue in hot environments (Fuller, Carter et al. 1998; Nielsen, Hyldig et al. 2001; Nunneley, Martin et al. 2002; Kayser 2003; Nybo, Nielsen et al. 2003; Schillings, Hoefsloot et al. 2003; St Clair Gibson, Baden et al. 2003; Cheung and Sleivert 2004; Tucker, Rauch et al. 2004).

In a recent investigation by Nybo & Nielsen (2001), it was reported that a high internal body temperature caused muscles that were not utilised during a primary exercise task to reduce their force output, and that this impairment in performance was associated with a reduction in the voluntary activation percentage of the muscle. Two potential mechanisms may contribute to a reduced central drive; the descending impulses from higher cortical structures to motor neurones may be reduced and/or afferent feedback (Type III/IV afferent fibres) may reduce excitability of motor neurones sub-cortically (Cheung and Sleivert 2004). As comprehensively reviewed by Febbraio (2000), some of the factors that have been suggested to be involved with this central limit to exercise performance in the heat include the influence of a higher than normal temperature on the CNS and neurohumoral responses. Nielsen et al. (2001) reported reduced brain activity (specifically, reduced β-wave activity [13-30Hz]), similar to that observed during sleep, while subjects exercised in hot compared to cool ambient conditions. This reduced brain activity may reflect a reduced state of arousal resulting in decreased exercise performance in hyperthermic conditions (Nielsen, Hyldig et al. 2001; Cheung and Sleivert 2004). A reduction in neural activity at the point of fatigue in the heat may also be related to changes in neurohumoral factors (Kayser 2003; Schillings, Hoefsloot et al. 2003; St Clair Gibson, Baden et al. 2003). Disturbances in neurotransmitter levels, particularly dopamine and 5-hydroxytryptamine (5-HT or serotonin), have been implicated in central fatigue, as serotonin influences levels of arousal, and dopamine is involved in the initiation of movement and may also inhibit serotonin production (Cheung and Sleivert 2004). Recently, Hasegawa and colleagues (2004) found that by inhibiting the reduction in dopaminergic activity via a dopamine and norepinephrine reuptake inhibitor during exercise in the heat, subsequent performance improved. Further, Robson-Ansley et al. (2004) found that administration of exogenous recombinant interleukin-6, a polypeptide messenger molecule that is actively produced during exercise, resulted in increased serum prolactin concentration and a subsequent reduction in performance. As prolactin has previously been used as a marker for serotonin activity, the reduction in performance may have been related to reduced arousal as a result of increased serotonin activity (Robson-Ansley, de Milander et al. 2004). However, Nybo et al. (2003) reported that after prolonged exercise in hyperthermic conditions, the cerebral tryptophan balance, the transporter of serotonin across the blood-brain barrier, was not different when compared to normothermic conditions. This led these authors to conclude that serotonin might not be related to the

enhanced perception of effort and the fatigue associated with exercise in the heat (2003). Alternatively, it has been suggested by Nybo et al. (2003) that central fatigue may be related to glycogen depletion in the brain. This suggestion was based on the finding that glucose uptake in the brain was enhanced during recovery from hyperthermic exercise (Nybo, Nielsen et al. 2003). This assumption is supported by earlier findings from the same group of researchers who reported an 18% reduction in global cerebral blood flow in exercising hyperthermic subjects compared to normothermic subjects (Nybo, Moller et al. 2002). This reduction in global cerebral blood flow may potentially lead to the glycogen depletion in the brain during exercise in the heat and may therefore contribute to central fatigue.

It should be appreciated that the body's response to thermal strain does not begin once a critical T_{core} is reached, rather it responds before the point of homeostatic crisis occurs. Marino (2004) reported that runners exposed to warm ambient conditions reduced their running speed well before T_{core} became excessively hot (T_{core} <38.5°C). Therefore, reduced performance in the heat may not be so much a fatigue process, but rather an "anticipatory regulation process influenced by rates of heat storage" (Cheung and Sleivert 2004).

It is apparent from the literature that central fatigue plays a role in reduced performance during hyperthermic conditions and the underlying components of this fatigue are likely to be multi-factorial. The use of a precooling manoeuvre prior to high-intensity exercise in the heat may be a useful model to help understand some of the mechanisms associated with fatigue in the heat. A potential mechanism related to the increased capacity to perform work after precooling is enhanced heat storage (Olschewski and Bruck 1988; Lee and Haymes 1995; Booth, Marino et al. 1997; Kay, Taaffe et al. 1999). Kay et al. (1999) used water immersion to precool the skin without a concomitant reduction in T_{core} and reported an increase in heat storage from 84 $W \cdot m^{-2}$ to 153 $W \cdot m^{-2}$. In addition, Booth et al. (1997) showed an increase in heat storage from 113 $W \cdot m^{-2}$ to 249 $W \cdot m^{-2}$ after reducing T_{core} by 0.7°C with cold water immersion. Therefore, the use of a precooling manoeuvre may delay the onset of the CNS-related protective mechanism that reduces exercise intensity as the body approaches its critical core

temperature. This "artificially enhanced capacity for heat storage" has become one of the most prominent explanations for improvements in performance following a precooling manoeuvre. However, it is not yet clear how increasing heat storage capacity prior to exercise in the heat affects these central fatigue components.

2.5.3 Thermoregulation, Cardiovascular Strain and Endotoxemia

The second potential mechanism that reduces an athlete's ability to perform exercise in the heat is the influence of heat strain on the cardiovascular system. In hot environments, the body's heat dissipation mechanisms compete with active muscle for blood flow. This increased blood flow to the skin for heat dissipation results in a greater cardiovascular strain for a similar workload in the heat compared to cool environments (Galloway and Maughan 1997) and a number of studies have shown that exercise heart rate for a given workload is reduced after precooling (Schmidt and Bruck 1981; Hessemer, Langusch et al. 1984; Lee and Haymes 1995). When skin and core temperature are reduced, it is likely that less blood flow is required for heat dissipation, resulting in an increased central blood volume, an increased stroke volume and an associated reduction in heart rate for a given exercise intensity after a precooling manoeuvre (Hessemer, Langusch et al. 1984; Patton and Vogel 1984; Lee and Haymes 1995; Marino 2002; Mitchell, McFarlin et al. 2003; Arngrimsson, Petitt et al. 2004). However, the effects of precooling on heart rate appear to dissipate after 10-15 min of exercise, with no differences apparent at the end of exercise (Booth, Marino et al. 1997; Marino 2002). In addition, studies investigating blood and plasma volume changes during fatiguing exercise in the heat report no significant changes (Galloway and Maughan 1997; Marino and Booth 2001; Marino, Mbambo et al. 2001; Marino 2002). Therefore, although the use of precooling results in a reduced thermal strain and an associated delay in the onset of sweating, changes in blood and plasma volumes are unlikely to contribute significantly to any performance benefit.

Alternatively, Sakurada & Hales (1998) have reported a marked reduction in gastro-intestinal blood flow in sheep when exercising in hyperthermic conditions. This redirection of blood flow from the abdominal region to enable necessary cooling can

result in a leakage of endotoxins from the gut into the circulation resulting in an endotoxemia triggered cytokine response. As reviewed by Davis & Bailey (1997), CNS fatigue may be influenced in the presence of such a cytokine response. In addition, the presence of cytokines may produce a more direct influence on fatigue within the active muscle. Supinski and colleagues (2000) have reported a 20-40% reduction in maximal force generating capacity of skinned rat muscle when exposed to endotoxins, and these authors speculate that this reduction in maximum force was a result of alterations in the contractile proteins. It is possible that the reduced thermal strain during exercise after precooling may minimise any reduction in abdominal blood flow, thereby delaying the leakage of endotoxins into the circulation and consequently contributing to improved performance.

2.5.4 Metabolic Disturbances

Disturbances to metabolism and cellular processes have also been suggested as potential mechanisms associated with reduced performance in the heat (Febbraio 2000). Metabolic perturbations are typical during exercise in the heat, and it has been reported that exercising in a hot environment augments the endogenous release of epinephrine and this in turn enhances carbohydrate utilisation via the β-adrenergic stimulation of glycogen phosphorylase (Bergh, Hartley et al. 1979; Richter, Ruderman et al. 1982; Febbraio, Lambert et al. 1998). Therefore, it has been suggested that blunting the rise in core temperature during exercise in the heat may result in an attenuation of net muscle glycogen utilisation (Febbraio, Snow et al. 1996; Febbraio 2000; Marino 2002). However, muscle glycogen content at the point of fatigue in the heat has been reported to be greater than at the point of fatigue in comfortable ambient conditions, indicating that glycogen depletion is not likely to be a cause of fatigue in the heat (Nielsen, Savard et al. 1990; Parkin, Carey et al. 1999). In addition, Booth et al. (2001) reported a reduced body temperature and cardiac frequency after whole body precooling, but found no differences in muscle glycogen, triglyceride, adenosine triphosphate, creatine phosphate, creatine or lactate contents following 35 min of exercise in 35°C and 50% rh compared to control conditions, thereby suggesting that precooling does not impact on metabolism. In addition, $\dot{V}O_2$ and the respiratory exchange ratio have been reported to

be unchanged following precooling, and there appears to be no relationship between $\dot{V}O_2$ and exercise performance after precooling (Lee and Haymes 1995; Booth, Marino et al. 1997; Kay, Taaffe et al. 1999).

2.6 Conclusion

With the popularity of summertime sports and the potential for another hot Olympic games in Beijing in 2008 it is likely that sport scientists will investigate methods that minimise the detrimental effects of hot ambient conditions on human athletic performance. Precooling the body prior to endurance exercise in the heat has been shown to have positive effects on exercise performance. While it is generally accepted that increasing the body's heat storage capacity is a primary mechanism that enables precooling to improve endurance exercise performance in the heat, the influence of increased heat storage capacity on brain activity, neurohumoral factors, cardiovascular strain and metabolism requires further investigation. Thus, before practical advice can be provided to athletes and coaches, research is required to identify which precooling strategies are optimal (physiologically, perceptually and logistically) during different types of elite endurance competition.

Chapter 3   Methodology

3.1 Subjects

Nine well-trained male cyclists from the local Ballarat, Victoria cycling community volunteered to participate in this experiment. Due to technical, personal and fitness reasons, three subjects were subsequently omitted from the study; hence, a total of six subjects completed all required testing sessions and were included in the statistical analyses. Each subject was informed of the associated risks, safeguards and experimental protocol and written informed consent was obtained (Appendix 1 – Informed Consent). The procedures used in this study were approved by the human research ethics committees of the Australian Institute of Sport, the University of Ballarat and Edith Cowan University (Appendix 2 – Ethics Approval).

3.1.1 Subject Preparation

Subjects were instructed to abstain from intense exercise in the 24 h period prior to each experimental trial and were asked to record any training that was completed. In the 24 h prior to each trial, subjects reported that they rode 46.3 ±26.2 km at an 'easy' intensity. Subjects were provided with instructions for consuming an appropriate amount of food and fluid in the 24 h prior to each trial (Appendix 3 – Dietary Standardisation). In addition, subjects were requested to complete a food diary for the day prior to each experimental trial and then repeat this diet for subsequent testing sessions. Revision of each food diary indicated that subjects consumed the same diet in the 24 h prior to each trial. All subjects were free from illness during each of the experimental trials.

3.2 Protocol and Procedures

3.2.1 Anthropometric Measures

Body mass, height, and body composition were determined for descriptive purposes at the subject's first visit to the laboratory. Subjects stood quietly with arms hanging by their side on a set of scales (0-150kg ±0.02 kg, Avery & Berkel, Taiwan) wearing only their cycling shorts and body mass was recorded to the nearest 0.1 kg. Height was determined in accordance with Norton et al. (2000) using a wall mounted stadiometer. Skinfold measurements were taken by a Level 2 International Society for the Advancement of Kinanthropometry (ISAK) accredited Anthropometrist across seven sites (Triceps, Subscapular, Biceps, Supraspinale, Abdominal, Mid Thigh and Calf) as outlined by Norton et al (2000), using calibrated Harpenden skinfold callipers (British Indicators, England).

3.2.2 Progressive Exercise Tests

Each subject reported to the laboratory on two separate occasions, separated by 14 ±2 d to complete a progressive exercise test for the determination of peak oxygen uptake ($\dot{V}O_{2peak}$) and lactate threshold. Subject's completed two progressive exercise tests to ensure an accurate assessment of their aerobic capacity was made and to ensure each subject was familiar and comfortable with the laboratory setting. Subject 5 was recruited after the others had completed one of the two tests; hence, he only completed one progressive exercise test. The $\dot{V}O_{2peak}$ test was conducted on a Velotron cycle ergometer (Racermate Inc., Seattle, Washington), which was fitted with the subject's own cycling pedals and shoes. After a 10 min warm up at 100 W, the test protocol started at 100 W and increased by 50 W every 5 min until volitional exhaustion. Maximal Aerobic Power (MAP) was calculated as per Equation 1.

$$MAP (W) = W_L + [(t/5) \times 50]$$

Equation 1. Calculation of Maximal Aerobic Power. W_L = the power output of the last complete workload (W), t = the time (min) for the final incomplete workload and 5 and

50 are the increments for each workload for time (min) and power output (W), respectively.

Expired air and ventilation rate were measured every 20 s during this test using a Vmax metabolic cart (SensorMedics, 29 Series, Yorba Linda, CA). The metabolic cart was calibrated immediately before each test using certified beta gas mixtures (CIG β gas, Melbourne, Victoria), and a 3 L syringe. $\dot{V}O_{2peak}$ was recorded as the average of the two highest consecutive $\dot{V}O_2$ values attained during the incremental test. In addition to calculating $\dot{V}O_{2peak}$, heart rate was measured using a Polar Vantage NV heart rate monitor (Polar Electro OY, Kempele, Finland). A finger-stick blood sample was collected at the end of each 5 min step and analysed for lactate using an Accusport Lactate Meter (Boehringer, Mannheim). Lactate threshold was defined as the point during the test at which there was a 1 mmol·L^{-1} increase in blood lactate above baseline levels (Coyle, Martin et al. 1983), and determined in conference by two experienced exercise physiologists.

3.2.3 Familiarisation Time Trial

A familiarisation time trial was performed 31 ±1 d following the second $\dot{V}O_{2peak}$ test to: 1) ensure subjects were comfortable with all experimental procedures, 2) enable a practice run at the performance trial, and 3) minimise any learning effect between experimental trials (Williams, Montfort-Steiger et al. 2004). The familiarisation time trial was also used to ensure that appropriate workloads were selected for the experimental performance trials. If subjects were unable to cope with the selected workloads during the familiarisation trial (i.e. unable to finish the performance trial), the workload was adjusted for the experimental trials (Appendix 4 – Prescribed and Adjusted Workloads). Subjects were prepared as per experimental trials (Section 3.2.4) except for an in-dwelling cannula in an antecubital vein. Once preparation was complete, subjects were shown the plunge pool and cooling jacket which were to be used in the experimental trials. They then entered the heat chamber (34°C and 40% rh) and sat quietly for 40 min. After this period, subjects moved onto an

electromagnetically braked cycle ergometer (Excalibur Sport, Lode, Groningen, Netherlands) and commenced their individual warm up protocol as outlined in section 3.2.4.4. Following the warm up, subjects completed the performance trial as described in section 3.2.4.5.

3.2.4 Experimental Trials

Forty-eight hours following the familiarisation trial, subjects performed the first of three experimental time trials; each of the subsequent trials was also separated by 48 h, consequently all trials were completed at the same time of day. A repeated measures crossover design was used, which was initially balanced (n=9), but due to the withdrawal of three subjects (previously described, section 3.1), the resulting design was not ideally balanced (Table 2). Consequently only one subject performed the Combination condition first, two subjects performed the Jacket condition first, and three subjects performed the Control condition first.

Table 2. Experimental treatment order

| | TREATMENT | | |
SUBJECT	Trial 1	Trial 2	Trial 3
1	Control	Combination	Jacket
2	Combination	Jacket	Control
3	Jacket	Control	Combination
4	Control	Combination	Jacket
5	Control	Jacket	Combination
6	Jacket	Combination	Control

3.2.4.1 Experimental Conditions

Three experimental conditions were investigated as depicted in Figure 5. During the Control trial, subjects sat quietly in a temperature controlled room (25.1 ±1.4°C) next to the plunge pool for a period of 30 min and then sat quietly in the heat chamber (34.4 ±0.2°C) for 40 min prior to starting the warm up and the performance trial. During the Jacket trial, subjects sat in the same temperature controlled room (25.1 ±1.4°C) beside the plunge pool for 30 min before moving to the heat chamber (34.5 ±0.3°C) where they wore a cooling jacket for 40 min before removing the jacket and beginning the warm up and the performance trial. During the Combination experimental condition, subjects were exposed to a plunge pool for 30 min, which was located in the same temperature controlled room (24.4 ±1.6°C). Following the plunge pool, subjects moved to the heat chamber (34.1 ±0.2°C) and sat wearing a cooling jacket for a period of 40 min, before removing the jacket and commencing the warm up and performance trial. Upon presentation at the laboratory subjects were instructed to consume 250 ml of 50% sports drink (Gatorade, Chicago IL) and were also provided with another 250 ml of the same sports drink that was to be consumed during the time trial. The plunge, jacket, warm up and performance trial protocols are described in detail below.
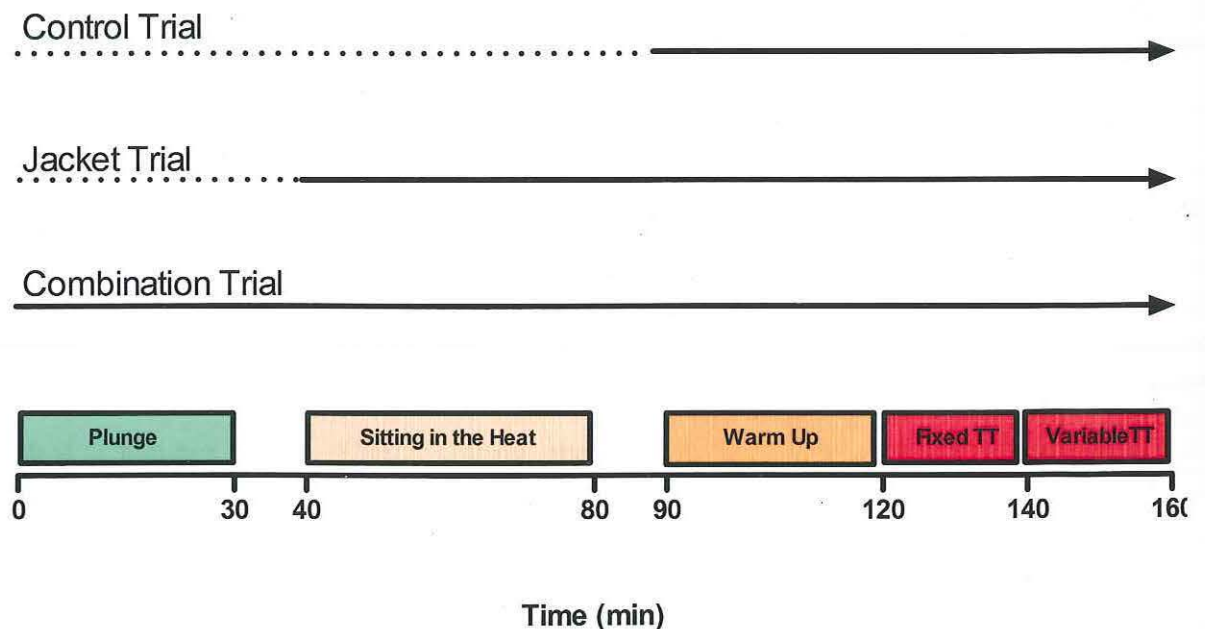
Figure 5. Figure depicting experimental design

3.2.4.2 Plunge Protocol

After preparation with rectal and skin temperature probes, heart rate monitor and in-dwelling cannula, subjects sat quietly for a period of 10 min prior to the collection of all baseline measures in a room that was 24.4 ±1.6°C. Subjects undergoing the Combination treatment were immersed in a plunge pool (Portacovery™, Australia), while subjects in the Jaeket and the Control trials sat quietly in a chair beside the plunge pool. The Portacovery™ plunge pool is an inflatable plastic pool holding ~420 L with dimensions of 1.6 m x 0.6 m x 0.8 m (Figure 6.). Subjects entered the water and semi-reclined with the water level at the neck for a period of 30 min. Time in the plunge pool commenced once the subject's chest thermistor was below the water line. The immersion protocol was modified from that of Marino & Booth (1998) to attain a similar cooling effect in a shorter time period. On immersion, water temperature was 28.8 ±0.5°C and this was maintained for the first five minutes. Water temperature was then reduced at a rate of ~0.2°C·min^{-1} so that the water temperature was 24.0 ±0.1°C after 30 min of immersion. The water temperature was reduced by adding an ice-slurry to the pool and stirring the pool to maintain an even temperature distribution and to avoid the creation of a warm layer of water around the subject's body. Water temperature was continuously monitored with a Testo 781 thermometer (Testo Term, Germany). At the end of the 30 min water immersion, subjects exited the pool, towelled dry and moved to the heat chamber for the next component of their trial.

3.2.4.3 Jacket Protocol

For the Jacket protocol, subjects entered the heat chamber (33.7 ±1.0°C) and were seated away from any direct air flow and the radiant heat source (Appendix 5 - Heat Chamber Floor Plan). During the Jacket and Combination experimental conditions, subjects wore a cooling jacket, while in the Control condition subject's sat quietly without a cooling jacket. The cooling jacket was developed by RMIT University (Melbourne, Australia) and is a waist length jacket with long sleeves and a hood (Figure 7.). The jacket is constructed from a polyester blend outer shell with a phase change

material (PCM) sewn on the inside. The PCM used in this jacket is designed to change phase at a temperature of 20°C, making the temperature inside the jacket being worn approximately 20°C. As subjects had one arm cannulated, they were unable to put this arm into the sleeve of the jacket. Therefore, the cannulated arm was zipped inside the jacket with a spare hood wrapped around the elbow to maximise the amount of skin exposed to the jacket. After a period of 40 min sitting quietly wearing the jacket, the jacket was removed and the subject began their individual warm up protocol.

3.2.4.4 Warm Up Protocol

Using the results from the progressive exercise test, each subject was prescribed a standard warm up protocol that is typically utilised by professional cyclists prior to a ~40 min time trial in the heat (personal communications, Dr. D.T. Martin). The prescribed warm up was 20 min in total and consisted of 3 min at 25% of MAP followed by 5 min at 60% of MAP then 2 min at 80% of MAP. This progression was completed twice (Appendix 4 - Prescribed & Adjusted Workloads). During the familiarisation trial, Subjects 1, 2, 3 and 6 were unable to complete the performance trial at 80% of their individual MAP. Therefore, the required power output for these subjects was adjusted (Appendix 5 – Prescribed and Adjusted Workloads). The warm up was completed on a calibrated Lode Excalibur Sport cycle ergometer (Groningen, Netherlands) that was fitted with the subject's own cycling pedals. The ergometer used during the warm up was situated away from both the radiant heat source and the fan used during the performance trial.
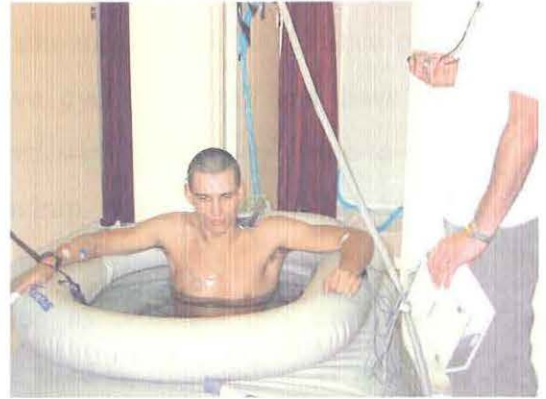
Figure 6. Plunge Pool.
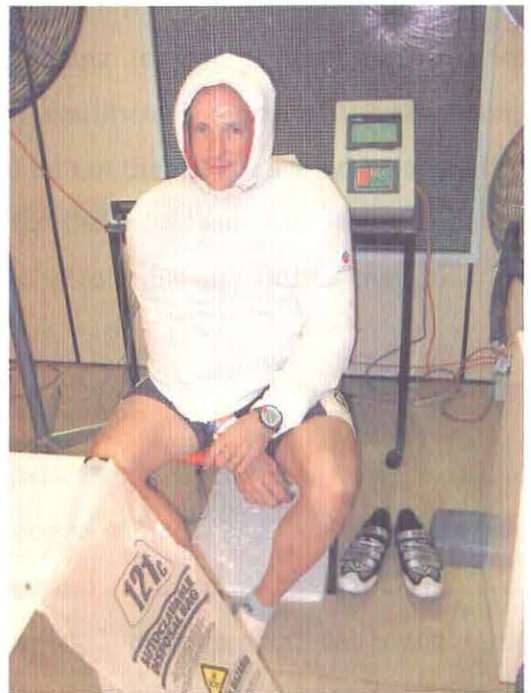
Figure 7. RMIT-AIS cooling jacket.

3.2.4.5 Performance Trial

The performance trial used in this study was a time trial protocol as opposed to a time-to-exhaustion protocol. This was due to the fact that "closed-loop" time trial protocols (where the subject is aware of the amount of work or distance required to complete) are more applicable to competitive cycling events and have a greater reliability associated with them when compared with "open-loop" time-to-exhaustion protocols (Coyle, Feltner et al. 1991; Jeukendrup, Saris et al. 1996). As the 2004 Olympic Cycling Time Trial was expected to last for approximately 40 min, the performance trial in this study was designed to replicate this time frame. The performance trial in this study, similar to that used by Jeukendrup et al. (1996) and Cotter et al. (2001), was divided into two components, a fixed workload component and a variable workload component, each requiring the subject to complete the same amount of work (kJ). The fixed workload component was included in the performance trial to reduce any effect of changes in pacing strategy resulting from the different experimental protocols on the various physiological variables (Cotter, Sleivert et al. 2001) and therefore allowed for an investigation into the physiological effects resulting from the different experimental conditions. The disadvantage to this type of performance protocol is the reduced ability to determine any detrimental effects of the precooling manoeuvre on pacing strategy during the first 20 min of the trial. It should be noted that a follow up study is planned that will not fix the workload after the precooling manoeuvres, allowing an investigation into any effects that precooling may have on pacing strategy.

The first half of the performance trial was originally fixed at a workload of ~80% of MAP for a period of 20 min and reduced in subjects 1, 2, 3, and 6 following the familiarisation trial (Appendix 5 – Prescribed and Adjusted Workloads). The fixed component of the performance trial was completed on a second calibrated Lode Excalibur Sport cycle ergometer (Groningen, Netherlands), which was operating in hyperbolic mode. This mode of operation results in a constant power output that is independent of cadence. The Lode ergometer achieves this by varying the resistance applied to the pedals as the cyclist changes their pedalling frequency. The work (kJ)

completed in the fixed workload component was calculated by multiplying the power output (W) by time (s) as a Watt is the work completed at a rate of one absolute joule per second (Anshel 1991). Therefore, if a subject cycled at a power output of 280 W for the 20 min period, the total amount of work completed, according to Equation 2, would be 336 kJ.

$$\text{Kilojoules} = [\text{Power (W)} \times \text{Time (s)}] / 1000$$

Equation 2. Calculation of work completed.

As described by Jeukendrup et al. (1996), after 20 min at a fixed workload, the cycle ergometer changed to a Linear operating mode and the subjects started the variable workload component of the performance trial. In the Linear operating mode, the Lode ergometer maintains a constant resistance. Therefore, the power output fluctuates with cadence, resulting in more work being completed when the subject increases their pedalling frequency. The rate of work on a Lode ergometer operating in the Linear mode, will increase according to Equation 3.

$$\text{Power (W)} = L \times (\text{rpm})^2$$

Equation 3. Calculation of power for Linear mode operation of a Lode ergometer. L is a (constant) linear factor and rpm is the pedalling rate.

The linear factor for each subject was chosen to provide a power output that was equal to the power output during the fixed component of the trial at a cadence of 100 rpm. For example: If a subject cycled at a power output of 280 W during the fixed component of the performance trial, the linear factor was chosen to provide a power output of 280 W at a cycling cadence of 100 rpm. Therefore, the linear factor for this subject would be 0.028.

The performance trial ended when subjects completed the same amount of work (kJ) in the variable component as was completed in the fixed component of the trial and

the measure of performance was the time required to complete this amount of work. For example: If a subject completed 336 kJ in the fixed component, the performance trial ended when the subject had completed a total of 672 kJ (336 x 2 = 672). The only feedback provided to the subject during the performance trial was the target kJ's and kJ's completed.

An important difference between laboratory trials and outdoor competition is the influence on heat loss by convection and evaporation from an adequate wind speed (Saunders, Dugas et al. 2004). Therefore, during the performance trial, a fan (custom, Australian Institute of Sport), which was 2 m in front of the subject, provided air flow at a speed of 18-20 $km.h^{-1}$. In addition, a radiant heat load incorporating six 500 W lights was used to simulate exposure to the sun and was applied from 2 m to the right side of the subject.

3.3 Physiological Variables

3.3.1 Body Temperature

Rectal temperature (T_{re}) was measured using a disposable rectal probe (Monatherm, Mallinckrodt Medical, St. Louis, MO, USA) which was inserted at least 12 cm beyond the anal sphincter. Skin temperature probes (YSI 409, Yellow Springs OH, USA) were fixed to the forehead, calf, thigh, chest and forearm using adhesive tape (Transpore, 3M, St Paul MN, USA) in accordance with Jirak et al. (1975). Rectal and skin temperatures were recorded at 5 min intervals throughout the experimental trials from an 8 Channel Digital Thermometer (Zentemp 5000, Zencor Pty Ltd, Australia). Rectal and skin temperatures were then used to calculate the mean skin temperature ($\overline{T}_{sk}$) according to the equation of Ramanathan (1964) and the mean body temperature ($\overline{T}_{b}$) as described by Schmidt & Bruck (1981).

$$\overline{T}_{sk} = 0.3 \ x \ (T_{Chest} + T_{Forearm}) + 0.7 \ x \ (T_{Thigh} + T_{Calf})$$

Equation 4. Ramanathan (1964) equation for calculation of the Mean Skin Temperature ($\overline{T}_{sk}$).

$$\overline{T}_{b} = 0.87 \ T_{re} + 0.13 \ \overline{T}_{sk}$$

Equation 5. Equation for the calculation of the Mean Body Temperature ($\overline{T}_{b}$) (Schmidt & Bruck, 1981).

Rates of body heat storage (HS) were calculated as described by Lee & Haymes (1995) and Atkinson & Thompson (2000), using the rate of change in $\overline{T}_{b}$, body mass (m), average specific heat of body tissue (3474 J.kg^{-1}.°C^{-1}), time (t) and the DuBois & DuBois (1916) method of estimating body surface area (A_D).

$$A_D = (Mass_{(Kg)}^{0.425} \ x \ Height_{(cm)}^{0.725}) \ x \ 0.007184$$

Equation 6. DuBois & Dubois (1916) equation for the estimation of body surface area.

$$HS \ (W.m^{-2}) = ((3474 \ x \ m \ x \ (\overline{T}_{b} final - \overline{T}_{b} \ initial) \ / \ t) \ / \ A_D$$

Equation 7. Equation for the calculation of rate of heat storage (HS) (Atkins and Thompson 2000).

3.3.2 Perceptions

At 5 min intervals throughout the experimental trials, subjects were asked to rate their perception of thermal comfort according to a 0-8 Thermal Sensation Scale (Young et al. (1987); Appendix 6 – Thermal Sensation Scale), where a rating of 1 is "unbearably cold", 4 is "comfortable" and 8 is "unbearably hot". In addition, during both the warm up and performance trial, subjects were asked for their rating of

perceived exertion according to a 6-20 Borg Scale every 5 min (Borg 1970); Appendix 7 – Rating of Perceived Exertion).

3.3.3. Heart Rate, Body Mass and Urine Specific Gravity

Upon arrival to the laboratory, subjects were also fitted with a heart rate strap and heart rate was recorded from a heart rate watch (s710i Polar, Finland) at 5 min intervals throughout the experimental protocol. Body mass was recorded prior to and at the conclusion of the warm up and the performance trial using calibrated portable scales (± 50g; UC 300 A&D, Japan). Subjects were able to void their bladder between the warm up and the performance trial and approximate sweat rates were determined by subtracting the change in mass between the warm up and the performance trial and the total change in mass. Urine specific gravity was evaluated on arrival to the laboratory, and immediately prior to the performance trial using a digital refractometer (UG-1, Atago, Japan) that was zeroed prior to each measurement using distilled water.

3.3.4 Blood Samples

Twenty minutes prior to each of the experimental trials, a 20 gauge Teflon cannula (Surflo, Terumo Corporation, Japan) was inserted into an antecubital vein and attached to a sterile three-way stopcock to allow for blood sampling. The cannula and stopcock were then covered with a plastic adhesive (Opsite, Smith+Nephew, England) and periodically flushed with 1.5 ml of sterile heparinised 0.9% saline to keep the vein patent. A total of six venous blood samples were drawn at 0, 35, 85, 115, 140 and 160 min (Figure 8). During each blood draw, the first 2.5 ml of blood was discarded before removing a 10 ml blood sample with a 10 ml syringe (Terumo, Japan). The 10 ml venous sample was then divided into two 2 ml tubes prepared with K_3EDTA and one 6 ml serum separator tube prepared with a clot activator (Greiner, Labortecnik, Kermsmunster, Germany). The K_3EDTA tubes were immediately centrifuged (4000 rpm, 5 min, 4°C), while the serum separator tubes were allowed to clot prior to being centrifuged. The supernatant from each tube was then transferred to 1.5 ml Eppendorf tubes and frozen at -20°C prior to shipment to permanent storage at -80°C and further

analyses. Finger-stick capillary blood samples were periodically collected (Figure 8) in heparinised 100 μL capillary tubes (Clinitubes, Radiometer Medical, Copenhagen, Denmark) and were immediately analysed for Lactate, Glucose, Sodium, Potassium, Calcium, Chloride, pH, pO_2 and pCO_2 by a blood-gas analyser (ABL 700series, Radiometer Medical, Copenhagen, Denmark).

3.3.5 Endocrine Variable Analysis

Various neurohumoral factors including the stress hormones prolactin, cortisol and testosterone and markers of muscle damage such as creatine kinase and c-reactive protein have been proposed as potential mechanisms for a reduced neural drive at the point of fatigue during exercise in hot ambient conditions (Jeukendrup, Vet-Joop et al. 2000; Kayser 2003; Schillings, Hoefsloot et al. 2003; Daly, Seegers et al. 2005). Consequently, these neurohumoral factors were measured in this study to investigate the potential role these variables may play in an enhanced exercise capacity following a precooling manoeuvre. Serum Cortisol and Testosterone were assayed by chemiluminescence – competitive immunoassay (Immulite, DPC, USA), which has a coefficient of variation of 7.6% and 7.7% respectively (Farmer and Pierce 1974; Jaffe and Behrman 1974). Prolactin and C-Reactive Protein (C-RP) were measured by chemiluminescence – immunometric assay (Immulite, DPC, USA), which has a coefficient of variation of 9.5% and 10% respectively (Djursing 1981). Plasma Creatine Kinase (CK) activity was determined at 30°C using an enzymatic assay with a coefficient of variation of 1.4% (Roche Diagnostics, Mannheim).

3.4 Ambient Conditions

Ambient conditions were monitored throughout the experimental trials with a portable digital weather tracker (Kestrel 4000, Nielsen-Kellerman, Australia). Ambient temperature, relative humidity, wet bulb temperature and heat index were recorded every 5 min. Radiant heat was measured using an Indoor Climate Analyser 1213 (Brüel & Kjaer, Denmark) with a Radiation MM 0036 Transducer (Units = P.I. Rad. Temp °C).
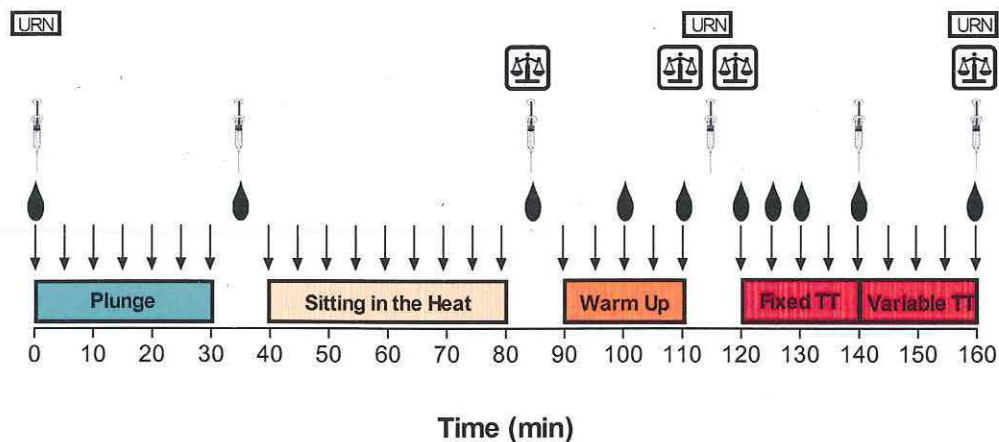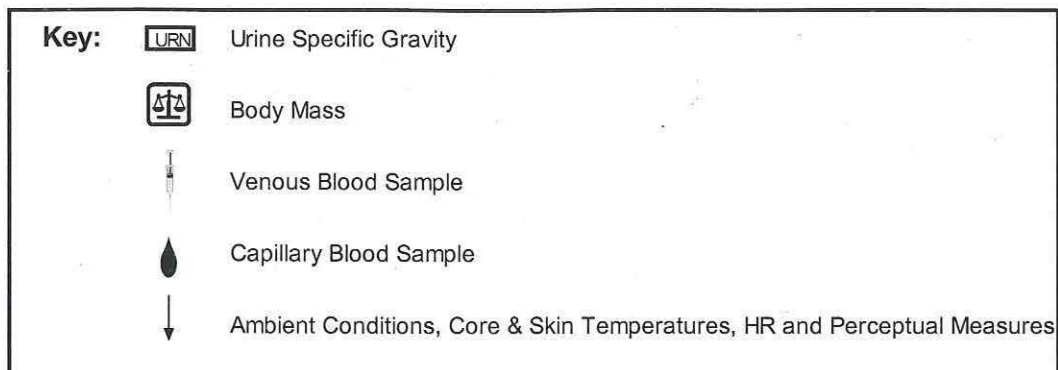
Figure 8. Measurement Schedule.

3.5 Statistical Analysis

A two way (Treatment x Time) repeated measures Analysis of Variance (ANOVA) was conducted to determine any difference between treatment means at each time point. Pairwise comparisons were conducted to determine where differences existed using a Newman-Keuls post-hoc test. Paired t-tests and Pearson's correlation coefficient were completed where appropriate and all statistical analyses were completed using the statistical software package Statistica version 6.1 (StatSoft, Tulsa, OK). Statistical significance was set at $p \leq 0.05$ and data are presented as mean $\pm$ standard deviation unless stated otherwise.

Chapter 4   Results

4.1 Subject Characteristics

A total of six subjects completed all of the treatments involved in this study. These subjects were active competitive cyclists and competed at A-grade level. One subject was a National Junior Time Trial Champion and one was currently riding for a professional cycling team in Europe. Table 3 contains the subjects' descriptive statistics including: age, height, mass, sum of seven skinfolds, cycling experience, $\dot{V}O_{2peak}$ and maximal aerobic power.

Table 3. Subject descriptive characteristics

SUBJECT	AGE	HEIGHT	MASS	SKIN-FOLDS ($\Sigma 7$)*	CYCLING EXPERIENCE	$\dot{V}O_{2peak}$	MAXIMAL AEROBIC POWER
	yr	cm	kg	mm	yr	$ml \cdot kg^{-1} \cdot min^{-1}$	W
1	35	178	75.2	48.6	9	69.0	360
2	26	183	76.2	39.5	1	72.8	415
3	29	191	78.9	55.5	2	65.9	360
4	23	177	77.3	57.3	13	74.0	410
5	28	180	70.0	35.5	9	70.9	365
6	25	181	72.8	64.1	2	75.8	395
Mean	28	182	75.1	50.1	6	71.4	384
SD	4	5	3.2	11.0	5	3.2	23

*Skinfold measurement sites included – Biceps, Triceps, Subscapular, Supraspinale, Abdominal, Thigh and Calf.

4.2 Ambient Conditions

The ambient temperature, relative humidity, calculated wet bulb temperature, heat index and the radiant heat for each experimental condition are presented in Figure 9. During the Control condition, calculated wet bulb temperature was 24.2 ±0.7°C, heat index, once subjects entered the environmental chamber, was 38.7 ±1.9°C, and radiant heat during the time trial was 66.4 ±5.5°C. There were no significant differences in calculated wet bulb temperature, heat index or radiant heat between experimental conditions (Figure 9).

Ambient temperature at the first time point was significantly different between the Control (25.8 ±1.6°C) and the Jacket treatment 24.0 ±0.9°C ($p = 0.01$), but was similar for the remainder of the plunge period (Control = 24.7 ±1.0°C, Jacket = 24.0 ±1.1°C). In addition, the ambient temperature in the Combination treatment was different to both the Jacket and Control treatments for the first 15 min of the plunge as the water temperature was reduced from 28.8 ±0.4°C to 24.0 ±0.1°C while subjects were submerged ($p < 0.05$). After the plunge, the ambient temperature was similar for each treatment for the remainder of the trial (Control = 34.7 ±1.0°C, Jacket = 34.2 ±0.9°C and Combination = 34.1 ±0.8°C). Similarly, relative humidity in the Combination treatment was higher than both the Control and Jacket treatments while subjects were exposed to the plunge pool (Control = 41.7 ±3.2%, Jacket = 43.5 ±6.0%, and Combination = 100%; $p < 0.001$), but was the same for each treatment during the remainder of the trial (Control = 41.7 ±1.9%, Jacket = 40.9 ±2.5% and Combination = 40.9 ±2.4%; Figure 9).
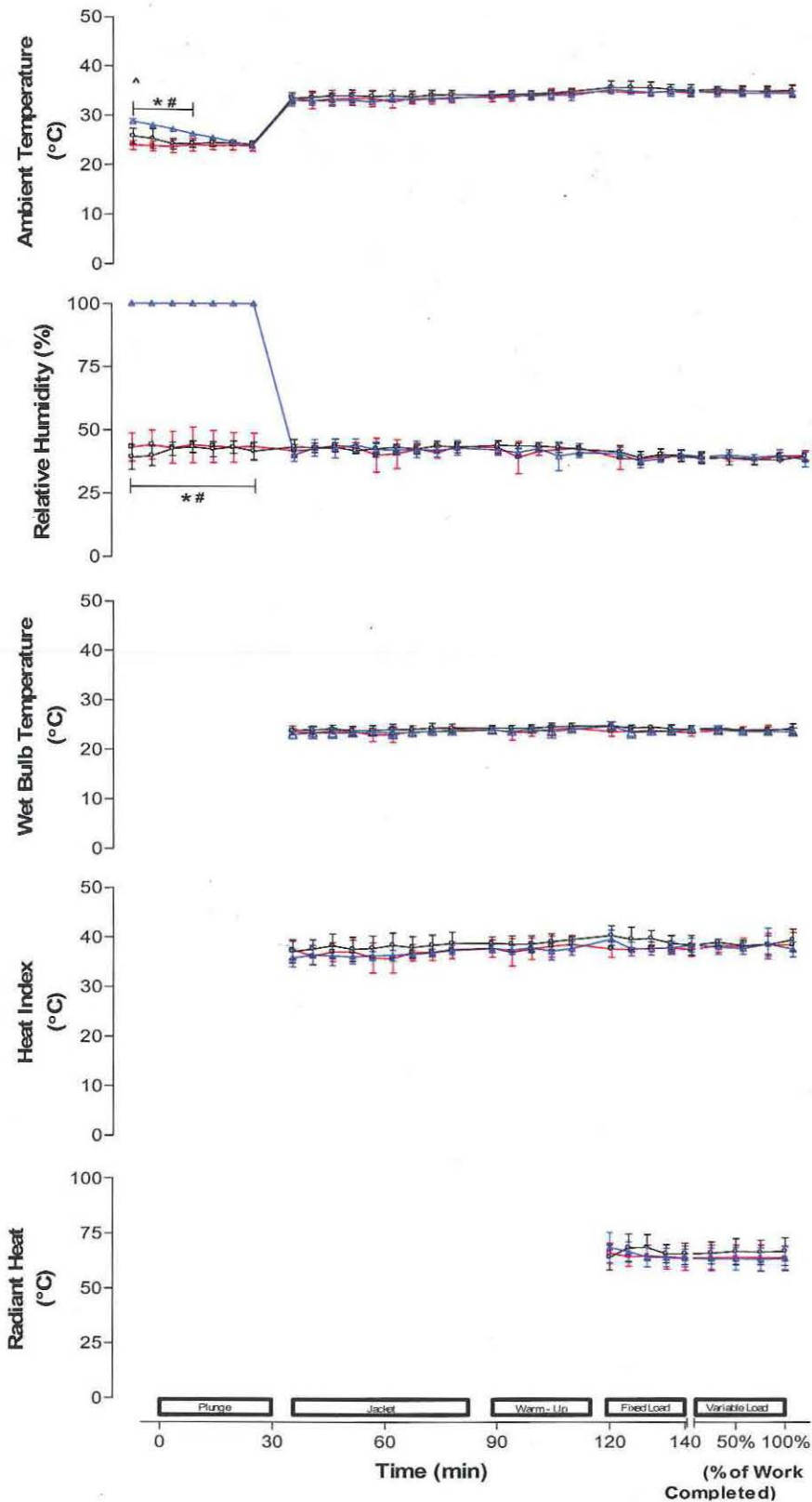
Figure 9. Ambient conditions measured throughout experimental trials. Values are mean ± SD. Control (○), Jacket (□) and Combination trial (△). *Combination significantly different from Control, # Combination significantly different from Jacket, ^ Jacket significantly different from Control ($p < 0.05$).

4.3 Performance Data

Performance times for the three experimental conditions are shown in Figure 10. In the Control condition, subjects finished the variable load component of the time trial in 1097 ±43 s (approximately 18.3 min; mean power = 313 ±30 W). After the Jacket treatment, performance time was reduced by 16 s (1.5%) to 1081 ±60 s (mean power = 318 ±26 W), but this difference was not significant (p = 0.35). The Combination treatment produced the fastest performance time of 1055 ±36 s (mean power = 325 ±26 W); 42 s (3.8%) faster than the Control condition (p = 0.009) and 26 s (2.4%) faster than the Jacket treatment (p = 0.06; Figure 10).

Figure 11 illustrates the pacing strategies used by the subjects after each of the experimental treatments. In the Control condition, subjects completed the first 25% of the variable component of the time trial in 278 ±30 s, with a similar pace maintained through the 50% split (281 ±15 s), but was reduced at the 75% split (273 ±9 s) and finished with the fastest split in the final quarter of the time trial (265 ±32 s). A similar pacing strategy was adopted following the Combination treatment where subjects completed the first 25% of the variable component of the time trial in 267 ±17 s, the 50% split in 271 ±10 s, the 75% split in 269 ±13 s and finished with the fastest split in the final quarter of the time trial (248 ±17 s); 17 s faster than the Control condition (p = 0.05). Following the Jacket treatment, the subjects' pacing strategy was altered. The first 25% of the variable component of the time trial was completed very quickly, in a similar time to that of the Combination condition (267 ±12 s). Subjects' then slowed through the 50% split (279 ±17 s) and slowed even further at the 75% split (284 ±31 s), before finishing the final quarter of the time trial very quickly (252 ±23 s; Figure 11).
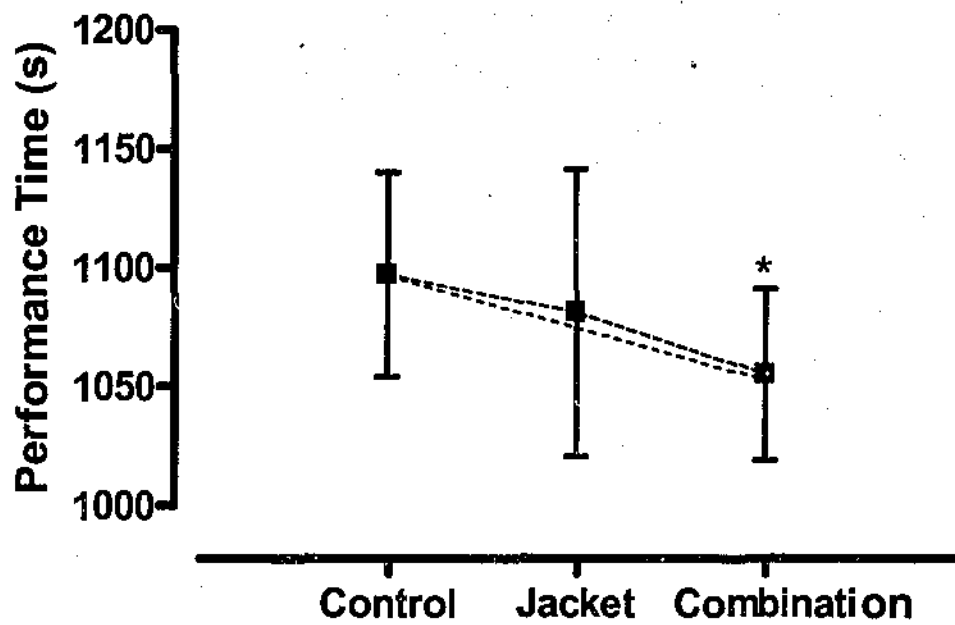
Figure 10. Time taken to complete the variable load component of the time trial in the three experimental conditions. Values are mean ± SD. *Significantly different from Control (p < 0.05).
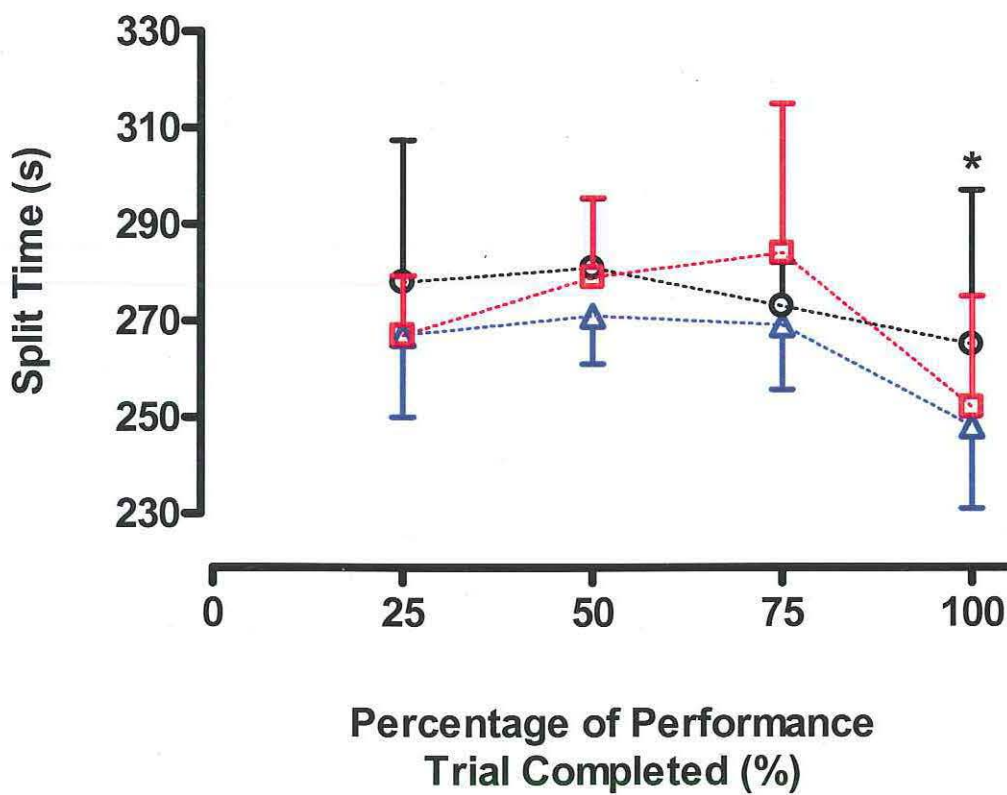
Figure 11. Split times for the variable portion of the performance trial for Control (○), Jacket (□) and Combination trial (△). Values are mean ± SD. *Combination significantly different from Control (p < 0.05).

4.4 Thermal Response

Figure 12 illustrates the effect of the precooling treatments on T_{re}, mean skin temperature ($\overline{T}_{sk}$) and body temperature ($\overline{T}_b$). Starting T_{re} was similar for each of the experimental conditions (Control = 37.1 ±0.2°C, Jacket = 37.2 ±0.2°C and Combination = 37.3 ±0.2°C). In the Control condition, T_{re} remained stable during both the plunge and 40 min of sitting in the heat and was 37.2 ±0.3°C at the start of the warm up. At 10 min into the warm up, T_{re} in the Control condition gradually rose to 37.8 ±0.1°C and continued to rise during the time trial. Subjects finished the time trial in the Control condition with a T_{re} of 39.6 ±0.4°C. As is depicted in Figure 12, a very similar T_{re} response was recorded during the Jacket treatment with no significant difference at any time point throughout the trial (end T_{re} = 39.7 ±0.5°C). In the Combination treatment, subjects exited the plunge pool with a similar T_{re} (37.2 ±0.2°C) to the Control and Jacket conditions. However, once subjects entered the environmental chamber and wore the cooling jacket, T_{re} began to fall. At the end of 40 min seated in the heat, the Combination treatment resulted in a T_{re} of 36.6 ±0.1°C; 0.7°C cooler than starting T_{re}, and 0.6°C and 0.5°C cooler than the Control and Jacket treatments at the same time point, respectively ($p < 0.001$). At the start of the warm up, T_{re} in the Combination condition was 36.5 ±0.3°C; 0.7 and 0.5°C cooler than the Control and Jacket conditions, respectively ($p < 0.001$). At the end of the warm up, T_{re} in the Combination treatment was 37.1 ±0.2°C; 0.7°C cooler than the Control and Jacket conditions ($p < 0.001$). A lower T_{re} in the Combination treatment persisted for 25 min into the time trial compared to the Control treatment ($p < 0.05$). While T_{re} in the Combination trial was cooler beyond 20 min of sitting in the heat until the end of the time trial ($p < 0.05$) in comparison to the Jacket treatment. End T_{re} in the Combination condition was 39.5 ±0.3°C; 0.1°C and 0.2°C cooler than the Control and Jacket conditions, respectively ($p = 0.035$; Figure 12).

Starting $\overline{T}_{sk}$ in the Control condition was 33.6 ±1.2°C and remained at 33.3 ±1.0°C during the plunge period. Once subjects entered the environmental chamber in the Control condition, $\overline{T}_{sk}$ rose to 35.7 ±0.3°C at the end of 40 min sitting in the heat. During the warm up, $\overline{T}_{sk}$ was maintained at 35.5 ±0.3°C and once the time trial began,

$\overline{T}_{sk}$ was reduced by ~1°C, with subjects in the Control condition finishing the time trial with a $\overline{T}_{sk}$ of 34.6 ±0.5°C. During the Jacket treatment, the $\overline{T}_{sk}$ response (33.0 ±1.0°C) was similar to that of the Control condition while sitting beside the plunge pool. However, once subjects entered the environmental chamber and put on the cooling jacket, $\overline{T}_{sk}$ at the end of 40 min sitting in the heat was 33.5 ±0.7°C; 2.2°C cooler than during the Control condition (p < 0.001). Once the cooling jacket was removed and the warm up began, $\overline{T}_{sk}$ in the Jacket condition was very similar to the Control condition, increasing to 35.1 ±0.6°C by the end of the warm up and reducing to 34.5 ±1.1°C at the end of the time trial. During the Combination condition $\overline{T}_{sk}$ started 1.9°C and 1.4°C cooler than the Control and Jacket conditions, respectively (p < 0.01), and $\overline{T}_{sk}$ was further reduced by 6.7°C to 25.0 ±0.6°C during the plunge period; 8.1°C and 7.9°C cooler than in the Control and Jacket conditions, respectively (p < 0.001). Once subjects in the Combination condition exited the plunge pool and entered the environmental chamber, $\overline{T}_{sk}$ increased from 27.8 ±0.7°C at the beginning to 30.4 ±0.9°C at the end of 40 min sitting in the heat; 5.3°C and 3.1°C cooler than the Control and Jacket conditions, respectively (p < 0.001). At the end of the warm up, $\overline{T}_{sk}$ in the Combination condition had risen to 34.1 ±0.4°C, which was 1.2°C and 1.0°C cooler than in the Control and Jacket conditions, respectively, although this difference was not significant (p = 0.16). Throughout the time trial, $\overline{T}_{sk}$ in the Combination condition was slightly cooler than the Control and Jacket treatments finishing at 33.8 ±1.0°C; 0.8°C and 0.7°C cooler than the Control and Jacket conditions, respectively, but this difference was also not significant (p = 0.48; Figure 12).

Starting $\overline{T}_{b}$ was similar for each experimental condition (Control = 36.7 ±0.3°C, Jacket = 36.7 ±0.3°C, Combination = 36.6 ±0.1°C). During the Control trial, initial $\overline{T}_{b}$ was maintained during the plunge period and was increased to 37.0 ±0.3°C by the end of the 40 min sitting in the heat. $\overline{T}_{b}$ then gradually increased during the warm up to 37.5 ±0.1°C and continued to rise during the time trial to finish at 39.0 ±0.4°C. In the Jacket condition, $\overline{T}_{b}$ was similar to the Control condition throughout the experimental trial (Figure 12). In the Combination trial, $\overline{T}_{b}$ was gradually reduced during the plunge

period to 35.6 ±0.2°C at the time subjects exited the plunge; 1.0°C and 1.1°C cooler than the Control and the Jacket conditions, respectively ($p < 0.001$). After 40 min of sitting in the heat, $\overline{T}_b$ in the Combination treatment was 35.8 ±0.4C; 1.2°C and 0.8°C cooler than the Control and Jacket conditions, respectively ($p < 0.001$). During the warm up, $\overline{T}_b$ in the Combination treatment gradually rose to 36.7 ±0.2°C, but remained 0.8°C and 0.6°C cooler than the Control and Jacket conditions, respectively ($p < 0.01$). $\overline{T}_b$ in the Combination treatment remained cooler than the Jacket condition throughout the time trial and apart from 30 and 35 min into the time trial, was also cooler than the Control condition ($p < 0.05$). Final $\overline{T}_b$ in the Combination treatment was 38.6 ±0.4°C; 0.4°C and 0.5°C cooler than the Control and Jacket conditions, respectively ($p < 0.002$; Figure 12).

Rates of heat storage were calculated for each component of the experimental trials and the results are presented in Table 4. During the Control condition, subjects stored a small amount of heat during the precooling manoeuvre. In the Jacket condition, subjects' heat storage was similar to Control while sitting next to the plunge pool, but while wearing the cooling jacket, heat was lost resulting in significantly less heat stored compared to the Control condition ($p = 0.007$). During the precooling manoeuvre, the Combination condition resulted in substantially less heat storage than both the Control and Jacket conditions ($p < 0.01$), with heat storage lower than both the Control and Jacket conditions during the plunge period ($p < 0.001$) and lower than the Control condition while sitting wearing the cooling jacket ($p = 0.04$). Once exercise started, rates of heat storage in the warm up tended to be greater in the Jacket ($p = 0.13$) and Combination ($p = 0.08$) conditions and also tended to be greater in the Jacket ($p = 0.1$) and Combination ($p = 0.08$) conditions during the fixed component of the time trial, but these differences were not significant (Table 4). During the variable component of the time trial, the rate of heat storage was similar across all conditions. Total heat storage during the time trial, although not significant, tended to be greater during the Combination condition ($p = 0.07$; Table 4). In addition, rates of heat storage during the precooling manoeuvre and during the variable component of the time trial were correlated with performance time ($r = 0.3$ and -0.3, respectively; $p > 0.2$).
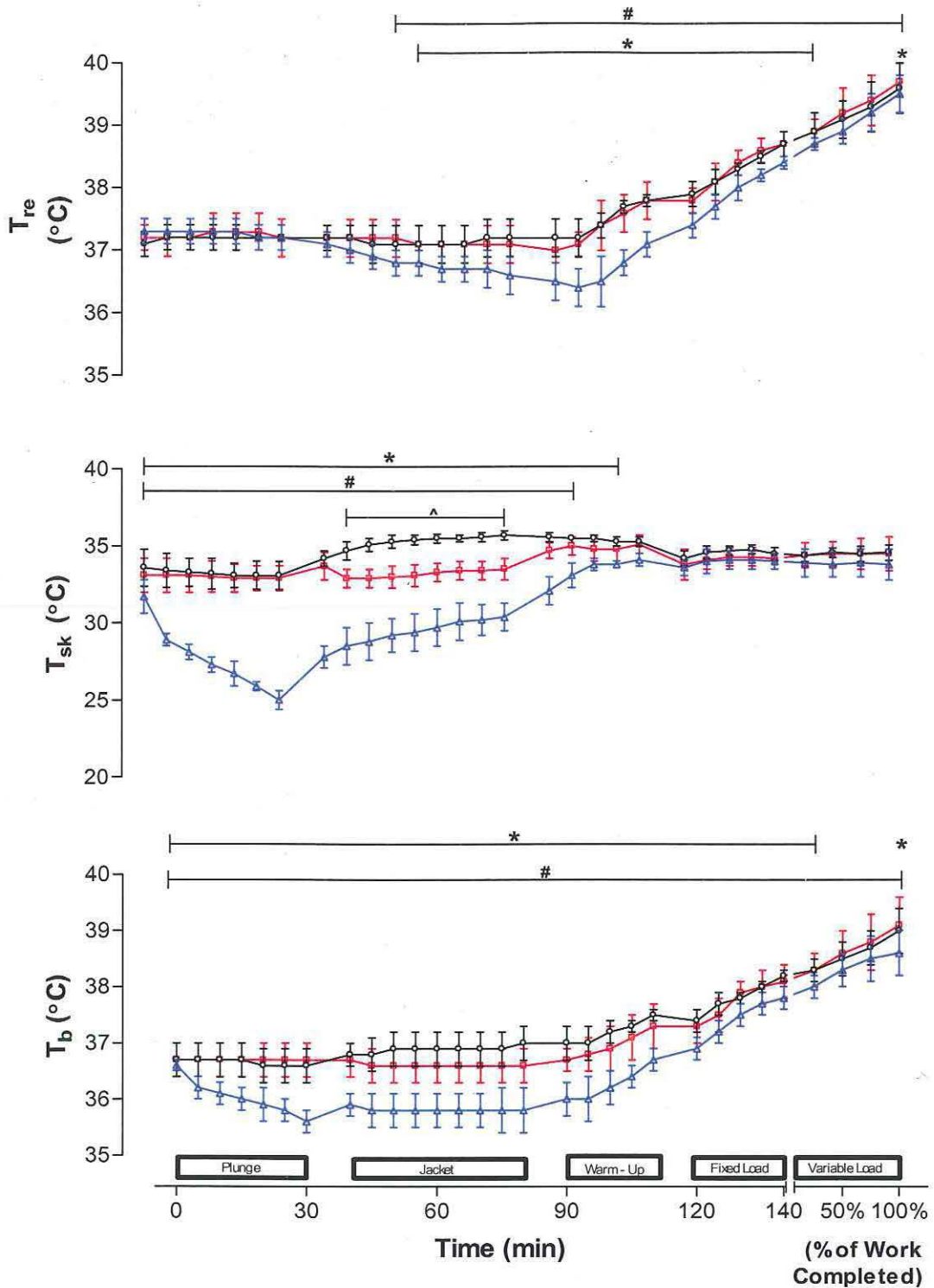
Figure 12. Time course of all body temperatures measured during each experimental condition, Control (○), Jacket (□) and Combination trial (△). Values are mean ± SD. *Combination significantly different from control, #Combination significantly different from Jacket, ^ Jacket significantly different from Control ($p < 0.05$).

Table 4. Rates of heat storage throughout the experimental trial for each condition.

	Heat Storage ($W \cdot m^{-2}$)		
	Control	Jacket	Combination
30 min Plunge	-3.7 ±6.4	-1.0 ±7.3	-69.3 ±19.4 *[#]
40 min Sitting	11.3 ±8.5	-6.1 ±7.1*	-5.7 ±10.1*
Precooling Manoeuvre	7.6 ±7.2	-7.1 ±8.5*	-75.0 ±26.7 *[#]
20 min Warm Up	58.0 ±22.6	82.3 ±29.5	81.7 ±27.9
Fixed Component of TT	80.8 ±29.6	93.3 ±30.8	108.7 ±17.2
Variable Component of TT	99.4 ±39.6	100.6 ±48.8	99.7 ±44.7
Total TT	180.2 ±61.4	201.6 ±58.4	208.4 ±49.0

Significantly different from Control (p<0.05)

[#] *Significantly different from Jacket (p<0.05)*

4.5 Perceptual Data

Subjects' ratings of Thermal Sensation and RPE are illustrated in Figure 13. During the Control condition, subjects rated their thermal comfort at 4 ±0.6 while sitting beside the plunge pool, which rose to 5 ±0.8 after 40 min of sitting in the heat, and to 7 ±0.6 by the end of the warm up. This was reduced to 6 ±0.6 at the start of the time trial, and then gradually increased through to the finish of the time trial (8 ±0.4). During the Jacket treatment, subjects completed sitting next to the plunge pool with a similar rating of thermal comfort as during the Control condition (4 ±0.7; p = 0.6). However, once subjects in the Jacket treatment entered the environmental chamber and put on the cooling jacket, ratings of thermal comfort were substantially reduced to 3 ±1.0 by the end of the 40 min sitting in the heat; 2 units lower than the Control condition (p < 0.001). However, by 10 min into the warm up, subjects in the Jacket condition tended to rate their thermal comfort slightly lower than the Control condition, but this difference was not significant (p = 0.9). Although subjects began with a comparable rating of thermal comfort in each condition (Control = 4 ±0.4, Jacket = 4 ±0.4, Combination = 4 ±0.8), after being exposed to the plunge pool, subjects in the Combination treatment

rated their thermal comfort as being substantially lower than both the Control and Jacket conditions (1 ±0.7; $p < 0.001$). After completion of 40 min seated in the heat, rating of thermal sensation experienced by the Combination treatment (2 ±0.8) was significantly lower than the Control condition ($p < 0.001$), but was similar to the Jacket condition. Rating of thermal sensation for the Combination treatment remained lower than the Control condition for up to 15 min into the warm up ($p = 0.03$), but was only rated cooler than the Jacket condition at the first time point of the warm up ($p = 0.01$). Throughout the time trial, subjects in the Combination condition tended to rate their thermal sensation lower than during the Control condition but this was only significant at the 0, 10 and 20 min time points of the time trial ($p < 0.03$). In addition, at the end of the time trial, subjects tended to rate their thermal sensation 1 unit lower than in the control condition ($p = 0.07$). During the Combination condition, subjects rated their thermal comfort throughout the time trial in a similar fashion to that of the Jacket condition (Figure 13).

RPE during the Control condition rose from 8 ±2 on the Borg scale at the start of the warm up, to 16 ±2 by the end of the warm up. RPE once the time trial began was 16 ±1 and gradually rose throughout the time trial to 20 ±0 at the completion of the trial. During both the Jacket and the Combination conditions, except for the final rating, RPE tended to be lower compared to the Control condition, although this difference was not significant ($p = 0.1$; Figure 13).
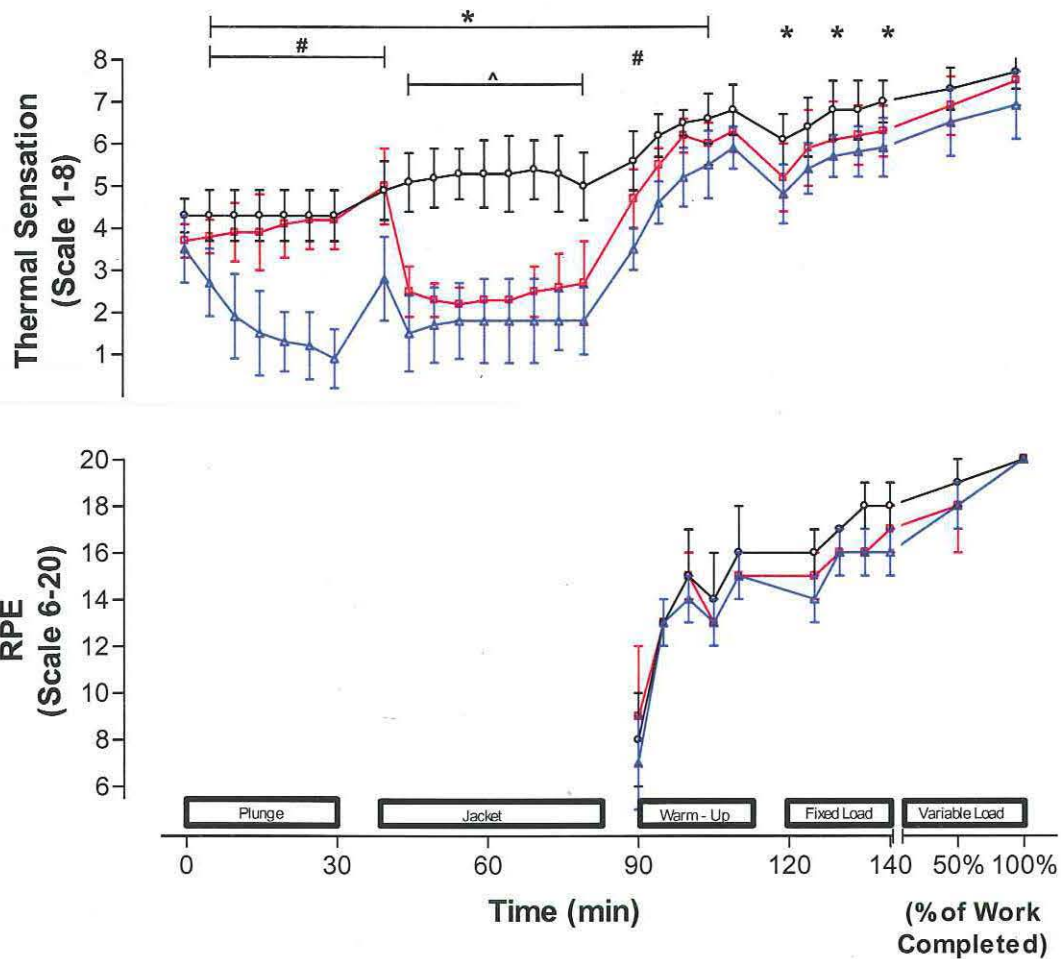
Figure 13. Perception's of thermal comfort and RPE during the Control (○), Jacket (□) and Combination trial (△).Values are mean ± SD. * Combination significantly different from Control, # Combination significantly different from Jacket, ^ Jacket significantly different from Control ($p < 0.05$).

4.6 Body Mass and Urine Specific Gravity

Body mass during the experimental trials is detailed in Figure 14 and changes in body mass, bladder void mass and estimated sweat loss are presented in Table 5. Subjects started the warm up with a similar body mass in each of the experimental conditions (Control = 76.8 ±3.4 kg, Jacket = 76.4 ±3.8 kg, Combination = 76.7 ±3.1 kg). In the Control condition, body mass was reduced to 76.4 ±3.3 kg at the end of the warm up and after voiding the bladder, subjects in the Control condition began the time trial with a body mass of 76.1 ±3.2 kg. At the conclusion of the time trial, subjects' body mass declined by 0.9 kg to 75.2 ±3.2 kg in the Control condition. Similar trends in body mass changes were recorded for both the Jacket and Combination treatments (Figure 14).

As outlined in Table 5, the total change in mass was similar throughout the experimental trials for the Control and Jacket condition and was slightly greater in the Combination condition ($p = 0.21$). Bladder void mass was similar between the Control and Jacket, and Jacket and Combination conditions. However, bladder void mass was greater in Combination compared to the Control condition ($p = 0.04$). Estimated sweat loss showed no significant differences between experimental conditions although tended to be lower in the Jacket ($p = 0.15$) and Combination ($p = 0.13$) conditions (Table 5).

Table 5. Changes in Total Body Mass, Bladder Void Mass and Estimated Sweat Loss during the three experimental conditions.

	Mass (kg)		
	Control	**Jacket**	**Combination**
Total Change in Body Mass	-1.60±0.30	-1.63±0.40	-1.84±0.33
Bladder Void Mass[#]	0.21±0.28	0.43±0.37	0.60±0.36*
Estimated Sweat Loss^	-1.39±0.25	-1.22±0.10	-1.24±0.26

* *Significantly different to Control trial ($p < 0.05$)*
[#]*Subjects voided their bladder between the warm up and the performance trial.*
^ *Estimated sweat loss was determined by subtracting the bladder void mass from the total change in mass*
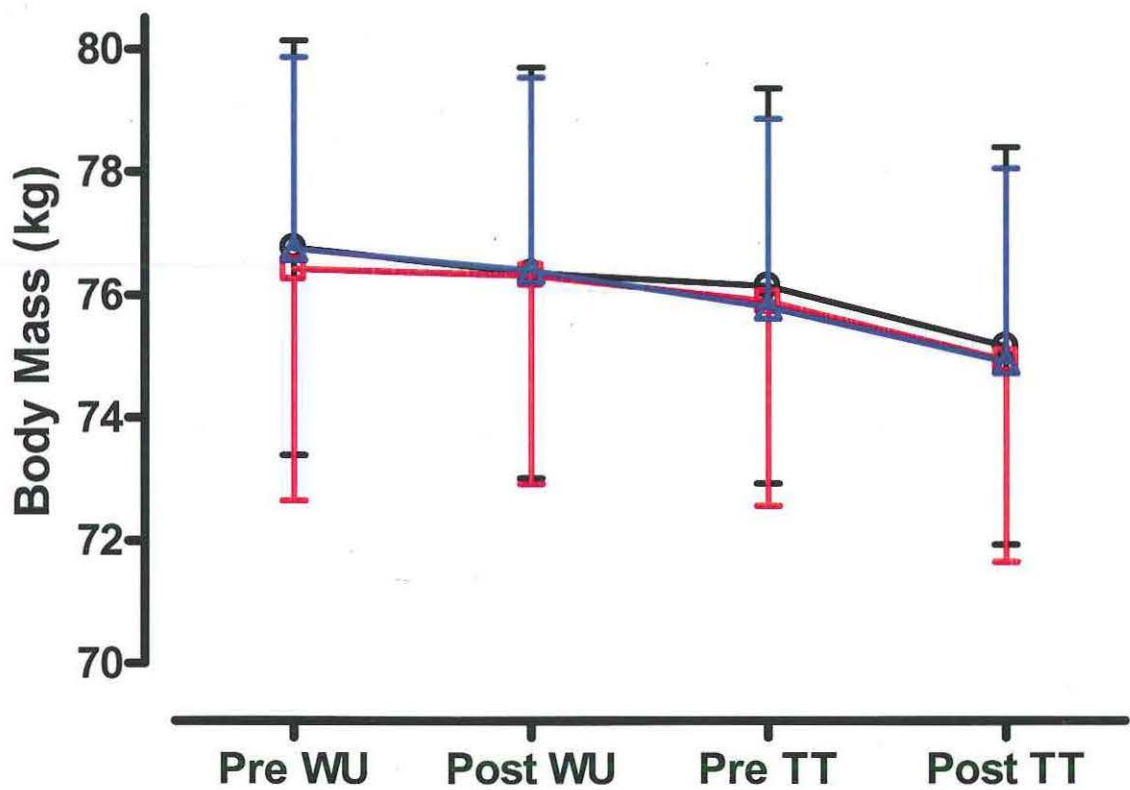
Figure 14. Changes in body mass during the Control (○), Jacket (□) and Combination trial (△).Values are mean ± SD.

Urine specific gravity measurements were taken on arrival at the laboratory and when subjects voided their bladder prior to the time trial (Table 6). Subjects presented with similar urine specific gravity values for each of the experimental conditions with no significant differences noted prior to the start of the time trial.

Table 6. Urine Specific gravity measurements

| | Urine Specific Gravity | | |
	Control	Jacket	Combination
On Presentation	1.014 ±0.010	1.013 ±0.008	1.010 ±0.009
Pre Time Trial	1.013 ±0.007	1.012 ±0.007	1.008 ±0.004

4.7 Heart Rate Response

The heart rate (HR) response during each of the experimental conditions is presented in Figure 15. During the Control condition, HR was maintained at 65 ±12 bpm while sitting next to the plunge pool and a similar HR was observed while sitting for 40 min in the environmental chamber (67 ±7 bpm). HR in the Control condition then rose during the warm up, finishing at 161 ±6 bpm. During the time trial, HR rose from 167 ±5 bpm at 5 min into the time trial to 192 ±11 bpm at the end of the time trial. HR in the Jacket condition while sitting next to the plunge pool (59 ±7 bpm) was similar to the Control condition and tended to be slightly lower while sitting in the environmental chamber and wearing the cooling jacket (56 ±5 bpm; p = 0.71). However, HR in the Jacket condition was only significantly lower than the Control condition at 20, 25 and 35 min into the 40 min heat sitting period and at the start of the warm up (p = 0.04). Subsequently, HR in the Jacket condition was very similar to the Control condition. In the Combination condition, HR during the plunge was similar to both the Jacket and the Control conditions (58 ±10 bpm). HR in the Combination condition then tended to be lower than in the Control condition after 15 min of sitting in the heat (p < 0.02) but was similar to the Jacket condition. After 5 min into the warm up, where HR was 14 bpm lower than both the Control and Jacket conditions (p < 0.04), the HR response in the Combination condition was similar to both the Control and Jacket conditions for the remainder of the trial (Figure 15).
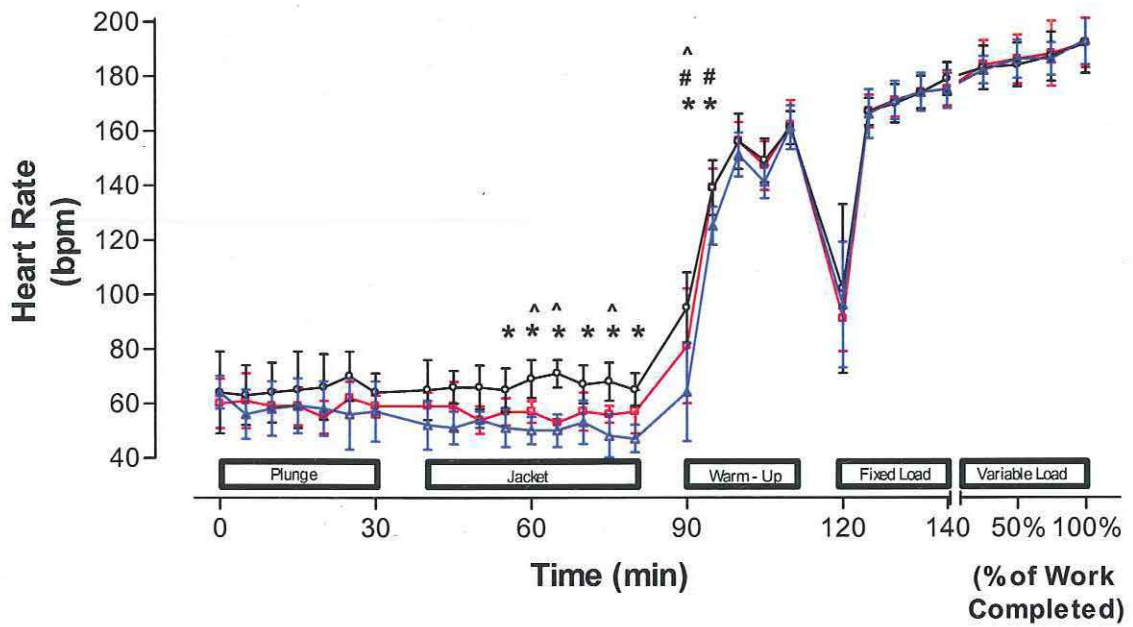
Figure 15. Heart rate response during the Control (○), Jacket (□) and Combination trial (△).Values are mean ± SD. * Combination significantly different from Control, # Combination significantly different from Jacket, ^ Jacket significantly different from Control (p < 0.05).

4.8 Metabolic Response

Figure 16 illustrates the blood lactate (La⁻), bicarbonate (HCO₃⁻), pH and glucose response for each experimental condition. Initial La⁻ concentration was similar across each of the experimental conditions (Control = 2.1 ±0.6 mmol.L⁻¹, Jacket = 2.0 ±0.6 mmol.L⁻¹, Combination = 2.1 ±0.5 mmol.L⁻¹). In the Control condition, La⁻ then rose to 4.0 ±1.5 mmol.L⁻¹ at the end of the warm up, was 2.6 ±0.6 mmol.L⁻¹ at the start of the time trial, then rose to 5.7 ±1.9 mmol.L⁻¹ at the end of the fixed component of the time trial with the final La⁻ in Control being 15.8 ±4.4 mmol.L⁻¹. As is illustrated in Figure 16, the La⁻ response was very similar to the Control condition for both the Jacket and Combination treatments except for the final readings. The final La⁻ in the Jacket condition was 19.8 ±4.3 mmol.L⁻¹; 4.0 mmol.L⁻¹ higher than the Control condition, and 2.3 mmol.L⁻¹ higher than the Combination treatment (p < 0.001). The final La⁻ in the Combination condition was 17.5 ±4.0 mmol.L⁻¹; 1.7 mmol.L⁻¹ higher than the Control Condition (p = 0.005).

Initial HCO₃⁻ concentration was similar for each of the three experimental conditions (Control = 24.0 ±0.5 mmol.L⁻¹, Jacket = 23.8 ±0.1 mmol.L⁻¹, Combination = 24.4 ±0.9 mmol.L⁻¹). During the Control condition, a similar HCO₃⁻ concentration persisted to the start of exercise. At the end of the warm up, HCO₃⁻ was reduced to 22.9 ±0.5 mmol.L⁻¹, where it continued to reduce through the fixed component of the time trial and ended at 14.0 ±2.7 mmol.L⁻¹ for the Control condition. As illustrated in Figure 16, no differences were noted for the HCO₃⁻ response in the Jacket and the Combination conditions compared with the Control condition.

pH was similar for each of the experimental conditions at the start of the trials (Control = 7.41 ±0.01, Jacket = 7.41 ±0.01, Combination = 7.42 ±0.03). During the Control condition, pH was not altered during the plunge segment nor while sitting in the heat for 40 min. However, at the end of the warm up, pH in the Control condition was reduced to 7.40 ±0.01 and at the end of the trial was 7.25 ±0.07. Despite a significant difference at the end of exercise in La⁻ for the different cooling treatments, there were no significant differences between the cooling treatments for pH (Figure 16).

Blood glucose concentration at the start of each trial was similar for each experimental condition (Control = 5.9 ±0.9 mmol.L^{-1}, Jacket = 5.8 ±0.9 mmol.L^{-1}, Combination = 5.9 ±0.6 mmol.L^{-1}). In the Control condition, glucose was maintained at ~ 5.5 mmol.L^{-1} throughout the experimental trial except for the final reading, which was 9.4 ±2.1 mmol.L^{-1}. Similar to HCO_3^- and pH, there were no significant differences between the cooling treatments for blood glucose concentration (Figure 16).

4.9 Endocrine Response

Table 7 contains the results of the endocrine measures taken throughout the experimental trials for each of the cooling treatments. No differences were found for Prolactin, Cortisol, Testosterone, Creatine Kinase or C-Reactive Protein between the cooling treatments at any of the time points sampled.
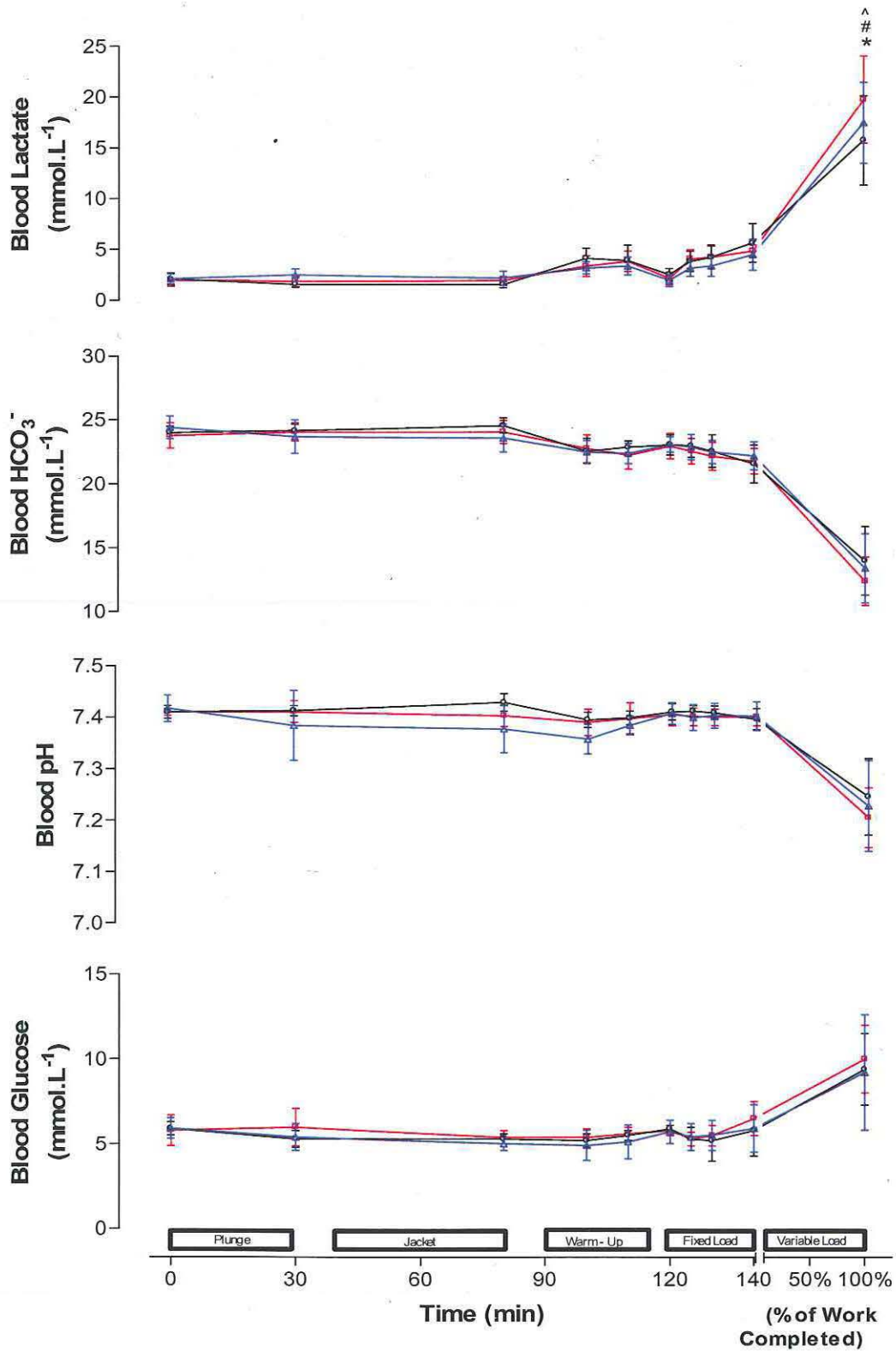
Figure 16. Blood La⁻, HCO₃⁻, pH and glucose response to the Control (○), Jacket (□) and Combination trial (△).Values are mean ± SD. * Combination significantly different from Control, # Combination significantly different from Jacket, ^ Jacket significantly different from Control ($p < 0.05$).

Table 7. Endocrine response for each cooling treatment throughout the experimental trials.

PARAMETER	EXPERIMENTAL CONDITION	SAMPLE					
		Pre Plunge	Pre 40min in Heat	Pre Warm Up	Pre Time Trial	20 min into Time Trial	Post Time Trial
Prolactin	Control	10.1 ±6.6	8.5 ±5.3	9.4 ±4.9	11.8 ±6.2	17.8 ±8.1	38.4 ±16.7
(ng/mL)	Jacket	11.9 ±9.1	11.1±9.9	8.2 ±7.0	11.2 ±6.4	19.5 ±14.1	34.1 ±15.3
	Combination	9.5 ±4.7	8.0 ±4.4	6.5 ±3.9	8.8 ±3.7	15.8 ±7.4	33.2 ±20.4
Serum	Control	453.5 ±76.4	444.0 ±110.2	528.3 ±53.9	487.8 ±113.3	641.2 ±146.9	636.0 ±164.7
Testosterone	Jacket	483.8 ±175.5	415 ±133.9	460.2 ±210.0	536.5 ±242.6	646.7 ±308.3	646.7 ±308.3
(ng/dL)	Combination	503.7 ±64.4	548.7 ±108.8	479.0 ±93.4	550.8 ±93.6	691.8 ±122.1	691.8 ±122.1
Serum	Control	324.2 ±153.1	328.5 ±231.1	356.2 ±211.9	266.5 ±151.1	288.5 ±135.	371.2 ±211.5
Cortisol	Jacket	323.4 ±211.1	318.4 ±329.7	286.1 ±153.5	280.7 ±148.1	262.2 ±138.6	383.3 ±179.1
(nM)	Combination	306.5 ±128.8	272.7 ±136.4	237.5 ±90.41	230.5 ±96.1	276.4 ±119.1	320.6 ±133.8
Creatine	Control	189.3 ±134.2	166.7 ±107.7	197.3 ±113.6	166.0 ±82.8	183.0 ±125.4	222.8 ±147.8
Kinase	Jacket	163.0 ±23.8	151.5 ±20.7	145.0 ±45.3	175.6 ±31.6	184.8 ±46.9	178.5 ±30.5
(μL)	Combination	159.5 ±86.5	180.2 ±110.8	171.3 ±95.8	169.0 ±95.3	173.3 ±90.0	190.8±105.2
C – Reactive	Control	0.038 ±0.018	0.046 ±0.021	0.053 ±0.021	0.043 ±0.028	0.048 ±0.026	0.064 ±0.025
Protein	Jacket	0.040 ±0.027	0.035 ±0.013	0.050 ±0.040	0.042 ±0.023	0.042 ±0.026	0.043 ±0.028
(ng/dL)	Combination	0.033 ±0.019	0.035 ±0.021	0.030 ±0.017	0.038 ±0.026	0.047 ±0.042	0.043 ±0.027

Chapter 5   Discussion

Ambient conditions for each of the three experimental treatments in this study were similar (Figure 9). In addition, subjects presented to the laboratory with similar blood glucose (Figure 16) and hydration levels (Table 6), indicating that results from each of the experimental conditions can be compared. Although a repeated measures experimental design was employed and each subject acted as their own control, the withdrawal of three subjects during the study caused the design to be not completely counterbalanced. As a result, more Combination treatments were completed as the first trial and more Control treatments were completed as the final trial (Table 2). Consequently, if a learning/residual fatigue effect was present, the results may have been biased. However, the familiarisation trial utilised in this study should have resulted in minimal learning/residual effects (Hopkins, Schabort et al. 2001; Laursen, Shing et al. 2003).

5.1 Performance Changes Following Precooling

The primary purpose of this research was to determine the effect of two practical precooling manoeuvres on cycling time trial performance. The results of this research indicate that subjects tended to improve their performance time by a non-significant 16 s (p=0.35) over the control condition following the use of a cooling jacket alone, but performance time was improved by 42 s compared to the control condition following the Combination strategy (p=0.009). It is not possible therefore, to accept the original hypothesis that both precooling strategies would significantly improve cycling time trial performance.

Although very few precooling studies have shown changes in cycling performance time for a set distance, the improvement in performance shown in the present study following the Combination strategy is similar to what has previously been reported by others. For example, Cotter et al. (2001) utilised a similar split exercise protocol (20 min at ~65% $\dot{V}O_{2peak}$ followed by a 15 min work-performance trial) in warm ambient conditions (35°C, 60% rh) and reported a 16% improvement in mean

power output following precooling with an ice vest and cold air (3°C). Moreover, Kay et al. (1999) used whole-body water immersion to precool the skin without a reduction in core temperature and reported a 6.8% increase in the distance cycled in a self-paced 30 min cycling time trial in 31°C and 60% rh. The effectiveness of a precooling manoeuvre has also been reported in cool ambient conditions (18°C) by Olschewski & Bruck (1988) who recorded a 12% improvement in cycling time-to-exhaustion at 80% of $\dot{V}O_{2\,max}$ following exposure to cold air. In addition, other researchers have reported improvements in performance in different exercise modalities following precooling. Booth et al. (1997) reported a 4% increase in distance run over 30 min, Lee & Haymes (1995) reported a 121% improvement in time-to-exhaustion while running at 82% of maximal aerobic capacity, Arngrimsson et al. (2004) reported a 1.1% improvement in 5km run time, Hessemer et al. (1984) reported a 6.8% increase in 1 h cycling work rate and Yates et al. (1996) reported a 1.8% improvement in 1000m rowing time. Thus, the present study and previous research clearly show that a precooling manoeuvre can positively influence endurance exercise performance.

Despite substantial literature investigating the impact of different precooling manoeuvres on endurance performance, very few investigators have examined the effect of precooling on pacing strategy. In this study, pacing strategy following the Combination treatment was similar to that used in the Control condition, suggesting that this precooling manoeuvre did not negatively influence the way in which subjects paced their time trial (Figure 11). This type of pacing strategy, where pace is held relatively consistent throughout the initial 90% of the trial, then followed by an 'end-spurt' during the last 10% is typical of exercise where the duration of the task is known in advance (Foster, Schrager et al. 1994; Noakes and St Clair Gibson 2004). In addition, this is the typical pacing strategy adopted by professional cyclists during competitive time trials in the heat and is the same pacing strategy that was adopted by the gold medallist in the 2004 Olympic cycling time trial in Athens (personal communications, Dr. D.T. Martin). While the pacing strategy was not altered following the Combination treatment, this was not the case following the Jacket treatment (Figure 11). Despite the workload being fixed for the first 20 min of the performance trial in an effort to reduce any effect of the precooling manoeuvres on pacing, subjects paced the time trial following the Jacket treatment differently. The first 25% of the Jacket time trial was completed in a similar

time to the Combination condition, but was slower throughout the middle component, before finishing the final 25% of the time trial quickly.

A disparity between the subject's actual thermal state and their perceived thermal state may have played a role in the miss-pacing of the time trial in the Jacket condition. During the Combination treatment, subject's T_{re} and $\overline{T}_b$ tended to be lower than during the Control condition throughout the majority of the trial (Figure 12). This lower rectal and body temperature was accompanied by a lower rating of thermal sensation (Figure 13). That is, not only was the subject's level of thermal strain lower during the Combination treatment, it was also perceived as being lower. However, during the Jacket treatment, this was not necessarily the case. Following the Jacket treatment, although subject's $\overline{T}_{sk}$ was lower than the Control condition while sitting in the heat, T_{re} and $\overline{T}_b$ were not different to the Control condition throughout the experimental trial (Figure 12). While rectal and body temperatures were not different, subjects rating of thermal sensation tended to be lower during exercise compared with the Control condition (Figure 13). Hence, as subjects may have perceived that they were under less thermal strain, they started the variable component of the time trial in the Jacket condition with a relatively high intensity, then once the time trial was under way, the body's "central governor" may have reassessed and adjusted the pacing strategy (Ulmer 1996). As it was not possible to disguise the treatments in this study, the faster initial pace shown in the Jacket condition could also have been the result of a placebo effect.

Ulmer (1996) proposed that the pacing of a performance trial is not purely controlled by feedback from the periphery. Rather, it is a complex integration of efferent signals providing force output, time and muscle metabolism information to the periphery, afferent information from not only muscle mechanoreceptors and chemoreceptors, but also other organs, and that a "central governor" or "black box" would also take into account factors such as training history, muscle reserve, metabolic rate, prior antecedent experiences and the projected finishing point. This integrated model of control was referred to as "teleoanticipation" by Ulmer (1996) and it may be that the Jacket condition in this study interfered with the subjects' teleoanticipation, resulting in a miss-pacing of their time trial.

5.2 Physiological Responses to Precooling

5.2.1 T_{re}, T_b, and Rate of Heat Storage

The hypothesis that a lower starting T_{re} would be related to a significantly improved performance time can be accepted, as following the Combination treatment, T_{re} was significantly reduced compared to the Control and Jacket trial and subsequent performance time was improved (Figures 10 & 12). Prior to the start of this study, it was suggested that the greater a precooling manoeuvre is able to reduce core body temperature; the greater will be the improvement in performance. Therefore during pilot work, a powerful precooling manoeuvre was sought. The Jacket treatment was also chosen, as it was easier to apply in the field, yet not as effective at reducing T_{re} as the Combination treatment. Thus, a comparison of the Jacket trial and the Combination treatment has provided insight as to the importance of a low starting core temperature.

During this study, the cooling jacket alone resulted in cooler $\overline{T}_{sk}$ while subjects sat in the heat (Figure 12), but there was no difference throughout the experimental trial between the Jacket and Control conditions for T_{re} or $\overline{T}_b$ (Figure 12). This result is in contrast to what has previously been reported in precooling studies that have utilised cooling jackets. Yates (1996) reported that the use of an ice jacket during a 30 minute warm up blunted the rise in T_{re} (0.34°C) and resulted in a 3 s improvement in 1000m rowing time. More recently, Arngrimsson (2004) reported that after subjects wore a cooling jacket during a 38 min active warm up, the rise in T_{re} was blunted during the warm up and 5 km run time was reduced by 13 s. The difference between these two studies and the current study was the way in which the cooling jacket was used. Both Yates (1996) and Arngrimsson (2004) effectively used cooling jackets to absorb some of the excess heat produced during the warm up and subsequently attenuated the rise in T_{re}. In the present study, however, the cooling jacket was used in an attempt to actively cool the subjects prior to the start of exercise. The fact that the Jacket treatment used in the present study was unable to reduce T_{re} or $\overline{T}_b$ prior to the start of exercise may help to explain why performance time was not significantly enhanced under this condition. Consequently, the use of cooling Jackets may only be appropriate as an external heat

sink to attenuate the rise in core body temperature during a warm up as opposed to an active precooling technique. However, the effect on pacing when using a cooling jacket in this way still needs to be determined.

A number of researchers have utilised water immersion to precool subjects to varying degrees. Kay et al. (1999) used a water bath to cool the skin without a concomitant reduction in the core body temperature. Marsh & Sleivert (1999) reduced T_{re} by 0.3°C after torso only immersion in cool water (18-12°C) while Crowley et al. (1991) reduced T_{re} by 0.4°C after submerging the legs of subjects in water at 11.5°C for 30 min. However, one of the largest reductions in T_{re} (-0.7°C) was reported by Booth et al. (1997) who utilised a 60 min water bath and gradually reduced the water temperature from ~29°C to ~23°C. In addition, the concept of combining precooling methods has also previously been used to great effect. Cotter et al. (2001) had subjects sit in a cool room (3°C) while wearing an ice jacket on the torso and cryogenic cuffs on the legs; after 45 min subjects mean body temperature had reduced by 2.8°C. However, the Combination treatment in the current study did not produce as large a reduction in T_{re} (-0.8°C) or $\overline{T}_b$ (-0.6°C) as was expected.

The ambient environmental conditions in the present study may be worth taking into account when considering these results. During the pilot trials, the Jacket precooling manoeuvre was able to repeatably lower T_{re} by 0.4°C and the Combination precooling manoeuvre was able to repeatably lower T_{re} by 1.5°C (Figure 4). However, during the data collection period, these protocols were not as effective, with the Jacket and Combination protocols only reducing T_{re} by 0.2°C and 0.8°C respectively (Figure 12). Although collection of data in the present study occurred during the summer months, this two week period was unusually cool, with the maximum ambient temperature on one day reaching only 12°C. After being exposed to cold ambient temperatures during the day, subjects were subsequently exposed to precooling manoeuvres. It is possible that subjects may have been in a "protective" state to cold temperatures, and as a consequence, the precooling manoeuvres used during the study might not have been as effective as during the pilot trials.

Although, the effectiveness of the precooling manoeuvres used in this study may have been reduced by the cold external environmental conditions, both the Jacket and the Combination treatments resulted in negative heat storage (-7.1 and -75.0 $W \cdot m^{-2}$ respectively) during the precooling protocols (Table 4). A similar degree of heat loss was calculated by Lee & Haymes (1995) and White et al. (2003), where subjects were reported to have lost 66 $W \cdot m^{-2}$ following 30 minutes exposure to cold (5°C) air, and 60 $W \cdot m^{-2}$ after 30 min immersion in cool water (20°C), respectively. In addition, Marino & Booth (1996) reported a reduction in heat content of 545 kJ following 60 min immersion in cool water (29-23°C) and Cotter et al. (2001) recorded a 401 kJ reduction in heat content following 45 min exposure to a cool room (3°C) while wearing an ice jacket on the torso and cryogenic cuffs on the legs.

Despite the enhanced heat storage capacity that is often used to explain the enhanced exercise performance following a precooling manoeuvre, few precooling studies have reported heat storage results. In the present study, the rate of heat storage tended to be greater in the precooled condition (Table 4). Such an increase in heat storage capacity following a precooling manoeuvre is similar to what has been reported in the literature. In a study by Kay et al. (1999), subjects heat storage was increased following precooling from 84 to 115 $W \cdot m^{-2}$ during a 30 min cycling time trial (31°C, 60% rh). Bolster et al. (1999) also reported an increase in heat storage following a precooling manoeuvre from 79 – 109 $W \cdot m^{-2}$ while cycling at 45% of $\dot{V}O_{2peak}$. Further, Booth et al. (1997) and Lee and Haymes (1995) both reported increases in heat storage of 113 – 249 $W \cdot m^{-2}$ and 143 – 173 $W \cdot m^{-2}$, respectively, during treadmill running in the heat following precooling. In each of these investigations, the increase in heat storage capacity was suggested as being a contributing factor to the improvement in performance. As such, it may be that the greater one can increase the heat storage capacity through a precooling manoeuvre, the greater the potential exists for the improvement of endurance performance in the heat.

In a recent study by Tucker et al. (2004), subjects were required to complete two exercise bouts in cool (15°C) and hot (35°C) environment conditions. In this study, subjects began to reduce their pace in the hot trial before 30% of the trial was completed, when rectal temperature was within normal limits (<38°C). That is, fatigue

was present in the absence of any thermal stress and the performance was not limited by the attainment of a critical T_{re}. Therefore, Tucker (2004) suggested that the reduction in pace may be an anticipatory response as a result of a central controller receiving afferent information regarding the body's rate of heat storage; the body then adjusts the work rate to ensure that normal temperature range is not exceeded and homeostasis is maintained. Such an anticipatory adjustment in pace has also been shown in the present study. In the Control condition, subjects' pace during the first 25% of the variable component of the time trial was slower than during the Combination treatment despite the fact that T_{re} was not at a critical level (< 39.0°C). This concept of an anticipatory adjustment of work rate is further supported by Marino et al. (2004), in their comparison of running performance in African and Caucasian runners to different environmental conditions. In this study, Marino et al. (2004) reported that the larger Caucasian runners adopted an anticipatory reduction in running speed in the heat, and the authors speculate that this may occur in order to avoid the attainment of a limiting hyperthermia before completion of the exercise task (Marino, Lambert et al. 2004). Marino et al. (Marino, Lambert et al. 2004) also suggest that the performance of the runners in the heat was "regulated by the rate of increase in rectal temperature and hence the rate of heat storage" In the present study, total rates of heat storage tended to be greater in the Combination treatment, although this difference was not significant (p = 0.07; Table 4). If the rate of heat storage is the afferent signal used by a central controller to anticipatorily adjust the work rate, and heat storage following a precooling manoeuvre is typically increased, then performance following a precooling manoeuvre would actually be worse, not improved. However, as suggested by Ulmer's (1996) teleoanticipation model of pace control, it is likely that the body integrates other signals in addition to the rate of heat gain. In the case of exercise in the heat, when anticipating the required pace to finish the time trial in as fast a time as possible, where the body is in its homeostatic temperature range may be taken into account. Therefore, the reduction in core body temperature and increase in heat storage capacity caused by precooling enables the body to maintain a greater rate of heat storage and subsequently an increased work rate.

5.2.2 Perceptions

As would be expected, subjects reported that they felt cooler during both the precooling manoeuvres and this sensation in the Combination condition remained during the warm up and fixed component of the performance trial (Figure 13). This conscious perception of being cooler during exercise in the Combination treatment is likely to be related to the lower T_{re} and $\overline{T}_b$ during this trial (St Clair Gibson, Baden et al. 2003). In addition, this reduced sensation of thermal strain may have contributed to a tendency to rate the perception of effort lower in the Combination treatment compared to the Control condition, despite a greater work rate (Figure 13). Following the Jacket treatment, ratings of thermal sensation and perception of effort tended to be lower than during the Control condition, but these differences were not significant. This is likely explained by the inability of the Jacket treatment in the present study to reduce core body temperature, resulting in no change in conscious perception of effort (St Clair Gibson, Baden et al. 2003).

5.2.3 Body Mass Changes

Changes in body mass for the three treatments were similar in this study with a tendency for a greater reduction in body mass following the Combination condition (Table 5). This tendency for a greater reduction in body mass following the Combination treatment is likely the result of a significantly greater increase in urine production during the Combination treatment (Table 5). It is probable that the Combination condition required less cutaneous blood flow for thermoregulation, leaving an increased blood volume in the central circulation and an associated increase in glomerular filtration rate and urine production from the kidneys. The increased urine production in the Combination trial might also have contributed marginally to the increased greater reduction in T_{re} and $\overline{T}_b$ shown in the Combination trial, as ~400ml more body water (at ~37°C) was eliminated from the subject prior to commencement of the performance test.

Despite an increase in work rate during the Combination treatment, estimated sweat rate in the present study tended to be greater in the Control condition. Hessemer et al. (1984) reported a similar finding; although subjects increased their mean 1 h work rate by 6.8%, sweat rate was 20.3% lower in the precooled condition. Schmidt & Bruck (1981) also reported a reduced sweat rate and a delayed onset of sweating following a precooling treatment. In addition, these authors suggested that this reduction in sweat rate may be indicative of a reduced thermoregulatory effort (Schmidt & Bruck 1981). Further, Lee & Haymes (1995) reported a reduced sweat rate following precooling, despite an increase in the exercise time to exhaustion of 121% while running at 82% of maximal aerobic capacity. It has been postulated that greater rates of sweating and the associated water loss may result in a reduced blood volume available for heat dissipation (Lee and Haymes 1995). Precooling and the associated reduction in sweat rates may therefore enhance athletic performance by assisting with thermoregulatory stability (Nadel 1987). However, in a study investigating the cardiovascular responses to running following a precooling manoeuvre, Marino & Booth (2001) reported that plasma volume and blood volume were not sufficiently reduced to account for a reduction in cardiovascular strain. As sweat rates were not substantially reduced and changes in stroke volume were not determined, it is difficult to infer an effect of reduced sweat rate on performance in this study, but this may have been one of a number of factors that contributed marginally to the improved performance witnessed following the Combination precooling condition.

5.2.4 HR Response

During the precooling treatments, HR was shown to be lower compared with the Control condition (Figure 15), and this is likely explained by the reduced thermoregulatory requirements placed on the cardiovascular system to circulate blood for cooling (Hessemer, Langusch et al. 1984). During fixed load exercise, HR is typically reduced during the first 10-15 min following a precooling manoeuvre (Schmidt and Bruck 1981; Lee and Haymes 1995), and this is similar to what was shown during the fixed load warm up in the present study (Figure 15). However, in exercise protocols following precooling where the pace is set by the subject, there is typically no difference in HR (Hessemer, Langusch et al. 1984; Booth, Marino et al.

1997; Kay, Taaffe et al. 1999; Arngrimsson, Petitt et al. 2004), and this was also shown during the variable workload component of the present study (Figure 15). As the thermal strain was shown to be reduced during the Combination treatment in the present study (reduced T_{re} & $\overline{T}_{b}$), it is likely that less blood volume was required for thermoregulation, making more oxygenated blood available to the working muscles and enabling the enhanced work rate that was shown (Marino 2002; Arngrimsson, Petitt et al. 2004).

5.2.5 Metabolic Response

Exercise in the heat results in an increase in carbohydrate relative to fat oxidation, which is mediated by a temperature related sympatho-adrenal response (Richter, Ruderman et al. 1982; Febbraio, Snow et al. 1994; Febbraio, Carey et al. 1996; Febbraio 2001). Consequently, it has been proposed that the blunting of the rise in core body temperature associated with precooling could result in a reduced metabolic perturbation and therefore contribute to the enhanced performance commonly exhibited (Febbraio, Snow et al. 1996; Marino 2002). However, Booth et al. (2001) investigated the effect of whole body cooling (water immersion) and reported no difference in muscle glycogen, triglyceride, adenosine triphosphate, creatine phosphate, creatine or lactate between a precooled and a control condition during 35 min cycling at 60% of $\dot{V}O_{2peak}$. This finding lead these authors to conclude that muscle metabolism is not altered by precooling and that exercise benefits are more likely derived from the reduced thermoregulatory and cardiovascular strain (Booth, Wilsmore et al. 2001). Similar to the findings of Booth et al. (2001), the present study found no differences in blood HCO^{-}_{3}, pH or glucose throughout the experimental conditions (Figure 16). In addition, La⁻ was similar for each condition with the exception of the final reading (end time trial), where La⁻ following the Combination treatment was greater than Control and La⁻ following the Jacket treatment was greater than both Combination and Control (Figure 16). Similar results have also been reported by Kay et al. (1999) where precooled subjects increased the distance cycled in 30 min despite similar levels of HR, RPE and $\dot{V}O_{2}$. While La⁻ was similar between conditions during the majority of the trial, increases in La⁻ during the final 10 min were greater following precooling,

suggesting a greater anaerobic ATP contribution in the final "end-spurt". The increased end La⁻ shown following the Combination treatment in the present study also suggests that the Combination precooling treatment enabled an increase in anaerobic ATP metabolism and an associated higher workload at the end of the TT.

The greater increase in La⁻ following the Jacket treatment in this study may be explained by subjects' miss-pacing the time trial following this treatment (Figure 11). Although beginning the TT with a high pace, subjects slowed considerably during the middle of the TT, then finished with a split time similar to the Combination condition. This miss-pacing of the time trial, the relatively high intensity at the finish, combined with the relatively high core and body temperatures are likely contributors to the greater final La⁻ readings following the Jacket treatment (Figure 16).

5.2.6 Endocrine Response

Neurohumoral factors have been proposed as potential mechanisms for a reduced neural drive at the point of fatigue during exercise in hot ambient conditions (Jeukendrup, Vet-Joop et al. 2000; Kayser 2003; Schillings, Hoefsloot et al. 2003; Daly, Seegers et al. 2005). Consequently, some stress hormones (prolactin, testosterone and cortisol) and markers of muscle damage (creatine kinase and c-reactive protein) were measured in this study to investigate the potential role these variables may play in an enhanced exercise capacity following a precooling manoeuvre. It was hypothesised that improved performance in the present study would be related to a significantly reduced endocrine disturbance. However, as no statistical differences between experimental conditions were found for any endocrine variable (Table 7), this hypothesis cannot be accepted. Although some trends were evident (increased testosterone and reduced prolactin, cortisol, creatine kinase and c-reactive protein following precooling), due to the variability associated with the measurement of endocrine variables, these non-significant results may be a consequence of the low statistical power secondary to the low subject numbers in this study. Therefore, further work with greater numbers of subjects is required to determine the influence of these variables on performance following a precooling manoeuvre.

Chapter 6   Conclusions and Recommendations for Further Research

6.1 Conclusions

The purpose of this research was to compare two practical precooling manoeuvres and to provide advice to Olympic coaches and athletes as to the best method of precooling prior to the 2004 Olympic cycling time trial in Athens. Results from the pilot work and this study indicate that not only is a combination treatment a powerful precooling manoeuvre, but it can significantly improve cycling time trial performance compared with no cooling or the use of a cooling jacket alone. In addition, the Combination precooling strategy used here does not appear to effect pacing. It is therefore recommended that the Combination precooling strategy be examined with a performance protocol that does not fix the work rate to ensure it has no effect on pacing and also for there to be a number of field trials in the lead up to the Athens Olympic Games to familiarise the athletes with the manoeuvre.

While previous research has demonstrated a potential benefit to endurance performance following the use of a cooling jacket, this study indicates that athlete pacing may be interrupted following their use. Coaches and athletes should therefore be aware of this potential negative effect associated with the use of cooling jackets. Consequently, it is recommended that prior to the use of a cooling jacket in the field, the jacket and cooling protocol be trialled with the athlete.

This study also investigated a number of variables associated with potential mechanisms that may improve endurance performance following a precooling manoeuvre. These data indicate that the performance benefit following the Combination treatment is likely to be related to the reduced thermal strain and subsequent increased heat storage capacity and not a reduced metabolic disturbance. While neurohumoral factors may play a role in the teleoanticipatory improvement in performance following precooling, a lack of statistical power in this study may have prohibited the determination of their role.

6.2 Recommendations for Further Research

A number of findings from this research warrant further investigation. Firstly, the impact of the Jacket protocol on pacing in this study is novel. To assist in the provision of advice to athletes and coaches as to the most appropriate ways to prepare for exercise in hot ambient conditions, the impact of cooling jackets on pacing deserves some attention.

In addition, despite evidence supporting an improvement in performance following skin cooling without a concomitant reduction in T_{core} (Kay, Taaffe et al. 1999), the performance results of this study indicate that the lower a precooling manoeuvre is able to reduce the core body temperature and hence the greater the potential gain in heat storage capacity, the greater the performance benefit. Certainly, however, too great a reduction in core body temperature may have detrimental effects on exercise performance. Therefore, the impact on performance and pacing of precooling the body to different degrees requires further investigation.

Finally, although changes in endocrine variables were not significantly different following the precooling treatments, levels of endocrine disturbance tended to be reduced in this study. Such neurohumoral responses have been reported to be associated with reduced fatigue while exercising in the heat (Daly, Seegers et al. 2005). Consequently, the role that these factors may play in improved endurance performance following precooling warrants further investigation.

Addendum

The Olympic cycling time trial took place in Athens, Greece on Thursday August 19, 2004 in moderate ambient conditions of ~29°C and 35% rh. Both of the Australian representatives in the cycling time trial (Mick Rogers – Men and Oenone Wood – Women) underwent precooling prior to the event. Unfortunately, as is often the case in applied situations, the precooling manoeuvre as described in this study was unable to be completed. Consequently, a modified cooling protocol was implemented. This involved the athletes standing in a cool shower for a period of twenty minutes before towelling dry and wearing the RMIT-AIS cooling jacket while travelling to the event site. Once at the event site, the athletes removed their jackets and began their individual warm ups. Oenone Wood finished 5th in the Women's time trial, while Mick Rogers finished 4th in the Men's time trial, this was the best ever result achieved by an Australian male road cyclist.
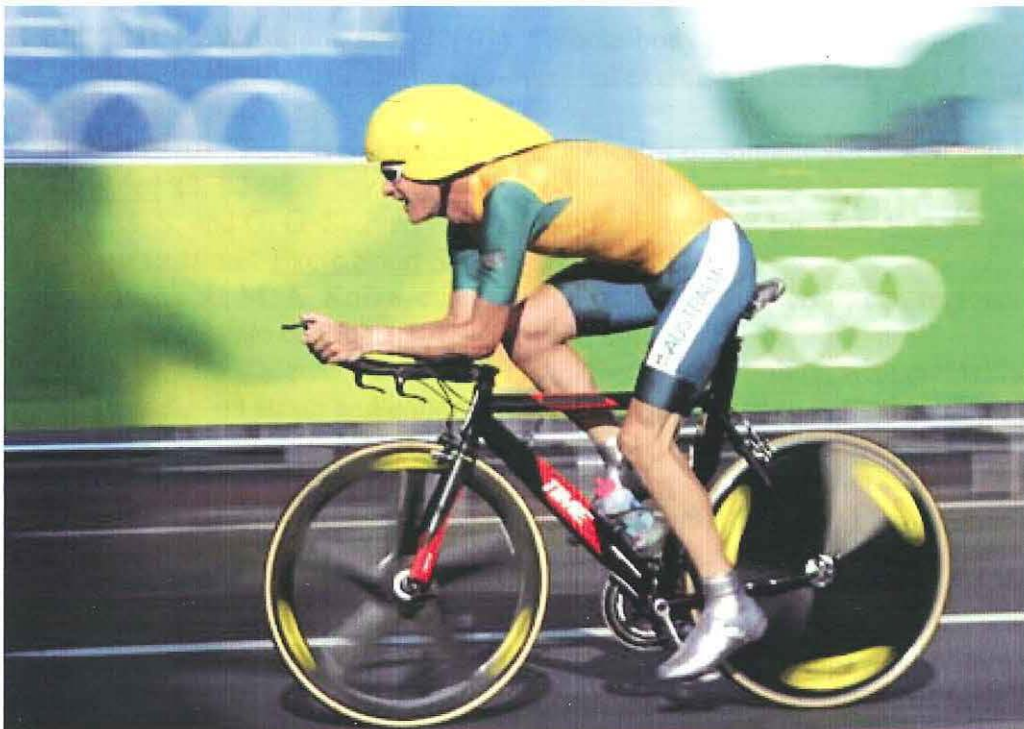
Figure 17. Australian cycling representative Mick Rogers, during the 2004 Olympic cycling time trial in Athens, Greece.

Chapter 7   References

Anshel, M. H., Ed. (1991). Dictionary of the sport and exercise sciences. Champaign, IL, Human Kinetics.

Arngrimsson, S. A., D. S. Petitt, et al. (2004). "Cooling vest worn during active warm-up improves 5-km run performance in the heat." J Appl Physiol 96(5): 1867-74.

Atkins, K. and M. Thompson (2000). "A spreadsheet for partitional calorimetry." Sport Science News 4(3).

Bazett, H. C., J. C. Scott, et al. (1937). "Effect of baths at different temperatures on oxygen exchange and on circulation." AM J Physiol 119: 93-110.

Bell, C. R. and K. A. Provins (1962). "Effects of high temperature environmental conditions on human performance." J Occup Med 4: 202-11.

Bergh, U. and B. Ekblom (1979). "Physical performance and peak aerobic power at different body temperatures." J Appl Physiol 46(5): 885-9.

Bergh, U., H. Hartley, et al. (1979). "Plasma norepinephrine concentration during submaximal and maximal exercise at lowered skin and core temperatures." Acta Physiol Scand 106(3): 383-4.

Bolster, D. R., S. W. Trappe, et al. (1999). "Effects of precooling on thermoregulation during subsequent exercise." Med Sci Sports Exerc 31(2): 251-7.

Booth, J., F. Marino, et al. (1997). "Improved running performance in hot humid conditions following whole body precooling." Med Sci Sports Exerc 29(7): 943-9.

Booth, J., B. R. Wilsmore, et al. (2001). "Whole-body pre-cooling does not alter human muscle metabolism during sub-maximal exercise in the heat." Eur J Appl Physiol 84(6): 587-90.

Borg, G. (1970). "Perceived exertion as an indicator of somatic stress." Scand J Rehab Med 23: 92-98.

Cheung, S. S. and G. G. Sleivert (2004). "Multiple triggers for hyperthermic fatigue and exhaustion." Exerc Sport Sci Rev 32(3): 100-6.

Cheuvront, S. N., M. A. Kolka, et al. (2003). "Efficacy of intermittent, regional microclimate cooling." J Appl Physiol 94(5): 1841-8.

Cotter, J. D., G. G. Sleivert, et al. (2001). "Effect of pre-cooling, with and without thigh cooling, on strain and endurance exercise performance in the heat." Comp Biochem Physiol A Mol Integr Physiol 128(4): 667-77.

Coyle, E. F., M. E. Feltner, et al. (1991). "Physiological and biomechanical factors associated with elite endurance cycling performance." Med Sci Sports Exerc 23(1): 93-107.

Coyle, E. F., W. H. Martin, et al. (1983). "Blood lactate threshold in some well-trained ischemic heart disease patients." J Appl Physiol 54(1): 18-23.

Crowley, G. C., A. Garg, et al. (1991). "Effects of cooling the legs on performance in a standard Wingate anaerobic power test." Br J Sports Med 25(4): 200-3.

Daly, W., C. A. Seegers, et al. (2005). "Relationship between stress hormones and testosterone with prolonged endurance exercise." Eur J Appl Physiol 93: 375-380.

Davis, J. M. and S. P. Bailey (1997). "Possible mechanisms of central nervous system fatigue during exercise." Med Sci Sports Exerc 29(1): 45-57.

Djursing, H. (1981). "Short- and long-term fluctuations in plasma prolactin concentration in normal subjects." Acta Endocrinol 97: 1-6.

Drust, B., N. T. Cable, et al. (2000). "Investigation of the effects of the pre-cooling on the physiological responses to soccer-specific intermittent exercise." Eur J Appl Physiol 81(1-2): 11-7.

DuBois, D. and E. F. DuBois (1916). "A formula to estimate the approximate surface area if height and weight be known." Arch Intern Medicine 17: 863-71.

Falls, H. B. and L. D. Humphrey (1970). "Effect of length of cold showers on skin temperatures and exercise heart rate." Res Q 41(3): 353-60.

Falls, H. B. and L. D. Humphrey (1971). "Cold water application effects on responses to heat stress during exercise." Res Q 42(1): 21-9.

Farmer, R. and C. Pierce (1974). "Plasma cortisol determinations: radioimmunoassay and competitive protein binding compared." Clin Chem 20: 411.

Febbraio, M. A. (2000). "Does muscle function and metabolism affect exercise performance in the heat?" Exerc Sport Sci Rev 28(4): 171-6.

Febbraio, M. A. (2001). "Alterations in energy metabolism during exercise and heat stress." Sports Med 31(1): 47-59.

Febbraio, M. A., M. F. Carey, et al. (1996). "Influence of elevated muscle temperature on metabolism during intense, dynamic exercise." Am J Physiol 271(5 Pt 2): R1251-5.

Febbraio, M. A., D. L. Lambert, et al. (1998). "Effect of epinephrine on muscle glycogenolysis during exercise in trained men." J Appl Physiol 84(2): 465-70.

Febbraio, M. A., P. Murton, et al. (1996). "Effect of CHO ingestion on exercise metabolism and performance in different ambient temperatures." Med Sci Sports Exerc 28(11): 1380-7.

Febbraio, M. A., R. J. Snow, et al. (1994). "Effect of heat stress on muscle energy metabolism during exercise." J Appl Physiol 77(6): 2827-31.

Febbraio, M. A., R. J. Snow, et al. (1996). "Blunting the rise in body temperature reduces muscle glycogenolysis during exercise in humans." Exp Physiol 81(4): 685-93.

Foster, C., M. Schrager, et al. (1994). "Pacing strategy and athletic performance." Sports Med 17(2): 77-85.

Fuller, A., R. N. Carter, et al. (1998). "Brain and abdominal temperatures at fatigue in rats exercising in the heat." J Appl Physiol 84(3): 877-83.

Galloway, S. D. and R. J. Maughan (1997). "Effects of ambient temperature on the capacity to perform prolonged cycle exercise in man." Med Sci Sports Exerc 29(9): 1240-9.

Gandevia, S. C. (2001). "Spinal and supraspinal factors in human muscle fatigue." Physiol Rev 81(4): 1725-89.

Geladas, N. and E. W. Banister (1988). "Effect of cold air inhalation on core temperature in exercising subjects under heat stress." J Appl Physiol 64(6): 2381-7.

Gold, A. J. and A. Zornitzer (1968). "Effect of partial body cooling on man exercising in a hot, dry environment." Aerosp Med 39(9): 944-6.

Gonzalez-Alonso, J., C. Teller, et al. (1999). "Influence of body temperature on the development of fatigue during prolonged exercise in the heat." J Appl Physiol 86(3): 1032-9.

Grether, W. F. (1973). "Human performance at elevated environmental temperatures." Aerosp Med 44(7): 747-55.

Hartung, G. H., L. G. Myhre, et al. (1980). "Physiological effects of cold air inhalation during exercise." Aviat Space Environ Med 51(6): 591-4.

Hasegawa, H., P. Watson, et al. (2004). Time trial performance in the heat is influenced by dopamine/noradrenaline reuptake inhibitor. 9th Annual Conference of the ECSS, Clermont-Ferrand, France, ECSS.

Hessemer, V., D. Langusch, et al. (1984). "Effect of slightly lowered body temperatures on endurance performance in humans." J Appl Physiol 57(6): 1731-7.

Jaffe, B. M. and N. R. Behrman, Eds. (1974). Methods of hormone radioimmunoassay, Academic Press.

Jeukendrup, A., W. H. Saris, et al. (1996). "A new validated endurance performance test." Med Sci Sports Exerc 28(2): 266-70.

Jeukendrup, A. E., K. Vet-Joop, et al. (2000). "Relationship between gastro-intestinal complaints and endotoxaemia, cytokine release and the acute-phase reaction during and after a long-distance triathlon in highly trained men." Clin Sci (Lond) 98(1): 47-55.

Jirak, Z., M. Jokl, et al. (1975). "Correction factors in skin temperature measurement." J Appl Physiol 38(4): 752-6.

Kay, D. and F. E. Marino (2000). "Fluid ingestion and exercise hyperthermia: implications for performance, thermoregulation, metabolism and the development of fatigue." J Sports Sci 18(2): 71-82.

Kay, D., D. R. Taaffe, et al. (1999). "Whole-body pre-cooling and heat storage during self-paced cycling performance in warm humid conditions." J Sports Sci 17(12): 937-44.

Kayser, B. (2003). "Exercise starts and ends in the brain." Eur J Appl Physiol 90(3-4): 411-9.

Lambert, E. V., A. St Clair Gibson, et al. (2005). "Complex systems model of fatigue: integrative homeostatic control of peripheral physiological systems during exercise in humans." Br J Sports Med 39: 52-62.

Lee, D. T. and E. M. Haymes (1995). "Exercise duration and thermoregulatory responses after whole body precooling." J Appl Physiol 79(6): 1971-6.

Livingstone, S. D., R. W. Nolan, et al. (1989). "Heat loss caused by immersing the hands in water." Aviat Space Environ Med 60(12): 1166-71.

Marino, F. and J. Booth (1998). "Whole body cooling by immersion in water at moderate temperatures." J Sci Med Sport 1(2): 73-82.

Marino, F. and J. Booth (2001). "Cardiovascular responses to self-paced running in warm humid conditions following whole-body precooling." South African Journal of Sports Medicine 8: 3-8.

Marino, F. B., J. (1996). Whole body precooling using cold water immersion. Australian Conference of Science and Medicine in Sport Abstracts, Canberra, ACT, Australia, Sports Medicine Australia.

Marino, F. E. (2002). "Methods, advantages, and limitations of body cooling for exercise performance." Br J Sports Med 36(2): 89-94.

Marino, F. E., M. I. Lambert, et al. (2004). "Superior performance of African runners in warm humid but not in cool environmental conditions." J Appl Physiol 96(1): 124-30.

Marino, F. E., Z. Mbambo, et al. (2001). "Influence of ambient temperature on plasma ammonia and lactate accumulation during prolonged submaximal and self-paced running." Eur J Appl Physiol 86(1): 71-8.

Marsh, D. and G. Sleivert (1999). "Effect of precooling on high intensity cycling performance." Br J Sports Med 33(6): 393-7.

Martin, D. T., A. G. Hahn, et al. (1998). "Ice Jackets are Cool." Sport Science News Nov-Dec: www.sportsci.org/news/news9811/AISjackets.html.

Mitchell, J. B., B. K. McFarlin, et al. (2003). "The effect of pre-exercise cooling on high intensity running performance in the heat." Int J Sports Med 24(2): 118-24.

Myler, G. R., A. G. Hahn, et al. (1989). "The effect of preliminary skin cooling on performance of rowers in hot conditions." Excel 6: 17-21.

Nadel, E. R. (1987). "Prolonged exercise and high and low ambient temperatures." Can J Sport Sci 12: 140S-142S.

Nielsen, B., T. Hyldig, et al. (2001). "Brain activity and fatigue during prolonged exercise in the heat." Pflugers Arch 442: 41-48.

Nielsen, B., G. Savard, et al. (1990). "Muscle blood flow and muscle metabolism during exercise and heat stress." J Appl Physiol 69(3): 1040-6.

Noakes, T. D. and A. St Clair Gibson (2004). "Logical limitations to the "catastrophe" models of fatigue during exercise in humans." Br J Sports Med 38: 648-9.

Norton, K., M. Marfell-Jones, et al. (2000). Anthropometric Assessment Protocols. Physiological tests for elite athletes. C. J. Gore. Champaign, IL, Human Kinetics: 66-85.

Nunneley, S. A., C. C. Martin, et al. (2002). "Changes in regional cerebral metabolism during systemic hyperthermia in humans." J Appl Physiol 92(2): 846-51.

Nybo, L., K. Moller, et al. (2002). "Effects of hyperthermia on cerebral blood flow and metabolism during prolonged exercise in humans." J Appl Physiol 93(1): 58-64.

Nybo, L. and B. Nielsen (2001). "Hyperthermia and central fatigue during prolonged exercise in humans." J Appl Physiol 91(3): 1055-60.

Nybo, L., B. Nielsen, et al. (2003). "Neurohumoral responses during prolonged exercise in humans." J Appl Physiol 95(3): 1125-31.

Olschewski, H. and K. Bruck (1988). "Thermoregulatory, cardiovascular, and muscular factors related to exercise after precooling." J Appl Physiol 64(2): 803-11.

Parkin, J. M., M. F. Carey, et al. (1999). "Effect of ambient temperature on human skeletal muscle metabolism during fatiguing submaximal exercise." J Appl Physiol 86(3): 902-8.

Patton, J. F. and J. A. Vogel (1984). "Effects of acute cold exposure on submaximal endurance performance." Med Sci Sports Exerc 16(5): 494-7.

Ramanathan, N. L. (1964). "A New Weighting System for Mean Surface Temperature of the Human Body." J Appl Physiol 19: 531-3.

Richter, E. A., N. B. Ruderman, et al. (1982). "Muscle glycogenolysis during exercise: dual control by epinephrine and contractions." Am J Physiol 242(1): E25-32.

Robson-Ansley, P. J., L. de Milander, et al. (2004). "Acute interleukin-6 administration impairs athletic performance in healthy, trained male runners." Can J Appl Physiol 29(4): 411-418.

Sakurada, S. and J. R. Hales (1998). "A role for gastrointestinal endotoxins in enhancement of heat tolerance by physical fitness." J Appl Physiol 84(1): 207-14.

Saunders, A., J. P. Dugas, et al. (2004). Air velocity influences heat storage and core temperature independently of fluid ingestion in humans cycling in hot, humid conditions. 9th Annual Conference of the ECSS, Clermont-Ferrand, France, ECSS.

Schillings, M. L., W. Hoefsloot, et al. (2003). "Relative contributions of central and peripheral factors to fatigue during a maximal sustained effort." Eur J Appl Physiol 90(5-6): 562-8.

Schmidt, V. and K. Bruck (1981). "Effect of a precooling maneuver on body temperature and exercise performance." J Appl Physiol 50(4): 772-3.

Shvartz, E. and A. Magazanik (1973). "Tolerance to heat following cold stress." Aerosp Med 44(7): 725-9.

Shvartz, E., E. Saar, et al. (1973). "Physique and heat tolerance in hot-dry and hot-humid environments." J Appl Physiol 34(6): 799-803.

Shvartz, E., E. Saar, et al. (1973). "Heat acclimatization while wearing vapor-barrier clothing." Aerosp Med 44(6): 609-12.

Sleivert, G. G., J. D. Cotter, et al. (2001). "The influence of whole-body vs. torso pre-cooling on physiological strain and performance of high-intensity exercise in the heat." Comp Biochem Physiol A Mol Integr Physiol 128(4): 657-66.

Smith, J. A., K. Yates, et al. (1997). "Pre-cooling improves cycling performance in hot/humid conditions." Med Sci Sports Exerc 29(5): S263 (Abstract).

St Clair Gibson, A., D. A. Baden, et al. (2003). "The conscious perception of the sensation of fatigue." Sports Med 33(3): 167-76.

Supinski, G., D. Nethery, et al. (2000). "Endotoxin administration alters the force vs. pCa relationship of skeletal muscle fibers." Am J Physiol Regul Integr Comp Physiol 278(4): R891-6.

Tatterson, A. J., A. G. Hahn, et al. (2000). "Effects of heat stress on physiological responses and exercise performance in elite cyclists." J Sci Med Sport 3(2): 186-93.

Tucker, R., L. Rauch, et al. (2004). Imparied exercise performance in the heat is associated with an anticipatory reduction in skeletal muscle recruitment. 9th Annual Conference of the ECSS, Clermont-Ferrand, France.

Ulmer, H. V. (1996). "Concept of an extracellular regulation of muscular metabolic rate during heavy exercise in humans by psychophysiological feedback." Experientia 52(5): 416-20.

Vaughan, J. A., E. A. Higgins, et al. (1968). "Effects of body thermal state on manual performance." Aerosp Med 39(12): 1310-5.

Webb, P. and J. F. Annis (1968). "Cooling required to suppress sweating during work." J Appl Physiol 25(5): 489-93.

White, A. T., S. L. Davis, et al. (2003). "Metabolic, thermoregulatory, and perceptual responses during exercise after lower vs. whole body precooling." J Appl Physiol 94(3): 1039-44.

Williams, C., V. Montfort-Steiger, et al. (2004). Reliability of a cycling performance test in well-trained adolescent cyclists. 9th Annual Conference of the ECSS, Clermont-Ferrand, France, ECSS.

Wimer, G. S., D. R. Lamb, et al. (1997). "Temperature of ingested water and thermoregulation during moderate-intensity exercise." Can J Appl Physiol 22(5): 479-93.

Yates, K., Ryan, R., Martin, D.T., Dobson, G.P., Smith, J., Tumilty, D. & Hahn, A. (1996). Pre-cooling rowers can improve laboratory 2000m performance in hot-humid conditions. Australian Conference of Science and Medicine in Sport Abstracts, Canberra, ACT, Australia, Sports Medicine Australia.

Young, A. J., M. N. Sawka, et al. (1987). "Cooling different body surfaces during upper and lower body exercise." J Appl Physiol 63(3): 1218-23.

Appendix 1 – Informed Consent

"Pre-Cooling To Enhance Cycling Performance"
'INFORMED CONSENT'

Project Title: Performing Successfully in the Heat of Athens: Which Active Cooling Strategies Represent "Best Practice" for Endurance Athletes?

Principal Researcher: **David T. Martin, Ph.D.**

Co-researchers: **Prof. Allan G. Hahn, Dr. Chris Gore, Dr. Shona Halson, Tammie Ebert, Scott Gardner, Marc Quod, Dr. Paul Laursen, Prof. Warren Payne**

This is to certify that I, _____ hereby agree to participate as a volunteer in a scientific investigation as an authorised part of the research program of the Australian Sports Commission under the supervision of **Dr. David T. Martin**

The investigation and my part in the investigation have been defined and fully explained to me by one of the researchers listed above and I understand the explanation. A copy of the procedures of this investigation and a description of any risks and discomforts has been provided to me and has been discussed in detail with me.

- I have been given an opportunity to ask whatever questions I may have had and all such questions and inquiries have been answered to my satisfaction.
- I understand that I am free to deny any answers to specific items or questions in interviews or questionnaires.
- I understand that I am free to withdraw consent and to discontinue participation in the project or activity at any time.
- I understand that any data or answers to questions will remain confidential with regard to my identity.
- I certify to the best of my knowledge and belief, I have no physical or mental illness or weakness (i.e., previously suffered from heat exhaustion or heat stroke) that would increase the risk to me (him/her) of participating in this investigation.
- I am (the child is) participating in this project of my (his/her) own free will and I have not been coerced in any way to participate.

Signature of Subject: _____   Date: ___/___/___

I, the undersigned, was present when the study was explained to the subject/s in detail and to the best of my knowledge and belief it was understood.

Signature of Researcher: _____   Date: ___/___/___

-95 -

Appendix 2 - Ethics Approval

Australian Institute of Sport

MINUTE

TO:	Dave Martin	**CC:**
FROM:	John Williams	
SUBJECT:	Approval from AIS Ethics Committee	
DATE:	22 October 2003	

I am pleased to inform you that at the last meeting of the AIS Ethics Committee held on 20th October 2003, the Committee saw no ethical reason why your project *Performing successfully in the heat of Athens: which active cooling strategies represent best practice for endurance athletes?* should not proceed subject to:

- *Having a medical practitioner provide a letter approving the biomedical procedures.*

The approval number for this project is 20031010.

It is a requirement of the AIS Ethics Committee that all researchers involved in the study be advised of Ethics Committee approval and conditions, and that the Ethics Committee be advised immediately (via the Secretary) of:

> any proposed changes to the research design,
> any adverse events that may occur,

Failure to comply with the above may render ethics approval null and void.

It is also a requirement of the AIS Ethics Committee that all researchers provide an annual status report, and on completion of the study, a brief report on the outcomes of the study and the manner in which the outcomes have been presented (eg. journal articles, reports, conferences, seminars etc)

If you have any questions regarding this matter, please don't hesitate to contact me on (02) ▮▮▮▮▮

Sincerely

John Williams
Secretary, AIS-EC

Human Research Ethics Committee (HREC)
HUMAN RESEARCH ETHICS APPROVAL FORM

> **Principal Researcher / Supervisor:** P Laursen
>
> **Associate Researcher/s / Student Researcher/s:** M Quod
>
> **School:** School of Human Movement & Sports Sciences

> **Ethics approval has been granted for the following project:**
>
> **Project Number:** 03/158
>
> **Project Title:** Performing successfully in the heat of Athens: Which active cooling strategies represent "Best Practice" for endurance athletes?
>
> **for the period:** 05/01/2004 **to** 18/01/2004
>
> **Meeting No:** EM15/03   **Meeting Date:** 27/11/2003

The Principal Researcher / Supervisor is requested to note the following comments:

- Clarification required on the question of a positive response to the Medical Questionnaire - e.g. if a person answers yes to the question "Have you smoked in the past?" does this automatically disqualify them from participating?

- In dot point 5 the Committee requested that a medical professional be available at the site. Does the researcher feel it is sufficient to have just persons with recent first aid qualifications present?

- The Executive Officer to receive notification of which pre-cooling technique are to be used following the meeting in Canberra on 11 December.

Within one month of the conclusion of the project, researchers are required to complete a Final Report Form and submit it to the HREC Executive Officer.

If the project continues for more than one year, researchers are required to compete an Annual Progress Report Form and submit it to the HREC Executive Officer within one month of the anniversary date of the ethics approval.

Signed:...   Date:...........................
             [Executive Officer, HREC]

EDITH COWAN

JOONDALUP CAMPUS

100 Joondalup Drive,
Joondalup
Western Australia 6027
Telephone 134 328
Facsimile (08) 9300 1257

ABN 54 361 485 361

25th June 2004

Mr Marc Quod
Laboratory Standards Assistance Scheme
Australian Institute of Sport
PO Box 176
Belconnen ACT 2616

Dear Mr Quod

PROJECT CODE	04-116	
PROJECT TITLE	Performing Successfully in the Heat of Athens: Which Active Cooling Strategies Represent "Best Practice" for Endurance Athletes	
CHIEF INVESTIGATOR	Mr M Quod	
ETHICS APPROVAL	FROM: 25th June 2004	TO: 30th November 2004

Thank you for your recent application for ethics approval. The ECU Human Research Ethics Committee notes that this project has been previously approved by the University of Ballarat and the Australian Institute of Sport, and has granted ethics approval for your project.

Please note the following conditions of approval:

The National Statement on Ethical Conduct in Research Involving Humans requires ethics committees to ensure there is appropriate monitoring of the conduct of all approved research until completion in order to ensure that the interests of the research participants are adequately protected. Compliance with monitoring requirements is a condition of approval and the primary responsibility for monitoring rests with the Chief Investigator. Please find attached a copy of the monitoring requirements and ethics report form.

With best wishes for success in your work.

Yours sincerely

Kim Gifkins
RESEARCH ETHICS OFFICER
Phone 6304 2170
Fax: 6304 2661
Email: research.athics@ecu.edu.au

Attachment – Monitoring form

Appendix 3 – Dietary Standardisation

PRE-COOLING STUDY

DEPARTMENT OF PHYSIOLOGY
AUSTRALIAN INSTITUTE OF SPORT

DIETARY STANDARDISATION INSTRUCTIONS

PREPARED BY PROFESSOR LOUISE BURKE,
DEPARTMENT OF SPORTS NUTRITION, AIS

In this study, we will be investigating whether pre-cooling strategies provide a benefit to cycling performance. To do this effectively, we need to reduce the "day to day variability" in cycling performance that might otherwise mask small, but worthwhile, improvements in performance from these strategies. One tactic is to standardise all the conditions under which trials are performed – including dietary preparation. Important factors include:

- Amount of carbohydrate and energy eaten during the 24 hours before the trial
- Fluid intake on the day before and morning of the trial
- Pre-trial meal

These instructions will help you to achieve a similar preparation for each trial

Carbohydrate and fluid goals

Aim: we want you to eat at least 6 g of carbohydrate per kg of your body weight on the day before each trial, and the same pre-trial meal on the morning of your trial (providing at least 1 g carbohydrate/kg). We also want you to consume at least 2 litres of fluid on this day (including all drinks consumed at meals or during training), and 400 ml of fluid at the meal consumed just before the trial

Steps:

1. Fill in your name.. and

   current body weight?...............................kg

2. Calculate your carbohydrate intake (minimum) for the day before the trial:

   6 x BM =............................g..

Calculate your carbohydrate intake (minimum) for the last meal, eaten 2 hours before you start the trial: 1 x BM =...............................g..

3. Keep a food record for the day before your first trial, concentrating on the carbohydrate-rich foods found in the table over the page, and the amount of fluid consumed. Use the table on the following page to add up how much carbohydrate is eaten at each meal or snack. Aim for the targets of at least 6 g/kg and at least 1 g/kg. Each of these "blocks" of food provides approximately 50 g of carbohydrate. It is not necessary to eat a whole block, or round numbers of blocks. Try to keep count in terms of quarter or half blocks

4. Once you have completed the first day's record, this sets the amount that you need to eat for the next trials. It is simplest to try to repeat a very similar meal pattern for each of these days – i.e. stick to the same type and amount carbohydrate foods. If this is impractical, use the carbohydrate counter to replace one carbohydrate food with the amount of another carbohydrate choice that provides a similar amount of carbohydrate.

Example, on day one you might have eaten 2 rounds of cheese and salad sandwiches (4 thin slices of bread) for lunch, with a Juice Popper (unsweetened orange juice). The carbohydrate counter tells you that this is equal to 1 block (50 g carbohydrate) for the bread and just under a half block (or about 20 g of carbohydrate) for the Popper. If you want to swap the lunch menu, this same amount of carbohydrate could be found in 2 english muffins (with a similar kind of filling) and one carton of low fat flavoured yoghurt.

5. Keep a record of each day's food intake so that we can check how well you were able to duplicate your carbohydrate intake and fluid intake for the next trials.

6. Repeat the same process for the meal eaten ~ 2 hours before the trial

Ready reckoner of 50 g carbohydrate serves from common foods

Professor Louise Burke, Australian Institute of Sport

CEREALS

Wheat biscuit cereal (e.g. Weetbix)	60g (5 biscuits)
'Light' breakfast cereal (e.g. Cornflakes, Weeties)	60 g (2 cups)
'Muesli' flake breakfast cereal (e.g. Sustain)	65 g (1.5 cups)
Toasted muesli	90 g (1 cup)
Porridge - made with milk	350 g (1.3 cups)
Porridge - made with water	550 g (2.5 cups)
Rolled oats	90 g (1 cup)
Cereal bar	2.5 x 30 g bar, 3 x 25 g bar
Rice cakes	6 thick or 10 thin
Rice, boiled	180g (1 cup)
Pasta or noodles, boiled	200 g (1.3 cups)
Canned spaghetti	440 g (large can)
Crispbreads and dry biscuits	6 large or 15 small
Fruit filled biscuits	5
Plain sweet biscuits	8-10
Cream filled/chocolate biscuits	6
Bread	110 g (4 slices white or 3 thick wholegrain)
Bread rolls	110 g (1 large or 2 medium)
Pita and lebanese bread	100 g (2 pita)
Chapati	150 g (2.5)
English muffin	120 g (2 full muffins)
Crumpet	2.5
Cake-style muffin	**115 g (1 medium)**
Pancakes	150 g (2 medium)
Scones	125 g (3 medium)
Iced fruit bun	105 g (1.5)
Croissant	140 g (1.5 large or 2 medium)
Rice-cream or creamed rice	330 g (1.5 cups)

FRUIT

Fruit crumble	1 cup
Fruit packed in heavy syrup	280 g (1.3 cups)
Fruit stewed/canned in light syrup	520 g (2 cups)
Fresh fruit salad	500 g (2.5 cups)
Bananas	2 medium-large
Mangoes, pears, grapefruit and other large fruit	2-3
Oranges, apples and other medium size fruit	3-4
Nectarines, apricots and other small fruit	12
Grapes	350 g (2 cups)
Melon	1,000 g (6 cups)
Strawberries	1,800 g (12 cups)
Sultanas and raisins	70 g (4 Tbsp)
Dried apricots	115 g (22 halves)

VEGETABLES AND LEGUMES

Potatoes	350 g potato (one very large or 3 medium)
Sweet potato	350 g (2.5 cups)
Corn	300 g (1.2 cups creamed corn or 2 cobs)
Green Beans	1,800 g (14 cups)
Baked beans	440 g (1 large can)
Lentils	400 g (2 cups)
Soy beans and kidney beans	400 g (2 cups)
Tomato puree	1 liter (4 cups)
Pumpkin and peas	700 g (5 cups)

DAIRY PRODUCTS

Milk	1 liter
Flavored milk	560 ml
Custard	300 g (1.3 cup)
'Diet' yogurt and natural yogurt	800 g (4 individual tubs)
Flavored non-fat yogurt	350 g (2 x 200 g individual tubs)
Ice-cream	250 g (5 scoops)

SUGARS AND CONFECTIONERY

Sugar	50 g
Jam	3 Tbsp
Syrups	4 Tbsp
Honey	3 Tbsp
Chocolate	80 g
Mars Bar (~ 60 g bar)	1.5 bars
Jelly confectionery	60g

MIXED DISHES

Pizza	200 g (medium -1/4 thick or 1/3 thin)
Hamburgers	1.3 Big Macs
Lasagna	400 g serve
Fried rice	200 g (1.3 cups)

DRINKS

Fruit juice - unsweetened	600 ml
Fruit juice - sweetened	500 ml
Cordial	800 ml
Soft drinks and flavored mineral water	500 ml
Fruit smoothie	250-300 ml

SPORTS FOODS

Sports drink	700 ml
Carbohydrate loader supplement	250 ml
Liquid meal supplement	250-300 ml
Sports bar	1-1.5 bars
Sports gels	2 sachets
Glucose polymer powder	60 g

TRIAL 1: DAY BEFORE date: name.................................

Meal	FOOD AND DRINKS	CALCULATION OF CARBOHYDRATE CONTENT	CALCULATION OF ml OF FLUID CONSUMED
Breakfast			
Lunch			
Dinner			
Snacks			

Total carbohydrate (AIM =   g)...

Total fluid (aim => 2000 ml) ....

TRIAL 1: MORNING OF TRIAL – LAST MEAL (2 HOURS PRE TRIAL)

date: **name...............................**

Meal	FOOD AND DRINKS	CALCULATION OF CARBOHYDRATE CONTENT	CALCULATION OF ml OF FLUID CONSUMED
		AIM = g	AIM = 400 ML

Note: if you have a late morning/early afternoon trial, you may choose to eat an early breakfast, followed by this last meal. If so, please record the breakfast and repeat for all subsequent trials

Meal	FOOD AND DRINKS	CALCULATION OF CARBOHYDRATE CONTENT	CALCULATION OF ml OF FLUID CONSUMED
		AIM = g	

TRIAL 2: DAY BEFORE   date: name...................................

Meal	FOOD AND DRINKS	CALCULATION OF CARBOHYDRATE CONTENT	CALCULATION OF ml OF FLUID CONSUMED
Breakfast			
Lunch			
Dinner			
Snacks			

Total carbohydrate (AIM =   g)...

Total fluid (aim = > 2000 ml) ....

- 107 -

TRIAL 2: MORNING OF TRIAL – LAST MEAL (2 HOURS PRE TRIAL)

date: **name.............................**

Meal	FOOD AND DRINKS	CALCULATION OF CARBOHYDRATE CONTENT	CALCULATION OF ml OF FLUID CONSUMED
		AIM = g	AIM = 400 ML

Note: if you have a late morning/early afternoon trial, you may choose to eat an early breakfast, followed by this last meal. If so, please record the breakfast and repeat for all subsequent trials

Meal	FOOD AND DRINKS	CALCULATION OF CARBOHYDRATE CONTENT	CALCULATION OF ml OF FLUID CONSUMED
		AIM = g	

TRIAL 3: DAY BEFORE   date: name................................

Meal	FOOD AND DRINKS	CALCULATION OF CARBOHYDRATE CONTENT	CALCULATION OF ml OF FLUID CONSUMED
Breakfast			
Lunch			
Dinner			
Snacks			

Total carbohydrate (AIM =   g)..

Total fluid (aim = > 2000 ml) ....

TRIAL 3: MORNING OF TRIAL – LAST MEAL (2 HOURS PRE TRIAL)

date: **name.............................**

Meal	FOOD AND DRINKS	CALCULATION OF CARBOHYDRATE CONTENT	CALCULATION OF ml OF FLUID CONSUMED
		AIM = g	AIM = 400 ML

Note: if you have a late morning/early afternoon trial, you may choose to eat an early breakfast, followed by this last meal. If so, please record the breakfast and repeat for all subsequent trials

Meal	FOOD AND DRINKS	CALCULATION OF CARBOHYDRATE CONTENT	CALCULATION OF ml OF FLUID CONSUMED
		AIM = g	

TRIAL 4: DAY BEFORE   date: name.................................

Meal	FOOD AND DRINKS	CALCULATION OF CARBOHYDRATE CONTENT	CALCULATION OF ml OF FLUID CONSUMED
Breakfast			
Lunch			
Dinner			
Snacks			

Total carbohydrate (AIM =   g)...

Total fluid (aim = > 2000 ml) ....

TRIAL 4: MORNING OF TRIAL – LAST MEAL (2 HOURS PRE TRIAL)

date: **name**...................................

Meal	FOOD AND DRINKS	CALCULATION OF CARBOHYDRATE CONTENT	CALCULATION OF ml OF FLUID CONSUMED
		AIM = g	AIM = 400 ML

Note: if you have a late morning/early afternoon trial, you may choose to eat an early breakfast, followed by this last meal. If so, please record the breakfast and repeat for all subsequent trials

Meal	FOOD AND DRINKS	CALCULATION OF CARBOHYDRATE CONTENT	CALCULATION OF ml OF FLUID CONSUMED
		AIM = g	

Appendix 4 – Prescribed and Adjusted Workloads

Subject	MAP (W)	Warm Up					
		3 min		5 min		2 min	
		Power (W)	% of MAP	Power (W)	% of MAP	Power (W)	% of MAP
1	360	90	25	16	60	288	80
2	415	104	25	249	60	332	80
3	360	90	25	216	60	288	80
4	410	103	25	246	60	328	80
5	365	91	25	219	60	292	80
6	395	99	25	237	60	316	80
1 Revised		79	21.9	189	52.5	252	70
2 Revised		93	23	224	54	300	73.6
3 Revised		83	23	199	55.2	265	73.6
6 Revised		88	22.2	210	53.2	280	70.8
Revised Mean	384.2	89.5	23.4	214.5	55.8	286.2	74.7
SD	25.6	8.2	1.4	20.1	3.4	27.0	4.4

Subject	MAP (W)	Performance Trial							Variable Workload Linear Factor
		Fixed Workload (20 min)		Variable Workload KJ Completed					
		(W)	(KJ)	25%	50%	75%	100%		
1	360	288	346	432	518	605	691		0.029
2	415	332	398	498	597	697	796		0.032
3	360	288	346	432	518	605	691		0.029
4	410	328	394	492	591	689	787		0.033
5	365	292	350	438	526	613	701		0.029
6	395	316	379	474	569	664	759		0.032
1 Revised		252	302	378	454	529	605		0.025
2 Revised		300	360	450	540	630	720		0.030
3 Revised		265	318	398	477	557	636		0.027
6 Revised		280	336	420	504	588	672		0.028
Revised Mean	384.2	286.2	343.4	429.3	515.1	601.0	686.9		
SD	25.6	27.0	32.4	40.5	48.6	56.7	64.8		

Appendix 5 – Heat Chamber Floor Plan
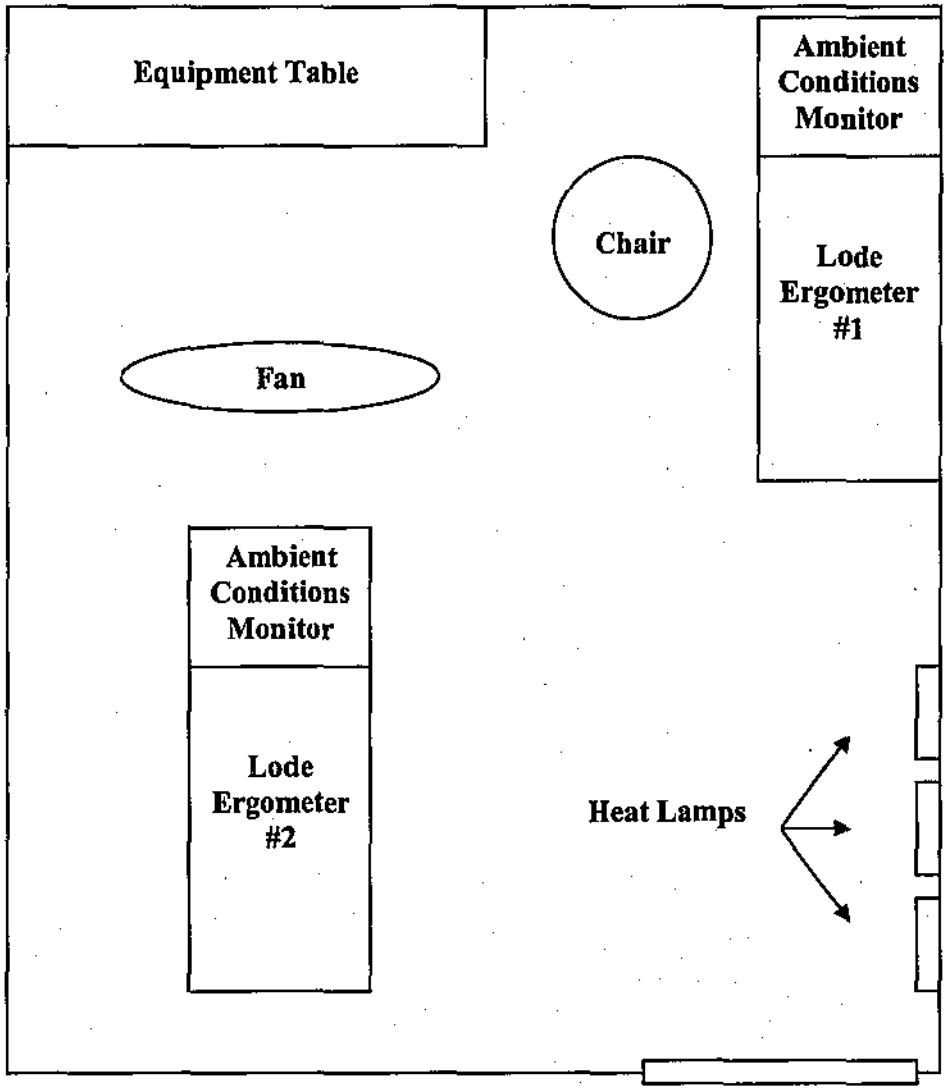
Appendix 6 – Thermal Sensation Scale

THERMAL SENSATION SCALE

0.0   Unbearably Cold

0.5

1.0   Very Cold

1.5

2.0   Cold

2.5

3.0   Cool

3.5

4.0   Comfortable

4.5

5.0   Warm

5.5

6.0   Hot

6.5

7.0   Very Hot

7.5

8.0   Unbearably Hot

Young et.al., (1987). *Journal of Applied Physiology.* 63(3): 1218 - 1223

Appendix 7 – Rating of Perceived Exertion

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