The effect of hand cooling on thermal and psychophysical strain and performance during high intensity intermittent training of elite swimmers.

by

Thomas Zochowski
B.Sc. Biomechanical Engineering, Stanford University, 2003

A Thesis Submitted in Partial Fulfillment of the
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MASTER OF SCIENCE

In the School of Physical Education

University of Victoria

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Dr. Lynneth Wolski
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Ben Sporer
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Abstract

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The purpose of the present study was to determine the effects of using intermittent hand cooling during high intensity, intermittent training on measures of thermoregulatory, performance and psychophysical variables in elite level swimmers in warm pools (30.5±0.5°C). Following a standard warm-up, ten male swimmers (20.3±3.2 yrs) were instructed to maintain the fastest average 100m time for an 8x100m freestyle swimming set separated in a cool pool (CP), warm pool with cooling (WPC), and warm pool with no-cooling (WPNC). Time at 50m and 100m, core temperature (Tc), and heart rate (HR), as well as the rate of perceived exertion (RPE), thermal comfort (ThC) and thermal sensation (ThS) were recorded following each repetition. Participants were cooled during the 90 second rest interval between repetitions using the Rapid Thermal Exchange (RTX) [AVAcore Technologies Inc., Ann Arbor, MI]. There was a significant increase in performance when comparing the second 50m split time (1.16 ± 1.58s) and 100m time (1.50 ± 1.98s) for the final repetition in the WPC condition compared to the final repetition in the WPNC condition ($p<0.05$). HR, ThC and ThS were lower in the CP condition than the WPC and WPNC conditions ($p<0.05$). There was no significant difference in Tc and RPE between conditions. It was concluded that the results may be due to a placebo effect and at this time there appears no physiological or psychophysical advantage in using the RTX during high intensity, intermittent training of elite swimmers.

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Symbols and Abbreviations

AVA	Ateriovenous Anastomoses
RTX	Rapid Thermal Exchange System
VO_2	Oxygen Consumption ($mL\cdot kg^{-1}\cdot min^{-1}$ or $L\cdot min^{-1}$)
VO_{2max}	Maximal Oxygen Consumption ($mL\cdot kg^{-1}\cdot min^{-1}$ or $L\cdot min^{-1}$)
WPC	Warm pool with cooling experimental condition
WPNC	Warm pool with no-cooling experimental condition
CP	Cool pool experimental condition
Tc	Core temperature
HR	Heart Rate
Lac	Blood Lactate
RPE	Rate of Perceived Exertion
ThC	Thermal Comfort
ThS	Thermal Sensation

Acknowledgements

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1 INTRODUCTION

Athletes regularly train and compete in thermally stressful environments that amplify physiological strain which can impair performance and/or the efficacy of training. For example, the environmental conditions during the 2004 Olympic Games in Greece ranged from 35°C to 40°C. Not only do these conditions affect athletes performing in land-based activities but also athletes in water sports. Outdoor swimming pool temperatures typically range from 29°C to 32°C. Typically heat illness occurs in hot and humid weather but can occur in thermally neutral conditions if there is excessive endogenous heat production or if heat loss is compromised. Uncompensable heat stress occurs when the air temperature exceeds 30°C and concomitantly relative humidity becomes greater than 60% (Blatteis, 2001). Hot and humid conditions, as well as warm swimming pools, limit the ability of the body to transfer heat to the environment. These conditions prevent the use of evaporation as a heat dissipation method which is the primary method of heat loss during exercise (Brealey & Finn, 2003). Exercise in these uncompensable conditions may be accompanied by adverse physiological and psychophysical responses, decreases in performance, and greater susceptibility to heat illness. Additionally, during exercise there is an increase in endogenous heat production. Approximately 75% of energy produced in the working muscle during exercise is stored as endogenous heat and consequently core temperature is usually elevated above the resting level of 37°C, even in moderate temperatures (Blatteis, 2001). As a result core temperature will rise due to metabolic heat production exceeding the heat exchange capacity of the environment. The increased physiological strain caused by hyperthermia can decrease exercise capacity or lead to exhaustion, heat injury and in extreme cases, death (Cheung & Sleivert, 2004). Furthermore it has been demonstrated that elevated core body temperature increases cardiovascular strain, thermal and perceptual discomfort and can be a limiting factor during exercise (Cheung & McLellan 1998; Gonzalez-Alonso et al., 1999; Olschewski & Bruck 1988; Walters et al., 2000).

Hyperthermia accelerates fatigue during exercise and can be a compromising factor for some types of performance (Galloway & Maughan, 1997; Gonzalez-Alonzo et al., 1999). Several studies have linked internal temperature to impaired physical performance in the heat in humans and animals. Tests on exercising rats (Walters et al., 2000) and humans (Gonzalez-Alonzo et al., 1999) have demonstrated a critical internal temperature at which exhaustion is reached regardless of the core temperature at the initiation of exercise or the rate of heat storage. This emerging critical internal temperature hypothesis suggests that a core temperature of ~ 40°C will cause exhaustion, however the underlying mechanism remains unclear (Gonzalez-Alonzo et al., 1999).

Similarly, there is evidence to support the effect of heat stress on pace selection. Marino (2004) suggested that pacing strategy is systematically adjusted, subconsciously, based on thermal comfort or core temperature. Tucker et al., (2004) also found that cyclists subconsciously selected a lower power output soon after the start of a 20km time trial in the heat (35°C) compared to cool condition (15°C). It appears that in heat stress environments athletes must reduce speed or intensity of work and could benefit from implementing tactics to reduce heat strain and maintain intensity.

If a high core temperature is a limiting factor during exercise in a heat stress environment, finding a way to prevent the attainment of a critical internal temperature could help the athlete maintain speed and performance. Swimming pools in warmer parts of the world are typically outdoors with temperatures of 29°C - 33°C. An environmental temperature of >30°C would add to the thermal load and increase the likelihood of a severe heat stress environment.

Therefore, devising an effective and safe method of dealing with heat stress during swimming training is important in the preparation of athletes training in tropical environments.

Several cooling techniques have been explored to determine their effectiveness at reducing thermal strain and enhancing performance. Pre-cooling (Marsh & Sleivert, 1999; Wilson et al., 2002) and active cooling (Poulton & Walker, 1987) have been shown to be effective in improving performance and reducing thermal strain during exercise in the heat. In swimming, some cooling methods are not practical and alternative strategies must be used. Recently, a new cooling device [Rapid Thermal Exchange (RTX), AVAcore Technologies Inc., Ann Arbor, MI] has been developed that uses the ateriovenous anastomoses (AVA) beneath the heat exchanging surfaces of the hands and feet. These specialized vessels constrict and dilate in response to higher and lower core body temperatures, respectively (Bergersen et al., 1997; Grahn et al., 1998; Hales et al., 1985; Midttum et al., 1998; Soreide et al., 1999). When dilated, AVAs promote heat loss by supplying blood to the venous plexus just below the skin surface, conducting heat to the ambient environment and then returning cooled blood to the core (Guyton & Hall, 2000). The cooling device uses negative pressure to increase blood flow to the target AVA and applies an appropriate heat sink to the surface of the skin to increase the extraction of heat from the circulating blood. Previous studies suggest that manipulation of the AVA of the hands and feet using cold water baths or cooled socks can be an effective means of heat removal during rest (Livingstone et al., 1995), active exercise (Livingstone et al., 1995), and exercise recovery (House et al., 1997; Livingstone et al., 1989) in able-bodied subjects exposed to thermally stressful conditions. Cooling of the periphery during intermittent training has been shown to enhance performance (Hayashi et al., 2004) but the effect of using AVA's as a heat dissipation mechanism during high intensity intermittent exercise performance has received no attention and the effectiveness of the RTX as a useful ergogenic aid still needs to be explored.

1.1 Purpose of Experiment

The purpose of this study was to examine the effects of using intermittent hand cooling during high intensity, intermittent training on measures of thermoregulatory, performance and psychophysical variables in elite swimmers in warm pools (30.5±0.5°C).

1.2 Hypothesis

The RTX device will reduce physiological and psychophysical strain and attenuate the decline in swim velocity typically seen throughout a training set in elite national-level swimmers.

1.3 Delimitations

The study will be delimited to swimmers who have attained a National qualification standard.

1.4 Limitations

The participants in the study will be elite athletes working on specific training programs under their respective coaches and consequently it was not be possible to maintain a consistent level of training throughout the study. However, the random balanced design attempted to account for any systematic effects of training. Due to the high intensity of the test set, participants may have felt anxious, possibly affecting results. Participants were extensively familiarized with testing procedures to limit such effects.

1.5 Assumptions

Because the participants were elite athletes it was assumed that they gave maximal effort during the testing protocol.

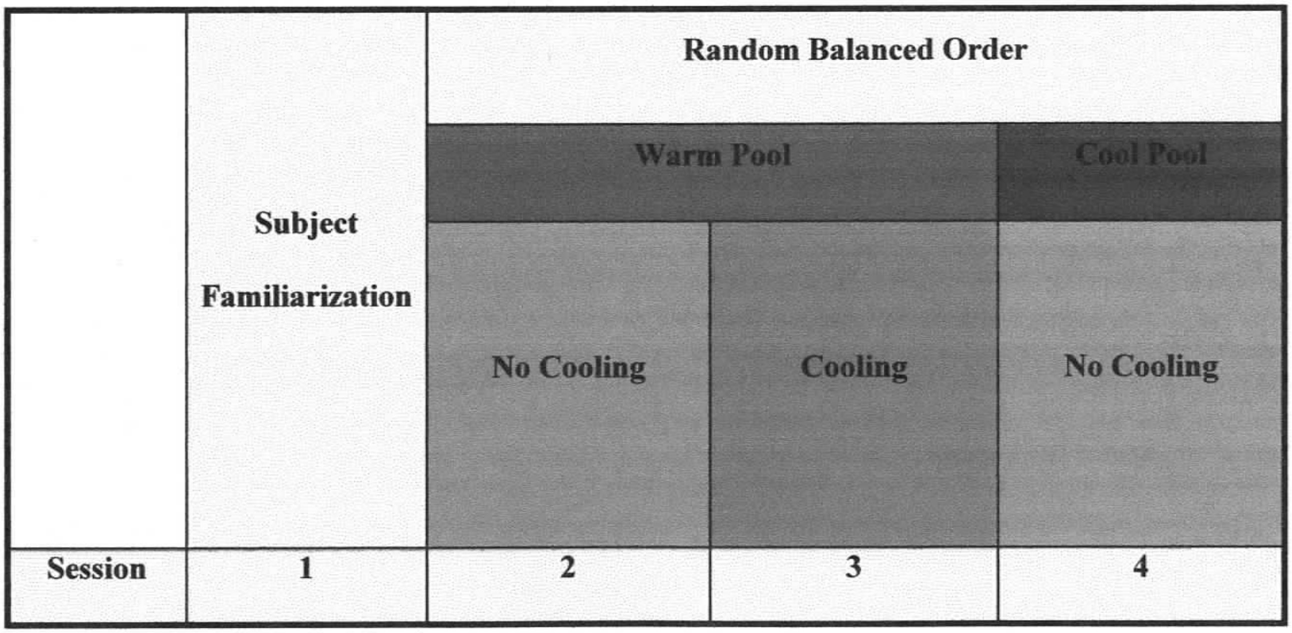
2 METHODS

2.1 Participants

Ten elite level swimmers were recruited from the Victoria area for this study. Participants were male between the ages of 18 and 26 years. All participants were informed of the study procedures and signed a consent form (Appendix A). This project was approved by the University of Victoria Human Research Ethics Board.

2.2 Experimental Design

A counter-balanced repeated measures design was implemented for this study (Figure. 2.1). The participants completed four sessions. In the first session the participants were familiarized with the test apparatus and procedures. During this session descriptive data including age, height, weight and skin folds were recorded.



	Subject Familiarization	**Random Balanced Order**		
		Warm Pool		**Cool Pool**
		No Cooling	**Cooling**	**No Cooling**
Session	**1**	**2**	**3**	**4**

Figure 2.1 Experimental Design

Following familiarization, participants completed three more sessions consisting of one of each of the three experimental conditions in counter balanced order. Participants swam in either a cool swimming pool (27.5±0.3°C) or a warm swimming pool (30.5±0.5°C) either with no-cooling (RTX with 30±1.5°C water) or with cooling (RTX with 20.9±0.5°C water).

The first participant was randomly assigned to one of the three conditions: warm pool cooling (WPC), warm pool no-cooling (WPNC) or cool pool (CP). Each subsequent participant was pseudo-randomly assigned to a balanced sequence of the three protocols in order to minimize any ordering effects. Trials were separated by one week to allow for recovery. Sessions were conducted on the same day of the week and at the same time of day to minimize the effects of circadian rhythms on heart rate and core temperature. The same participants performed all the conditions.

2.3 Anthropometric measures

Skin-fold thickness was measured at seven sites (bicep, triceps, subscapular, iliac, abdominal, front thigh and calf) in triplicate using skin-fold calipers (Harpenden, John Bull British Industries Ltd., England) and the median value was used to calculate total skin-folds. Both height (m) and body weight (kg) were recorded following the Canadian Physical Activity, Fitness and Lifestyle Appraisal protocol (CSEP, 1998). Body mass was measured to the nearest 100 g using an electronic precision balance (digital weighing scales, model D1-10, Teraoka weigh system, PTE Ltd, Singapore). Height was measured using the stretch type method (CEPAFLA, 2003).

2.4 Experimental Session

All ten participants were tested during each testing session under different experimental conditions (Figure 2.2). In the morning of a test day participants swallowed a biocompatible, telemetric temperature sensor (Vital Sense, Mini Mitter Co. Inc., Bend, OR). Upon arrival to the pool in the afternoon, participants completed a standard warm-up protocol followed by five minute rest period. Core temperature (Tc) was measured immediately before and immediately following warm-up. Heart rate (HR), rate of perceived exertion (RPE), thermal comfort (ThC) and thermal sensation (ThS) were collected immediately following warm-up. Participants were instructed to maintain the fastest average 100m time for an 8x100m freestyle swimming set. Time at 50m and 100m was recorded for each repetition. During the 90 second rest interval following each repetition the participants were exposed to the RTX and measures of Tc, HR, RPE, ThC and ThS were collected.

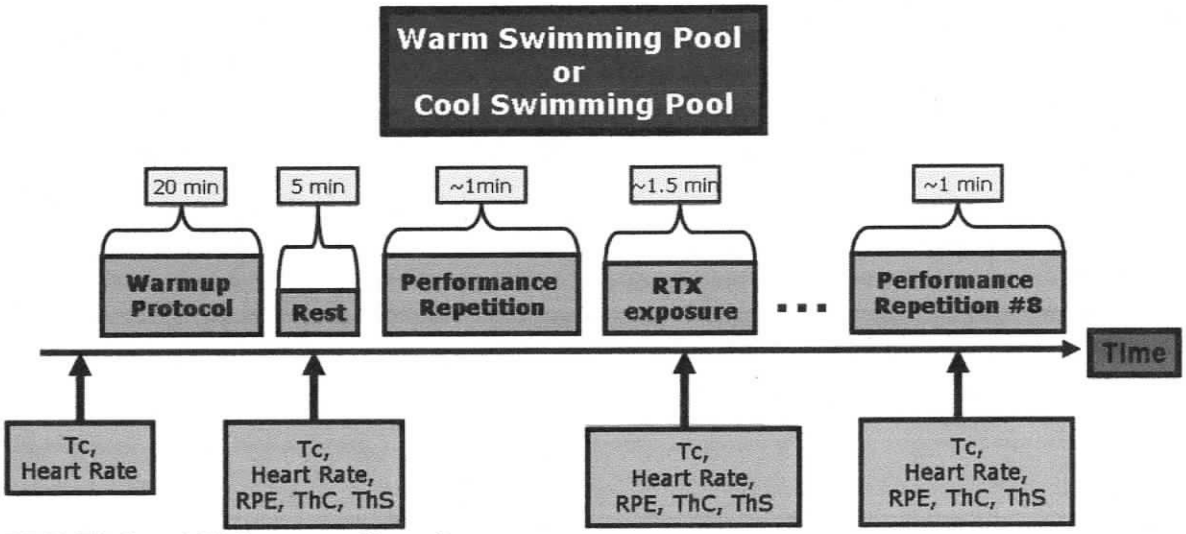


Figure 2.2 Time course of events during each testing session.

2.4.1 Swimming Pool Temperature

Participants swam in either a warm or cool 25 meter swimming pool. Those swimming in the cool pool were exposed to a water temperature of (27.5±0.3°C) whereas those swimming in the warm pool were exposed to water temperature of (30.5±0.5°C).

2.5 Warm-up

The participants performed a standard warm-up designed to simulate a pre-training warm-up.

Table 2.1 Description of standard warm-up protocol.

Distance	Description	Interval
400m	Freestyle for 50m alternate with non-freestyle for 50m	6min 30sec
8x50m	Descending time 1-8 with a heart rate range of 120-150bmp	40sec
300m	50m arms only pulling alternate with 50m kegs only kick	5min
6x20m (swim easy to 50m)	2 repeats kick / 2 repeats pull / 2 repeats swim	1min
200m	50m drill alternate with 50m swim	3min 30sec
4x50m	Build effort throughout 50m. Last 15m of each repeat is fast and last 10m of each repeat no breathing.	50sec
200m	Swim easy	

2.5.1 Performance Test Set

After the warm-up and a five minute rest period the participants began the test set which consisted of 8x100 freestyle with 90 second rest interval after each 100m swim. Participants were instructed to pace themselves in order to achieve the best average 100m time for the set of 8 repetitions. Repetitions were timed using a Seiko S143 stop watch (Seiko Corporation of America, New Jersey, USA).

2.5.2 Interval rest period

Participants placed both hands in separate RTXs for 90 seconds following each repetition. Measures of Tc, HR, RPE, ThC and ThS were collected.

2.6 Cooling Techniques

2.6.1 Cooling Intervention: Rapid Thermal Exchange System

As seen in figure 2.3 the Rapid Thermal Exchange (RTX) [AVAcore Technologies Inc., Ann Arbor, MI] cooling device uses negative pressure to increase blood flow to the target AVA and applies an appropriate heat sink to the surface of the skin to increase the extraction of heat from the circulating blood.

The water bath temperature of the RTX device was 20.9±0.5°C for the cooling trials and 30±1.5°C for the no-cooling condition. The duration of RTX exposure was a full 90 seconds recovery period between each interval. Participants remained in the water during the cooling process while placing their hands in the AVAcore device. They remained in the water to avoid evaporative heat loss and to simulate typical training conditions.

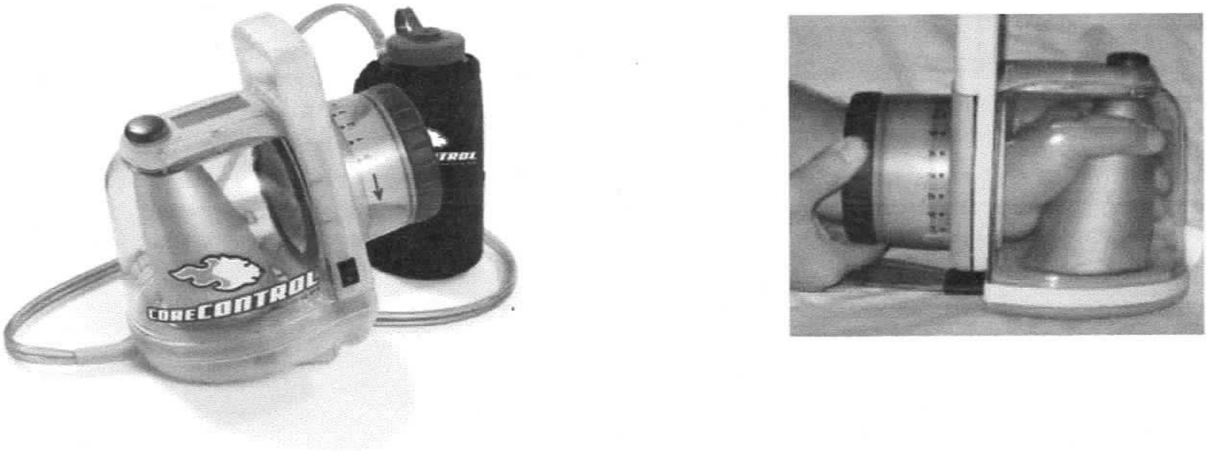


Figure 2.3 Rapid Thermal Exchange (RTX), AVAcore Technologies., Ann Arbor, MI.

2.7 Temperature measurements

Throughout the testing protocol core temperature was monitored continuously using a telemetry system and ingestible, biocompatible, telemetric capsules (Vital Sense, Mini Mitter Co. Inc., Bend, OR). The sensors use low-power radio frequency transmissions to communicate with the monitor every 15 seconds. McKenzie and Osgood (2004) compared the VitalSense telemetric physiological monitoring system (Mini Mitter CO., Inc., Bend, OR) to a standard rectal thermistor probe (Mini-Logger Series 2000) during rest and intense exercise. There was no significant difference found between the mean core temperature readings.

All participants were screened regarding any contraindications to swallowing a telemetric capsule using a series of questions prepared by a physician (Appendix B). If any contradictions had been indicated the participant would have been referred to a physician before proceeding with the study. There were no contraindications to swallowing the telemetric capsule during the present study.

2.8 Cardiovascular and Psychophysical Strain

Heart rate was monitored using a Polar heart rate monitor (Polar B1 Heart Rate Monitor, Polar Electro Inc., Port Washington, NY, USA). Rate of perceived exertion using the 20 point Borg scale (Appendix C) was measured (Borg, 1982). Thermal comfort (Appendix D) and thermal sensation (Appendix E) were also determined (Gagge, Stolwijk, & Hardy, 1967). All measures were recorded immediately following warm-up and during each rest interval.

2.9 Statistical Analysis

Means and standard deviations were used to describe all data. A repeated measures analysis of variance (two-way: condition by repetition) was used to determine any main or interaction effects. Post-hoc comparisons were conducted with Bonferroni adjusted paired t-tests. Type I error was protected at 5% and n=10 gave adequate statistical power as calculated by G*Power (Dr Grant Devilly, Department of Criminology, University of Melbourne, Australia). Power requirements were determined from heart measures from preliminary data collection (Appendix F). Comparisons were made with repetition 1, 4 and 8 of the protocol. All statistical procedures were performed using SPSS for Windows version 14 statistical software (SPSS, LEAD Technologies Inc., USA).

3 RESULTS

3.1 Subject characteristics

The physical characteristics of the 10 male participants are listed in Table 3.1. The age of the participants ranged from 18 to 26yrs (20.3±3.2yrs), height ranged from 177.7cm to 209.1 cm (188.4±8.9cm), weight ranged from 69.4kg to 94.0kg (82.3±7.5kg) and sum of seven skin folds ranged from 32.3mm to 78.0mm (54.4±17.4mm). Participants were elite swimmers as indicated by their best competition time as a percentage of the world record in their particular event ranged from 85.8% to 98.1% (mean=91.9±4.2%).

Table 3.1 Physical characteristics of subjects.

Subject	**Age (yrs)**	**Height (cm)**	**Weight (kg)**	**Sum of Seven (mm)**	**Personal Best as percent of WR (%)**
1	18	182.0	69.4	40.6	87.9
2	18	191.0	82.8	76.5	94.6
3	18	177.7	75.9	77.0	89.8
4	18	187.5	79.2	46.0	85.8
5	20	184.4	78.1	53.1	93.0
6	26	193.6	94.0	78.0	98.1
7	24	188.0	81.4	34.8	96.3
8	19	180.0	81.7	32.3	87.2
9	20	209.1	89.9	49.8	91.2
10	24	190.6	90.9	56.3	95.4
Mean	**20.3**	**188.4**	**82.3**	**54.4**	**91.9**
SD	**3.2**	**8.9**	**7.5**	**17.4**	**4.2**

3.2 Warm-up

3.2.1 Physiological Responses

Heart rate post-warm-up was similar between the two warm pool treatments but significantly lower in the cold pool. In all three conditions subjects showed a moderated increase in core temperature as expected after a warm-up but the extent of hyperthermia was lower in the cold pool than either of the two warm pool conditions.(Table 3.2)

Table 3.2 Physiological effect pre and post warm-up.

	Heart Rate (bpm)			Tc Pre (^{o}C)			Tc Post (^{o}C)		
	WPC	WPNC	CP	WPC	WPNC	CP	WPC	WPNC	CP
Mean	120.7	117.3	108.8*	36.5	36.5	36.5	38.1*	38.2*	37.9*
SD	19.8	22.1	17.9	1.9	1.9	2.0	0.3	0.5	0.3

WPC = warm pool cooling, WPNC = warm pool no cooling, CP = cool pool no cooling
Statistically significant difference (*)

3.2.2 Psychophysical Responses

Following the standard warm-up protocol RPE, thermal comfort and thermal sensation were measured. (Table 3.3) There was a significant difference in thermal sensation in the CP condition when compared to both the WPC and WPNC conditions. Thermal sensation in the CP was in the "slightly cool" to "neutral" range whereas the thermal sensation in the WPC and the WPNC was in the "slightly warm" range. There was no significant difference in RPE and thermal comfort across conditions. RPE was in the "light" range and thermal comfort was in the "slightly uncomfortable range".

Table 3.3 Psychophysical effects following warm-up.

	RPE			Thermal Comfort			Thermal Sensation		
	WPC	WPNC	CP	WPC	WPNC	CP	WPC	WPNC	CP
Mean	11.7	10.4	11.3	2.1	2.4	1.8	6.2	6.1	4.6*
SD	1.5	2.3	1.3	0.7	0.9	0.8	0.9	0.8	2.0

WPC = warm pool cooling, WPNC = warm pool no cooling, CP = cool pool no cooling
Statistically significant difference (*)

3.3 Performance Parameters

3.3.1 First 50m time

There was no significant interaction effect or main effect indicated when comparing first 50m time in WPC, WPNC and CP conditions ($p<0.05$) (Figure 3.1).

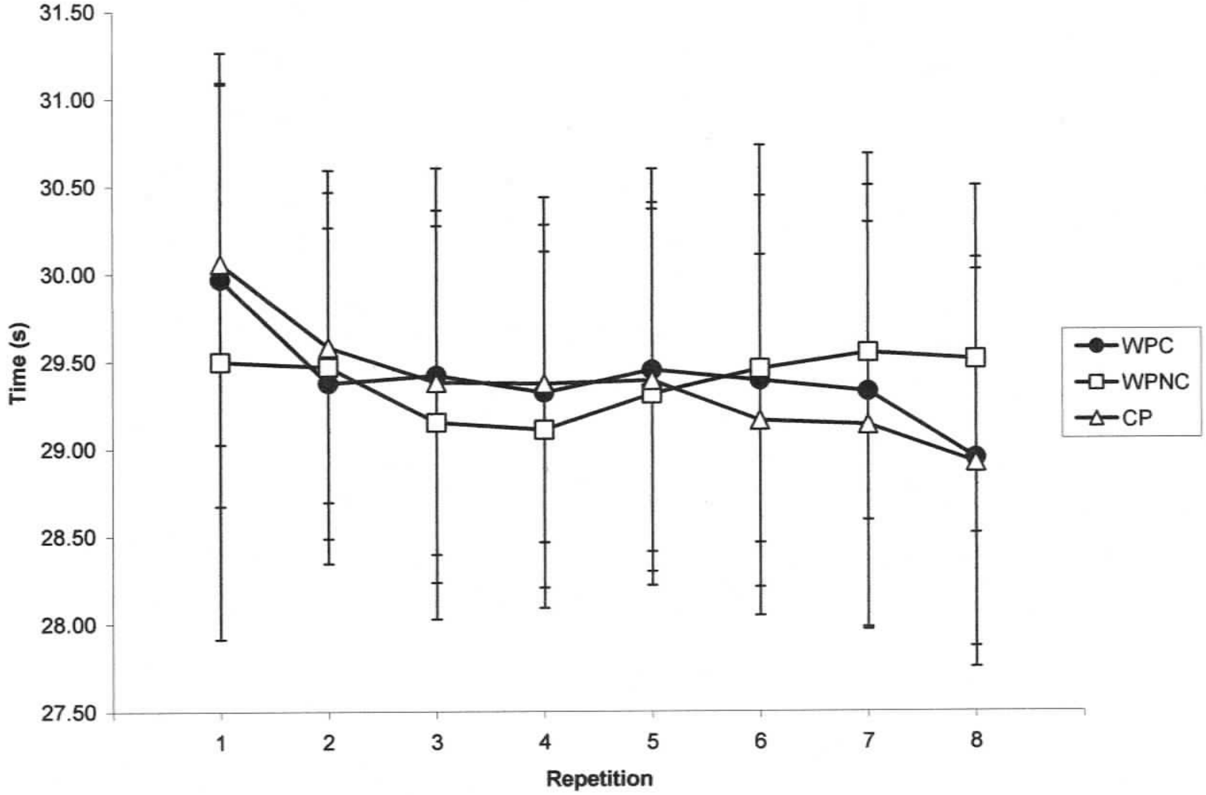


Figure 3.1 Mean (SD) first 50m time for each repetition during WPC, WPNC and CP conditions. (No significant interaction effects among conditions, n=10)

3.3.2 Second 50m time

There was a significant interaction effect (condition x repetition) and post-hoc comparisons indicated that the 2nd 50m time on the final repetition was significantly slower (1.16 ± 1.58s) in the WPNC condition compared to the WPC condition (p<0.05). Although the CP condition also was faster than WPNC (1.06 ± 1.83s) the difference did not reach significance (Figure 3.2).

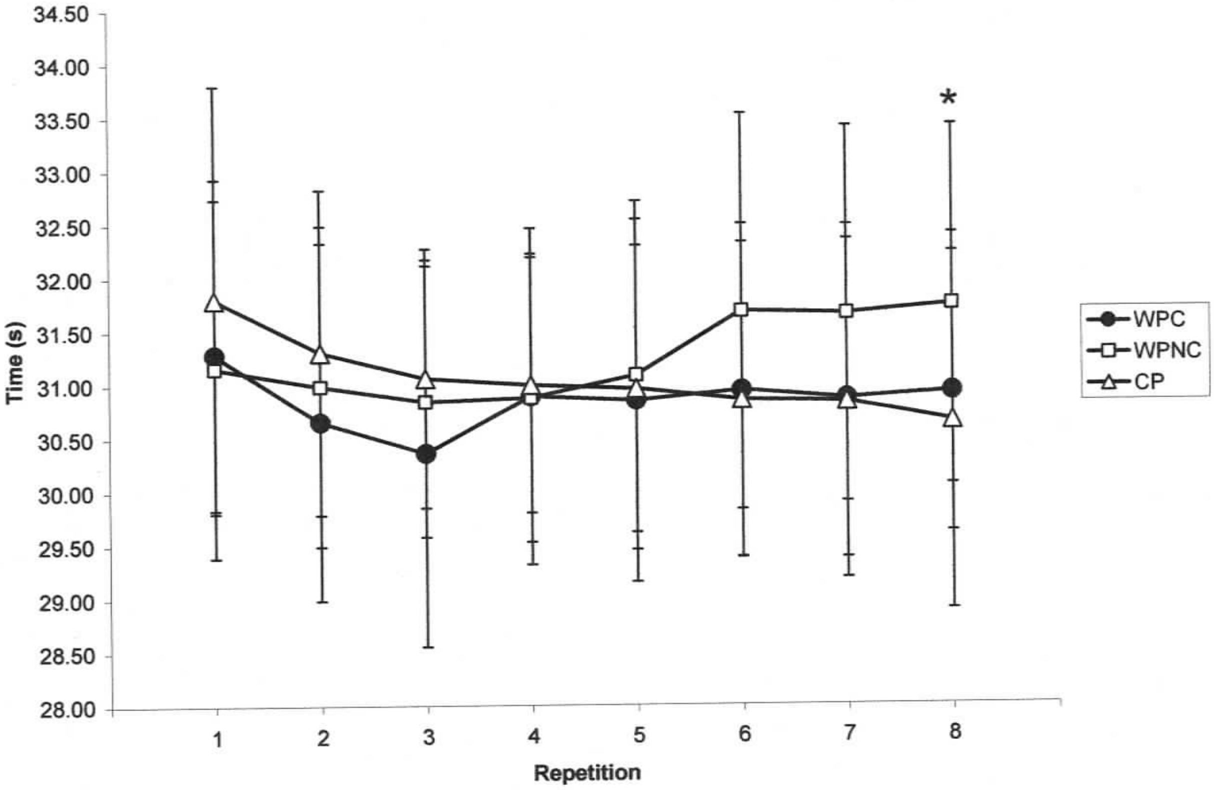


Figure 3.2 Mean (SD) 2nd 50m time for each repetition during WPC, WPNC and CP conditions. (WPC and WPNC significant difference = *, p=0.05, n=10)

3.3.3 100m time

There was a significant interaction effect (condition x repetition) and post-hoc comparisons indicated that the 100m time on the final repetition was significantly slower (1.50 ± 1.98s) in the WPNC condition compared to the WPC condition (p<0.05) (Figure 3.3). As the number of repetitions increase, 100m time in the WPNC condition became increasingly slower when compared to the WPC and CP conditions.

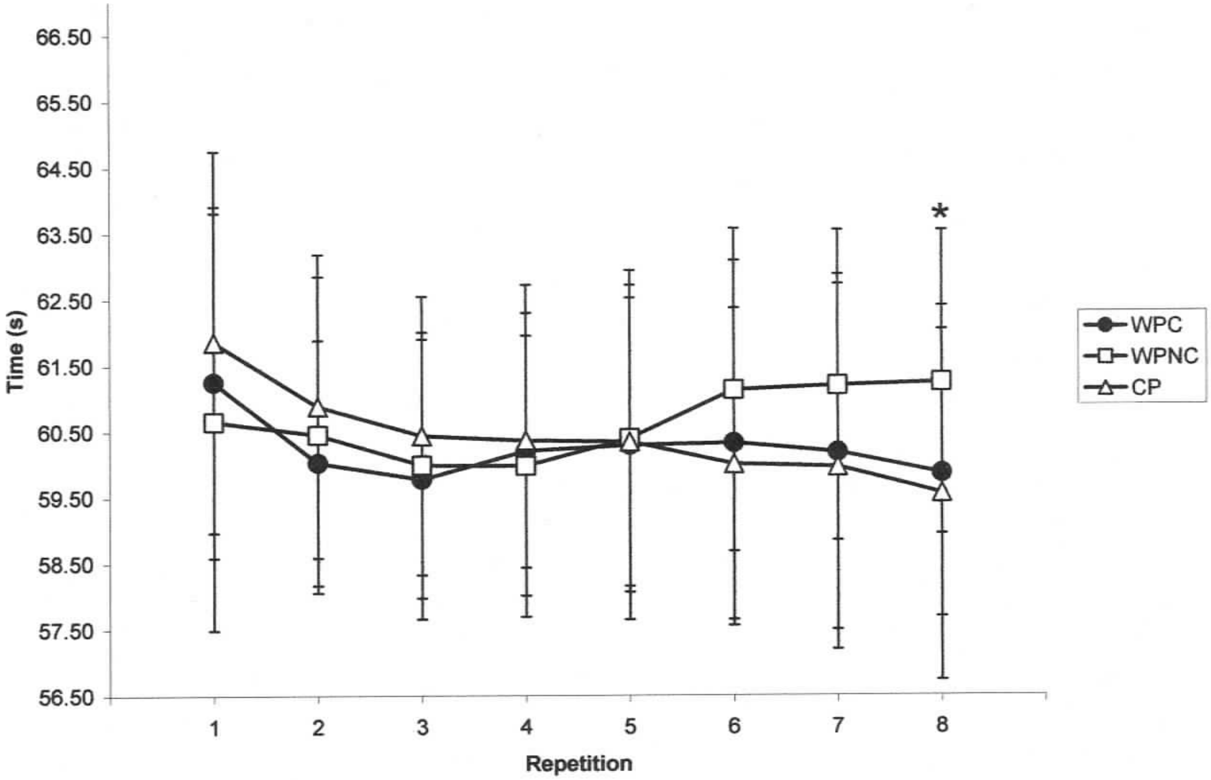


Figure 3.3 Mean (SD) 100m time for each repetition during WPC, WPNC and CP conditions. (WPC and WPNC significantly different = * $p<0.05$, n=10).

3.4 Physiological Parameters

3.4.1 Heart Rate

There were significant main effects for both condition and repetition. WPC and WPNC exhibited higher heart rates than the CP condition ($p<0.05$) (Figure 3.4). On average, heart rate in the CP condition was lower than heart rate in both the WPC (8 ± 6 bpm lower) and WPNC conditions, (7 ± 7 bpm lower). Heart rate continued to increase across the repetitions within the set and was significantly different between Rep1 vs. Rep4, Rep1 vs. Rep8 and Rep4 vs. Rep8 ($p<0.05$). After Rep8 heart rate, on average, was 17 ± 7 bpm higher than repetition1 and 5 ± 3 bpm higher than Rep4.

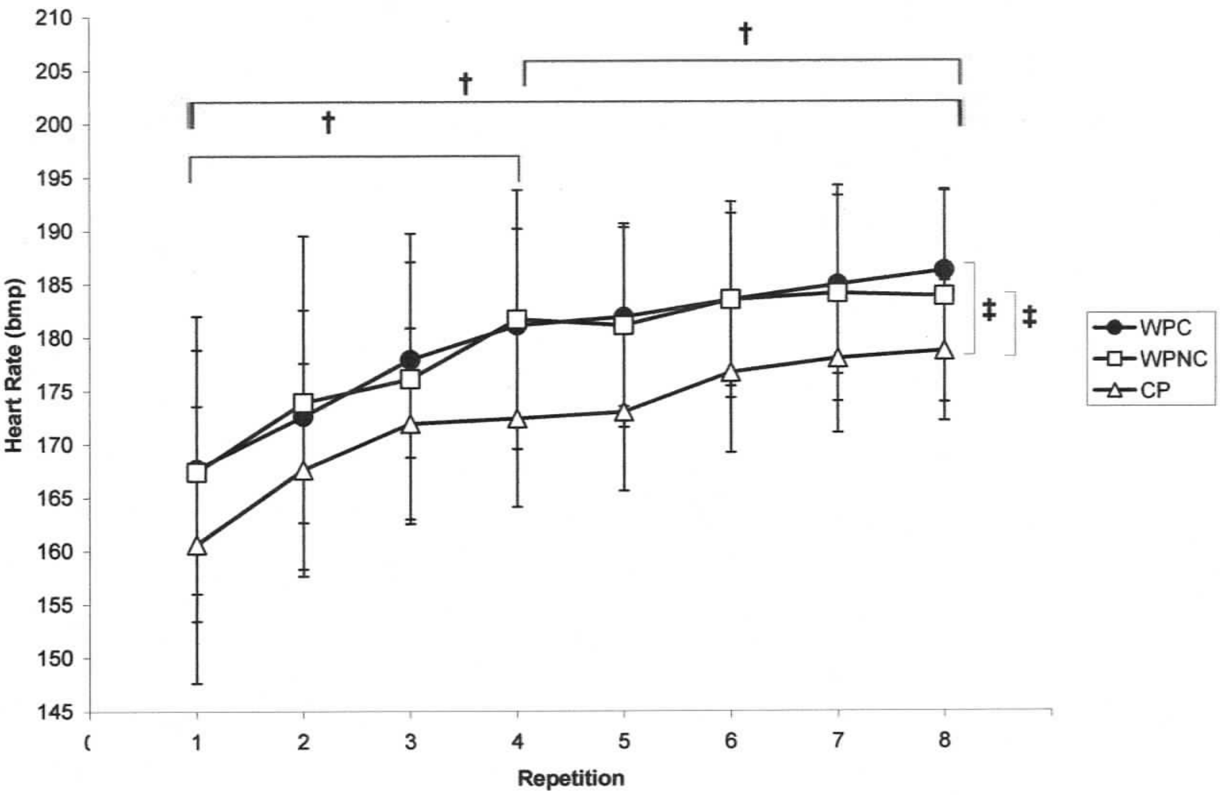


Figure 3.4 Mean (SD) heart rate for each repetition during WPC, WPNC and CP condition. (Significant repetition effect (†) between Rep1 vs. Rep4, Rep1 vs. Rep8, and Rep4 vs. Rep8 (p<0.05, n=10). Significant treatment effect (‡) between WPC vs. CP and WPNC vs. CP (p<0.05, n=10)).

3.4.2 Core Temperature

There was no significant interaction effect when comparing core temperature in WPC, WPNC and CP conditions but there was a significant main effect for repetition. Core temperature continued to increase throughout repetitions and was significantly different between Rep1 vs. Rep4, Rep1 vs. Rep8 and Rep4 vs. Rep8 ($p<0.05$) (Figure 3.5). After Rep8 core temperature was, on average, 0.41 ± 0.17°C higher than Rep1 and 0.23 ± 0.11°C higher than Rep4.

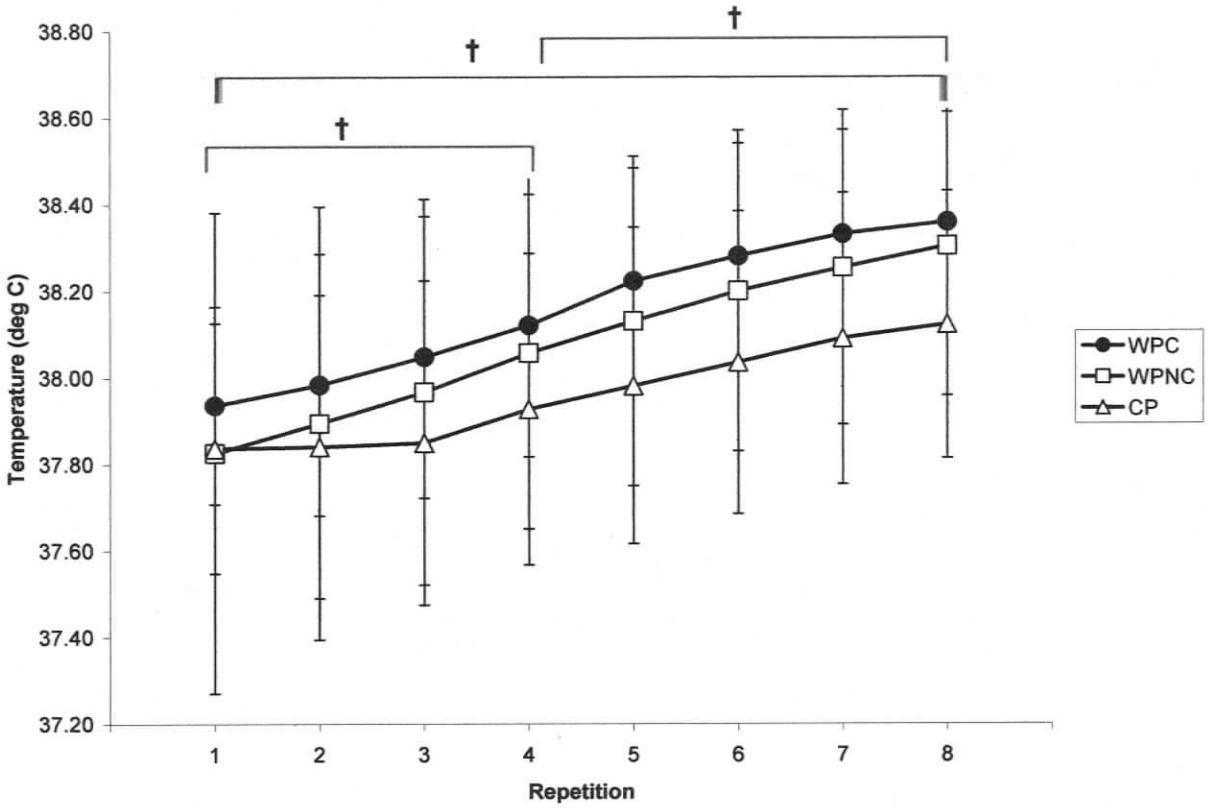


Figure 3.5 Mean (SD) core temperature for each repetition during WPC, WPNC and CP conditions. (Significant repetition effect (†) between Rep1 vs. Rep4, Rep1 vs. Rep8 and Rep4 vs. Rep8 ($p<0.05$, n=10)).

3.5 Psychophysical Parameters

3.5.1 Rate of Perceived Exertion

There was no significant interaction effect but a main effect of repetition when comparing rate of perceived exertion (RPE) in WPC, WPNC and CP conditions. RPE continued to increase across the repetitions and was significantly different between Rep1 vs. Rep4, Rep1 vs. Rep8 and Rep4 vs. Rep8 ($p<0.05$) (Figure 3.6). After Rep8, RPE was 3.3 (± 1.2SD) higher than Rep1 and 1.5 (± 1.0SD) was higher than Rep4.

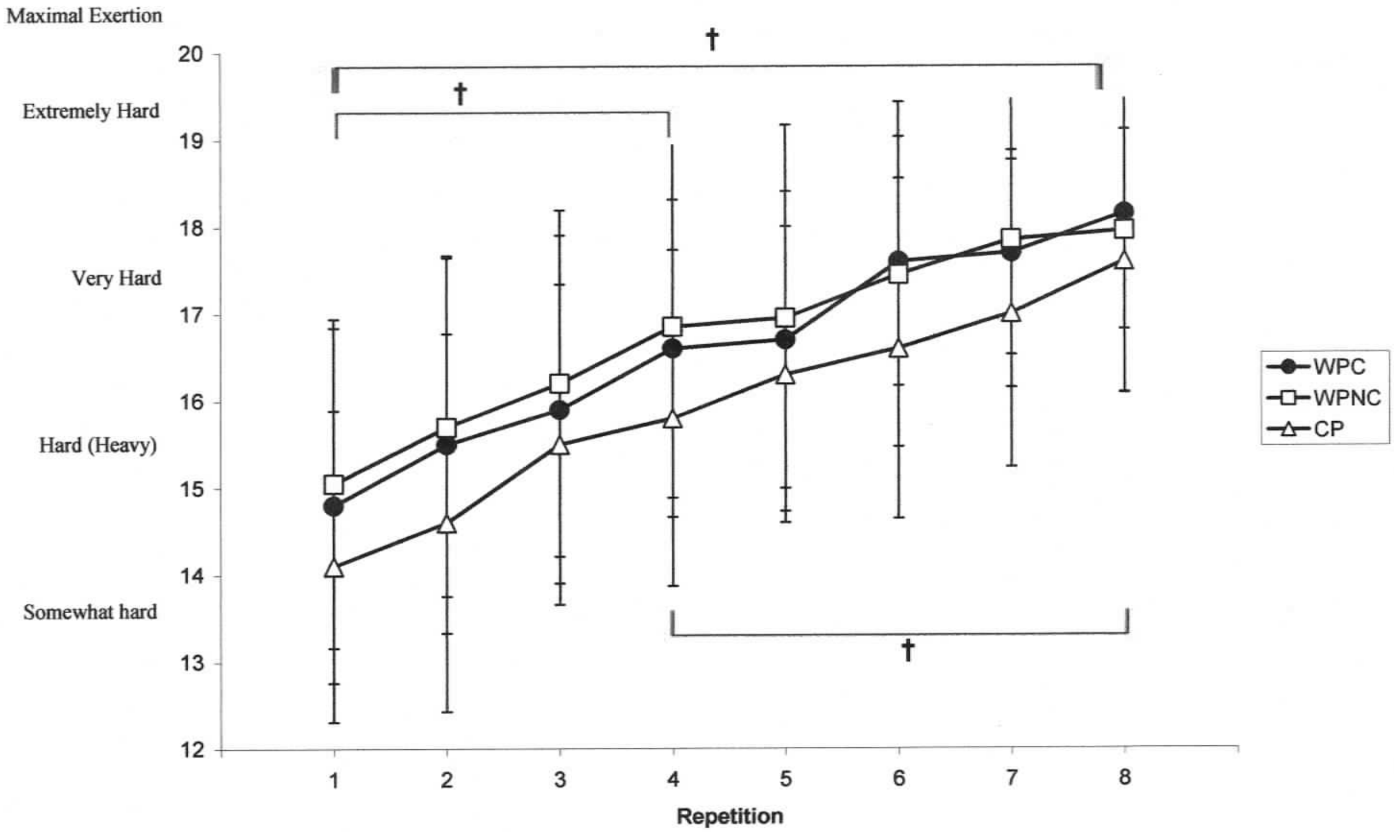


Figure 3.6 Mean (SD) rate of perceived exertion for each repetition during WPC, WPNC and CP conditions. (Significant repetition effect (†) between Rep1 vs. Rep4, Rep1 vs. Rep8 and Rep4 vs. Rep8 ($p<0.05$, $n=10$)).

3.5.2 Thermal Comfort

There was no significant interaction effect but significant main effects for repetition and condition when comparing thermal comfort in WPC, WPNC and CP conditions. Thermal comfort continued to increase throughout repetitions and was significantly different between Rep1 vs. Rep4, Rep1 vs. Rep8 and Rep4 vs. Rep8 ($p<0.05$). After Rep8 thermal comfort was, on average, 1.1 ± 0.8 higher than Rep1 and 0.5 ± 0.6 higher was than Rep4. Similarly there was a significant difference between treatments. Both WPC and WPNC had higher thermal comfort than the CP condition ($p<0.05$) (Figure 3.7). On average, thermal comfort in the CP condition was lower than thermal comfort in both the WPC and WPNC conditions (WPC 0.9 ± 0.8, WPNC 1.2 ± 1.0).

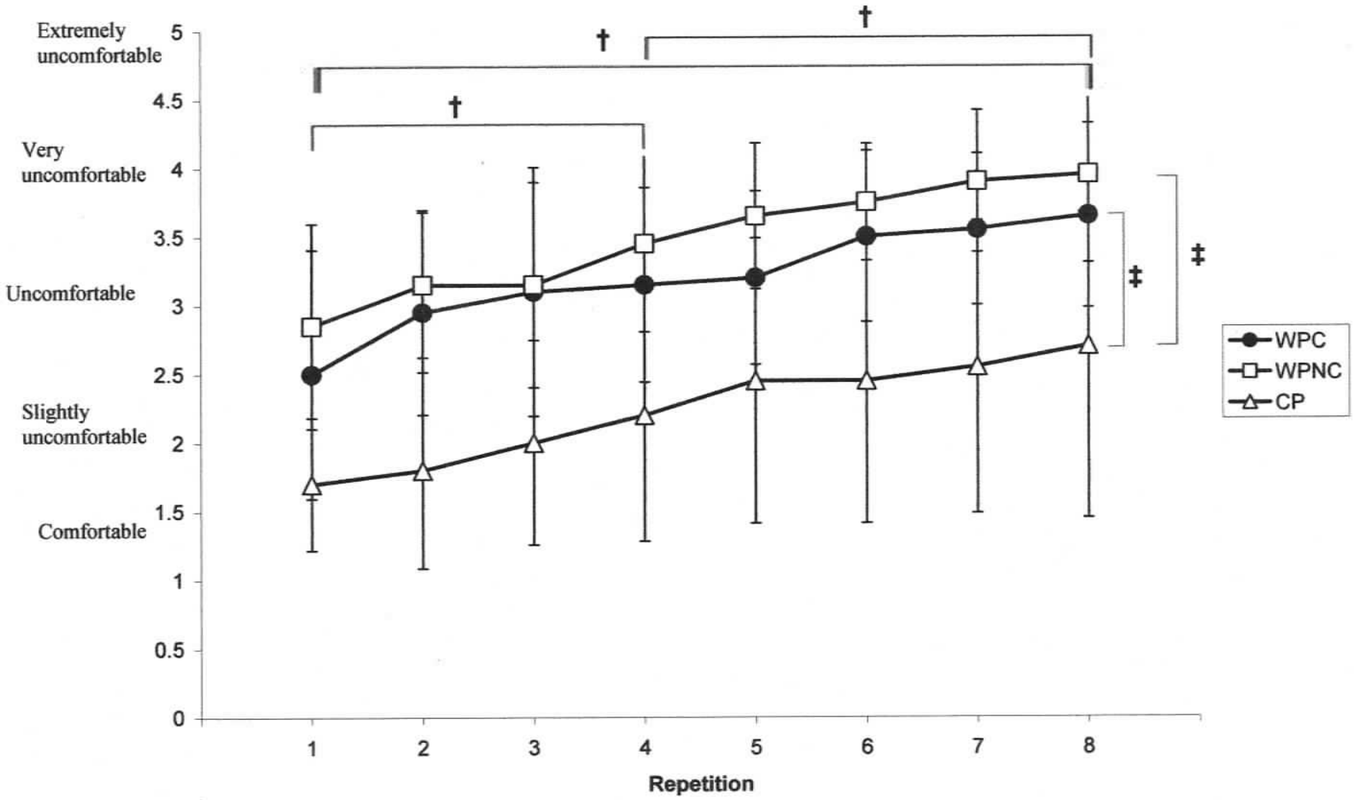


Figure 3.7 Mean (SD) thermal comfort for each repetition during WPC, WPNC and CP conditions. (Significant repetition effect (†) between Rep1 vs. Rep4, Rep1 vs. Rep8 and Rep4 vs. Rep8 (p<0.05, n=10). Significant treatment effect (‡) between WPC vs. CP and WPNC vs. CP (p<0.05, n=10)).

3.5.3 Thermal Sensation

There was no significant interaction effect for thermal sensation but significant repetition and condition main effects when comparing WPC, WPNC and CP conditions. Thermal sensation continued to increase throughout repetitions and was significantly different between Rep1 vs. Rep4, Rep1 vs. Rep8 and Rep4 vs. Rep8 (p<0.05). After Rep8, thermal sensation was, on average, 1.5 ± 1.0 higher than Rep1 and 0.7 ± 0.7 higher than Rep4.

Similarly there was a significant difference between treatments. Both WPC and WPNC had higher thermal sensation than the CP condition ($p<0.05$) (Figure 3.8). On average thermal sensation in the CP condition was lower than thermal sensation in both the WPC and WPNC conditions (WPC 1.6 ± 1.4, WPNC 1.8 ± 1.5).

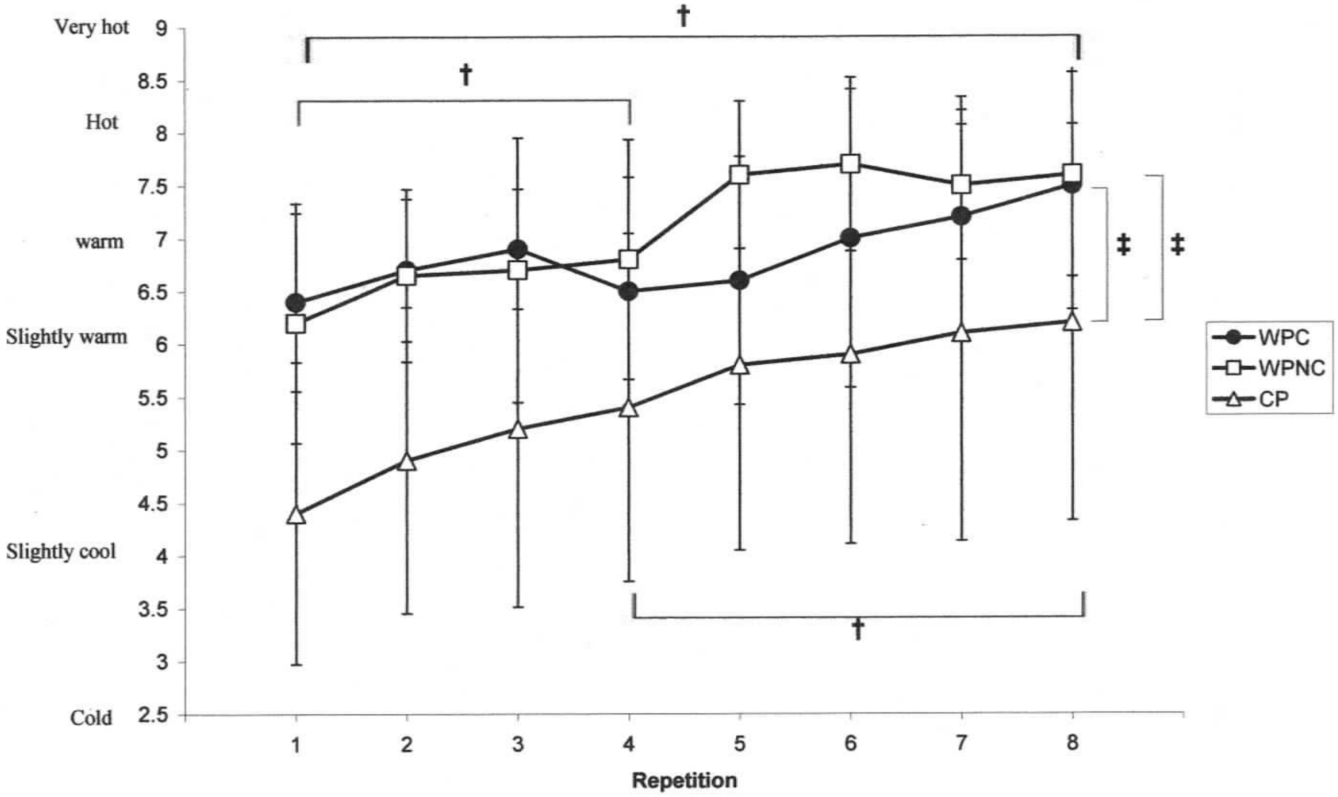


Figure 3.8 Mean (SD) thermal sensation for each repetition during WPC, WPNC and CP conditions. (Significant repetition effect (†) between Rep1 vs. Rep4, Rep1 vs. Rep8 and Rep4 vs. Rep8 ($p<0.05$, $n=10$). Significant treatment effect (‡) between WPC vs. CP and WPNC vs. CP ($p<0.05$, $n=10$)).

4 DISCUSSION

The purpose of this study was to compare the effects of using intermittent hand cooling during high intensity, intermittent training on measures of thermoregulatory, performance and psychophysical variables in elite swimmers in competition pools (27.5±0.3°C) and warmer pools (30.5±0.5°C). Pre-cooling (Marsh & Sleivert, 1999; Wilson et al., 2002) and active cooling (Poulton & Walker, 1987) have been shown to be effective in improving performance and reducing thermal strain during exercise in the heat. In swimming, some cooling methods are not practical and alternative strategies must be used. The Rapid Thermal Exchange (RTX, AVAcore Technologies Inc., Ann Arbor, MI) has been developed to focus on heat extraction using the ateriovenous anastomoses (AVA) contained beneath the surface of the hands and feet and may offer a practical method of cooling in swimming environments. The effectiveness of using the AVA's as a continuous heat dissipation mechanism has been demonstrated during prolonged exercise (Hsu et al., 2005) but high intensity intermittent exercise has received little attention. A better understanding of the effectiveness of this cooling technique during high intensity intermittent exercise in swimming may result in appropriate cooling recommendations for swimmers training in a thermal stressful environment.

The present study demonstrated that there may have been a placebo effect associated with the performance benefit demonstrated with cooling using the RTX during high intensity intermittent training in a warm swimming pool during the final repetition of a test set (8 repetitions of 100m) when compared to not using the RTX. Heart rate was lower in the CP condition when compared to both the WPC and WPNC conditions. There was no difference recorded in core temperature between any of the conditions. Similarly, there was no difference in the rate of perceived exertion between conditions. Heart rate, thermal comfort and thermal sensation were all lower in the CP condition when compared to both the WPC and WPNC conditions. Although there was a performance enhancement it is difficult to explain this result from a physiological perspective.

4.1 Performance Parameters

All participants completed the test set on three occasions. There was a significant increase in performance when comparing the second 50 split time ($p<0.05$) and 100m time ($p<0.05$) for the final repetition with cooling to the final repetition without cooling in the warm pool. The increase in performance in the later stages of the test-set with cooling was consistent with previous research despite differences in the mode of activity and exercise environment. Hsu et al., (2005) found that, during the last 20% of a 30km cycling trial, subjects who were cooled using the RTX sustained a workload that was 14±5% higher than subjects who were not cooled. However, conditions in the Hsu et al., study were quite different than the present study. For example, participants performed a 30km cycling time trial in a heated room ($31.9 \pm 0.1^{\circ}$C) and were continuously cooled. These conditions were significantly different from the conditions in the present study where the participants were performing short duration intermittent exercise with intermittent cooling in a swimming pool.

4.2 Cardiovascular Strain

There were no significant effects of cooling on heart rate when comparing the cooling and non-cooling trials in the warm pool. A study comparing different cooling techniques in joggers experiencing heat strain found similar results (Clapp et al., 2001). When comparing cooling of the torso and cooling of the hands to a non-cooling condition there was no associated change in heart rate. Gonzalez-Alonso et al., (1999) found similar results when comparing pre-cooled subjects to both preheated and control subjects while exercising in the heat.

There were significantly higher heart rates during repetitions in the warm pool conditions when compared to repetitions in the cool pool. This is consistent with Cotter et al., (2000) who found that heart rate decreased with cooling during a cycling exercise. Additionally, there was an increase in heart rate as the subjects progressed through the eight repetitions. This may reflect cardiovascular drift which would be consistent with previous research that found subjects walking on an increasingly steep treadmill experienced cardiac drift during cooling and non-cooling conditions (Grahn et al., 2005). Cardiovascular drift has been attributed to a decrease in stroke volume possibly caused by dehydration (Coyle & Gonzalez, 2001). It is not known whether or not this was a cause for increased heart rate as dehydration was not measured in the present study. Stroke volume may also have been decreased due to reduced ventricular filling during exercise. As blood is directed to the working muscles and the peripheries for cooling ventricular filling is reduced and therefore in order to maintain cardiac output heart rate must be increased (Febbraio, 2000). Alternatively, heart rate may not have had sufficient time to reach a plateau during the test set as is typical during steady state exercise (Hsu, 2005). With an increase in the number of repetitions it may be possible to determine whether or not heart rate reaches plateau.

4.3 Thermal Strain

There was a continual increase in core temperature in all conditions from repeat one to repeat eight. Cooling using the RTX failed to lower core temperature. There are several factors that may affect thermal strain.

4.3.1 Surface Area

In a recent study comparing the effect of ankle cooling to a control condition it was found that there was no significant change in core temperature (Palmieri et al., 2006). This is contrary to the findings of Livingstone et al., (1989) who found that hand emersion in cold water lead to a significant rate of heat extraction and, therefore, a decrease in core temperature. Palmieri et al., used an ice treatment of the ankle whereas Livingstone et al., used various water temperatures (10, 15, 20, 25 and 30°C). Pamieri et al., did not show a change in core temperature whereas Livingstone et al., showed that heat extraction was inversely proportional to water temperature. Although ice is colder than a water bath it does not make contact with a large surface area whereas water immersion maximizes contact with the heat exchange surface. These results were further confirmed by Hayashi et al., (2004) when they showed that full leg water immersion at 20° C decreased core temperature in cyclists. It seems like cooling is more effective with a larger heat exchange surface area. In the present study only the palmer surface of the hand was cooled. It is possible that this surface area was too small to elicit a significant cooling effect.

4.3.2 Cooling Medium and Cooling Surface Temperature

Hayashi et al., (2004) investigated the effects of brief leg-cooling after moderate exercise on the responses to subsequent exercise in the heat. Following 40min of ergometer cycling participants immersed their legs in a 20°C water bath (cooling condition) or 35°C water bath (non-cooling condition) for 5min. Results indicated that core temperature was lower in the cooling condition than the non-cooling condition during the subsequent exercise bout. The cooling temperature of the water bath was similar to the present study in which the cooling surface temperature was 20.8±0.5°C. Despite this fact there was no difference in core temperature between the cooling and non-cooling conditions in the warm pool. This may be due to the difference between convective cooling and conductive cooling. In the Hayashi et al., study convection and conductive cooling were used in the water immersion bath whereas in the present study only convective cooling was used during the cooling period. However, because the participants were swimming in water that was cooler than their core temperature it is possible that they also experienced conductive cooling. The warm pool temperature was 30.5±0.5°C and, therefore, would not have the same convective cooling effect as the cold water immersion of 20°C in the Hayashi et al., study.

Additionally Hayashi et al., (2004) exposed their subjects to 10min of water immersion cooling whereas in the present study participants were only exposed to 1.5min of cooling during each rest interval. Although the effectiveness of continuous cooling is well documented (Grahn et al., 2005) intermittent cooling has received less attention but is supported by Cadarette et al., (2006). They showed that participants walking on a treadmill for 80min had less increase in core temperature while cooled intermittently at 2min intervals (0.5±0.2°C) compared to a no-cooling condition (1.6±0.2°). A cooling garment covering 72% of body surface area was used. This is in contrast to the present study in which a much smaller surface area was used for cooling leading to a smaller heat exchange surface.

4.3.3 Ateriovenous Anastomoses

The vasodilation of the AVAs is central to the success of the RTX as a cooling mechanism. Bergersen et al., (1997) demonstrated that blood velocity in the AVAs decreased substantially below a temperature range of 23 to 20°C. They examined the influence of local cooling from 35°C to 19°C on spontaneous arterial blood velocity fluctuation in the acral skin of thermoneutral subjects. In the present study the surface temperature of the RTX during the cooling condition was 20.8±0.5°C. Typically this may cause the AVAs to constrict while the participants are being cooled thereby reducing blood velocity and inhibiting core temperature reduction. However, the RTX utilizes a slight negative pressure environment (35-45 mmHg) to address this situation and force the AVAs to remain open. Grahn et al., (2005) used the combination of local subatmospheric pressure (35-45 mmHg) and a heat sink (18-22°C) on the entire hand to extract heat from the circulating blood. Participants walked uphill (5.63 km/h) on a treadmill in a 40°C environment. The slope of the treadmill was held constant during experimental trials. It was hypothesized that the cooling mechanism increased blood flow to the hand as reflected by an attenuation in the rate of rise of esophageal temperature during exercise (2.1±0.4°C/h and 2.9±0.5°C/h) with and without cooling. This research supports the assumption made in the present study that blood flow is increased with a subatmospheric environment even though the RTX surface temperature is 20.8±0.5°C during the cooling condition. Although the Grahn study does not measure blood flow to the hand directly the utility of a subatmospheric environment is further supported by a study from Midttun and Sejrsen (1998). They showed that blood flow through the AVAs decreased at the onset of exercise before increasing after approximately 3min. It is possible that the subatmospheric environments in the RTX helps maintain blood flow at the onset of exercise and therefore may facilitate heat dissipation.

Similarly, Hales et al., (1985) indicated that although core temperature plays a dominant role in the control of peripheral blood flow, once core temperature is at a level requiring increased heat loss (1°C above normal) skin temperature exerts a potent influence on the nature and magnitude of change in skin blood flow. According to Hales et al., (1985) the flow pattern reflects a negative feedback mechanism which aims at maintaining skin temperature at 40°C.

Because the RTX surface temperature is 20.8±0.5°C during the cooling condition it can be assumed that blood flow to the hand is maximized as the body attempts to maintain a 40°C skin temperature.

4.3.4 Measures of body temperature

This experiment was dependent on accurate measurements of core temperature. Currently, the most accurate and widely available techniques for measuring core temperature in humans are rectal temperature (Trec) and esophageal temperature (Tes). A review by Moran and Mendal (2001) indicated that although thermistor placement at the esophagus site is difficult, it may be preferred because of its rapid response time. Similarly, they discussed that rectal temperature measures, while slower in responding than esophagus measures, are considered the most practical and accurate for measuring core temperature. However, because both methods require wire connections between the thermistors and monitoring devices neither are ideal for studies in swimming because the participants are continually moving up and down the pool.

Telemetry monitoring systems using ingestible core temperature monitors have become commercially available. McKenzie and Osgood (2004) compared the VitalSense telemetric physiological monitoring system (Mini Mitter CO., Inc., Bend, OR) to a standard rectal thermistor probe (Mini-Logger Series 2000) during rest and intense exercise. There was no significant difference found between the mean core temperature readings, however, the telemetric system recorded significantly lower core temperatures with less variation during high intensity exercise compared to the standard rectal thermistor probe.

The efficacy of the core temperature measuring method may have affected results. Moran and Mendal (2001) reported that core temperature using the esophageal area responded faster than rectal temperature. Because a telemetric core temperature pill system was used in the present study it is possible that core temperature changes due to cooling during the test set were not reflected by the telemetric system. Furthermore, the telemetric system may not respond as quickly as rectal temperature (McKenzie & Osgood, 2004). The telemetric system recorded significantly lower core temperatures with less variation during high intensity exercise when compared to the standard rectal thermistor. Although the response time of the telemetric system could have affected core temperature measures early in the test set any significant changes should have been evident as the set progressed.

Hsu et al., (2005) used the RTX system and found it lowered core temperature, as measured by tympanic thermistors, during cycling exercise. The tympanic membrane receives blood from the branches of the internal carotid artery that supply blood to the thermoregulatory centre in the hypothalamus of the brain. As a means of measuring core temperature the ear canal is easily accessible but many studies have demonstrated that this method of measurement is problematic during physical activity in the heat. Errors in measurement can be a result of dirt, and inaccurate and inconsistent placement that do not lead to an accurate measurement of core temperature (Briner, 1996; Cattaneo, 2000). Although Hsu et al., (2005) used the RTX, it is difficult to compare the effects of the RTX on core temperature with this study because they used tympanic temperature.

For application in the present study the Vital Sense system (Mini Mitter CO. Inc., Bend, OR) validated by McKenzie and Osgood (2004), was the most effective means of measuring core temperature. The accuracy, responsiveness and ease of measurement was practical and regarded as valid for swimming studies which involve core temperature measurement.

4.4 Psychophysical Strain

There was no difference in rating of perceived exertion between conditions during the test set (Figure 3.6). This is consistent with the findings of Hayashi et al., (2004) who used a protocol of cold water immersion of the legs and found there was no change in RPE between cooling and non-cooling trials. However, the findings of the present study differed from the findings of Gonzalez-Alonso et al., (1999) who showed that full body immersion in cold water before exercise reduced RPE in the first 10 min of exercise. RPE at exhaustion, however, was the same in both the cooling and none cooling trial. The differences in the two studies may be explained by the cooling techniques that were used. Pre-cooling was used in the Gonzalez-Alonso et al., (1999) study whereas intermittent cooling and a smaller surface area of the body cooled occurred in the present study.

Cooling had no effect on thermal comfort and thermal sensation during trials in the warm pool but both parameters were lower during the cool pool trial (Figure 3.7 and Figure 3.8). On average the thermal comfort difference between the warm pool trials and the cool pool trials was 0.9±0.8 (warm pool cooling) and 1.2±1.0 (warm pool no cooling). Similarly, the average differences in thermal sensation between the warm pool trials and the cool pool trial were 1.6±1.4 (warm pool cooling) and 1.8±1.5 (warm pool no cooling). Although the practical implications of a one or two point difference on a perceptual scale are minimal, according to Tucker et al., (2004) it may play a role in pace selection. Tucker et al., (2004) compared a 20km self-paced cycling time trial in hot conditions (35°C) to cool conditions (15°C). Although core temperature, heart rate and ratings of perceived exertion were similar during the trials in both conditions, power output and integrated electromyographic activity (iEMG) of the quadriceps muscle decreased early in the hot condition. This adaptation appears to form part of an anticipatory response which adjusts muscle recruitment and power output to reduce heat production (Tucker et al., 2004). This mechanism helps maintain thermal homeostasis during exercise in the heat.

When the cooling ability for individuals exceeds their ability to dissipate heat, heat stress occurs and they perceive that are getting hotter. It is possible that the physiological component of heat strain does not match to the psychophysical component. A recent study examined physiological markers of heat stress (core temperature and heart rate) and compared them to psychophysical markers (rate of perceived exertion, thermal comfort and thermal sensation, Tikuisis et al., 2002). At similar levels of heart rate and core temperature there was a lower perceived heat tolerance for untrained participants compared to trained participants. This could indicate that untrained individuals have higher perceptual strain for the same amount of physiological strain. It could also indicate that trained individuals underestimate physiological strain. This can be seen with trained subjects attaining a core temperature of 39.7 to 40.2°C which can potentially increase the risk of heat strain injury if they are allowed to continue to exercise in the heat according to their perception (McLellan, 2001). This may be a factor in the present study as the participants were high performance athletes. The participants best competition time as a percentage of the world record in their particular event ranged from 85.8% to 98.1% (mean=91.9±4.2%).

When considering thermoregulatory response, skin temperature is important. Frank et al., (1999) demonstrated that the ratio of contribution of core temperature to skin temperature for thermal comfort is 1:1 whereas the contribution to autonomic and metabolic responses is 3:1. Skin plays a critical role in an individual's thermoregulatory response because it is sensitive to changes in the external environment and allows behavioral changes to be made before changes in core temperature occur.

Tucker et al., (2004) proposed that sensory input from the skin plays a role in mediating a decrease in central recruitment by informing the brain that the capacity for heat dissipation is reduced and, therefore, heat production must be reduced to attenuate the rise in core temperature. These results promote the theory of a central nervous system governor which detects afferent signals from the peripheral receptors and initiates a protective thermoregulatory response to heat stress injury (Noakes et al., 2005). Similarly, Morrison (2004) showed that voluntary muscle activation and isometric force production were reduced when subjects were passively heated to a core temperature of 39.5°C regardless of skin temperature. These studies suggest that skin plays a role in providing afferent feedback for the central governor. Therefore, skin temperature may play an important role in determining pacing strategies during uncompensable heat stress. In contrast to the findings in the present study, where there was no difference in pace selection across conditions early on during the test set. Furthermore, the sensation of thermal comfort in the cool pool did not lead to a lower RPE during those trials. Although there was a significant effect of time on RPE over the eight repetitions ($p<0.05$) there was no treatment effect. Final RPE scores were between 17 and 18, indicating that individuals performed to a very high level in each condition. These results are supported by previous research (Cotter et al., 2000; Tucker et al., 2004) which found that RPE was not closely related to an individual's perception of thermal sensation or comfort. This disparity may have adverse effects on pace selection. If an individual perceived they were working less hard in a hyperthermic state they may be inclined to increase power output and, thereby, increase endogenous heat production leading to heat strain injuries. However, in the present study, because the perception of effort was the same for all conditions, the participants work rate was such that they did not attain the critical limiting core temperature.

This may be explained by the fact that the participants were exercising in water which is cooler than air and, therefore, experienced a lower skin temperature.

4.5 Placebo Effect

There is a possibility that the way in which cooling was applied in the present study produced a placebo effect. It was not possible to blind participants from the cooling condition even though attempts were made to control for this effect. Participants were told that the study was attempting to determine if there were any detrimental effects of cooling on performance. However, although there seemed to be a performance benefit from the cooling intervention, there was no difference in physiological and psychophysical when comparing the cooling to the non-cooling condition which indicated that the participants may have experienced a placebo effect. This is further supported by Hornery et al., (2005) who found that a cooling intervention failed to induce any significant thermoregulatory effects but showed significant performance increases. They examined a 1 hr cycling protocol consisting of 30 min at 75% VO2max followed by a 10 min cooling protocol (application of cooling jacket) and a second 30 min exercise bout consisting of 20 min at 75% VO2max, immediately followed by a 10 min maximal effort. Although performance benefits were noted during the cooling trial, there appeared to be a significant placebo effect from the cooling because there was no difference in heart rate or core temperature between the cooling and non-cooling trials in the warm pool.

4.6 Conclusions

Cooling, using the RTX, during high intensity intermittent training in a warm swimming pool increased performance during the final repetition of a test set compared to not cooling. This allowed the swimmers to train at a higher intensity in a warm swimming pool. However, because there was no difference in physiological or psychophysical variables when comparing cooling to non-cooling in the warm pool these results may be due to a placebo effect.

Based on the present study, the RTX does not appear to provide any physiological or psychophysical benefit during high intensity, intermittent training of elite swimmers. Further study is required to determine the efficacy of the RTX as a tool to improve swimming training performance in a heat stress environment. For example, the number of repetitions in the test set could be increased and dehydration measured in order to better determine cardiovascular effects. Additionally, the surface area of cooling can be increased and the temperature of the cooling surface can be altered in order to increase the thermal gradient and opportunity for heat exchange. With these alterations it is possible that the performance benefit indicated in the present study will be explained with differences in physiological and psychophysical variables.

5 LITERATURE REVIEW

5.1 Introduction

The human body is able to tolerate large variations in environmental temperature and maintain a relatively constant core temperature of 37°C. The ability to maintain this constant temperature under ambient conditions that vary widely is important because any deviations in core temperature from its normal limits are pathologic and may be potentially lethal. The thermoregulatory control centre is located in the hypothalamus and it integrates many systems of the body with the common goal of maintaining a constant core temperature. After receiving input from local and peripheral receptors regarding the thermal state of different parts of the body, the hypothalamus evaluates these signals and activates the appropriate effector mediated responses in an attempt to maintain body temperature near its set point (Blatteis, 2001).

The combination of environmental heat load and exercise produced metabolic heat production requires greater than normal heat dissipation. Swimmers training in thermo-stressful environments face this challenge regularly. One potential method for dealing with the increase in heat strain during training is by lowering core temperature between training repetitions. The recent development of a new cooling device [Rapid Thermal Exchange (RTX), AVAcore Inc., Palo Alto, CA] has provided the opportunity to study the effects of intermittent cooling during swimming training. The RTX cooling device relies on manipulation of the specialized vessels underlying the palm of the hand (ateriovenous anastomoses [AVA]). These specialized vessels constrict and dilate as a response to higher and lower core temperatures, respectively (Bergersen et al., 1997; Grahn et al., 1998; Hales et al., 1985; Midttum et al., 1998; Soreide et al., 1999). However, the utility of the RTX is yet to be fully assessed. This chapter will review the physiological, performance and psychophysical responses to exercise induced hyperthermia and the use of the RTX to minimize the detrimental effect of hyperthermia on performance.

5.2 Thermal Homeostasis

Core temperature in humans is maintained in a narrow range which corresponds to optimal body function (Blatteis, 2001). This implies that heat loss and heat gain in the body stay in relative balance despite large variations in environmental conditions. Heat gain is the product of endogenous (metabolic) and exogenous (environmental) thermal strains. Heat loss is the result of thermal exchange with the environment through conduction, convection, radiation or evaporation. When heat production exceeds heat dissipation heat storage occurs causing a corresponding increase in core temperature. This often occurs during exercise when heat gain occurs due to increases in metabolic rate, increased muscle activity, and augmented heat transfer from a warm environment (Blatteis, 2001).

Heat produced by working skeletal muscles is transferred from the muscle primarily through the convective heat flow of the blood and dissipated to the surrounding environment by conduction, convection, radiation or evaporation occurring at the skin. This is an important process as the body does not effectively convert chemical energy into mechanical work and consequently up to 80% of energy produced during muscle contractions is lost as heat (Blatteis, 2001). Under normal circumstances the body is able to balance heat gains and losses in order to maintain a constant core temperature.

The following heat production and storage equation is used to determine body core temperature by metabolic heat production and the transfer of body heat to and from the surrounding environment (Blatteis, 2001):

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

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

5.2.1 Thermoregulation – Afferent inputs

The thermoregulatory control center is located in the hypothalamus and receives input from local as well as peripheral receptors regarding the thermal state of different parts of the body. Both cutaneous temperature and core temperature (Tc) reception provides afferent input for the regulation of body temperature (Morrison et al., 2004). Although skin temperature (~12-40°C) varies much more than core temperature (~35-40°C), cutaneous thermoreceptors typically influence thermal response mechanisms only approximately 10% as much as core thermoreceptors (Cotter et al., 1996). Cutaneous thermoreceptors are sensitive to ambient temperature and provide information regarding the surrounding environmental conditions. These receptors fire constantly but will modify their firing frequency based on changes in the environment. For example, receptors fire spontaneously at 33°C (mean skin temperature) and increase during moderate skin warming (Blatteis, 2001). However, central thermal receptors are located directly in the hypothalamus in the preoptic and anterior portions. The receptors also respond to increases and decreases in temperature by altering their firing frequency. For example, during exercise, the warm blood that perfuses the brain stimulates the thermosensitive neurons and causes an increase in firing rate. Upon receiving thermal information from both central and peripheral receptors the hypothalamus compares and integrates the information before activation of the appropriate thermoregulatory effectors. These effectors will alter body temperature in a direction opposite to the direction of the stimulus. It has been suggested that although core and skin temperature contribute equally towards thermal comfort, it is core temperature that dominates the regulation of the autonomic and metabolic responses (Frank et al, 1999).

Recently, the theory of teleoanticipation has suggested that the hypothalamus also sends feed-forward signals based on previous experiences, arousal and motivation (Lambert et al., 2004). This model associates the predicted end point of exercise as well as pacing strategies with higher regulator centers. Teleoanticipation integrates experiences from prior exercise bouts and relies on both feed forward planning and feedback from metabolic structures and the external environment. Recent research has demonstrated that passive heat decreases central drive (Morisson et al., 2004). In this study, motor unit recruitment and MVC force decreased over time with increasing core temperature while electrically evoked maximal force was unchanged. The findings suggest that hyperthermia diminishes central drive and reduces the ability to activate muscle in the heat, therefore facilitating fatigue. According to the central governor model during self-paced exercise the central nervous system continually modifies pace (Noakes et al., 2004). Ultimately the thermoregulatory control center is responsible for evaluating the incoming signals and activating the appropriate effectors mediated responses to maintain body temperature at its set point (Blatteis 2001).

5.2.2 Effector Mechanisms

The hypothalamus effects core temperature by converting afferent thermal inputs into efferent signals. These efferent signals direct the thermoregulatory effectors that induce physiological adjustments. Although some studies on mammals with extensive hypothalamic lesions indicate that lower sections of the brain stem and spinal cord are capable of converting thermal afferent inputs into efferent signals (Simon et al., 1986) this review will focus on efferent signals that initiate in the hypothalamus.

The two types of effector responses to thermal stimulation are behavioral and physiological. Behavioral thermoregulation is a "first line of defense" strategy used by athletes to minimize the effects of heat stress. These responses may include exercising during the coolest part of the day, wearing minimal clothing, staying well hydrated and acclimatizing. In an athletic context these strategies may be limited in certain situations during training and competition. The physiological effector response to heat strain includes increased cutaneous vasodilation to enhance heat transfer from the core of the body to the body surface where it can be dissipated through radiation and evaporation. The body dissipates excess heat largely through hairless skin areas that are underlain with ateriovenous anastomoses (AVAs) and the subcutaneous venous plexuses. These specialized surfaces include the palms of the hand and the soles of the feet as well as the face and ears. The result is a change in the temperature of venous blood returning to the heart thereby decreasing core body temperature (Grahn et al., 1998). The major mechanism by which skin blood flow is increased during heat stress includes reduced activity of sympathetic vasoconstrictor nerves, increased activity of the cutaneous vasodilator system and the local effects of increased skin temperature (Johnson & Proppe, 1996).

5.3 Critical Temperature Hypothesis

Exercise is limited in thermally stressful environments and hyperthermia accelerates fatigue during prolonged exercise (Galloway & Maughan, 1997). Because heat exchange capacity is less than the rate of heat production during uncompensable heat stress, the ability to dissipate heat effectively is reduced and, therefore, core temperature increases. Typically, a decrease in exercise output or a change in pacing strategies is necessary so that exercise can continue without a risk of cellular injury (Marino, 2002). A number of reports have linked a critical internal temperature to exhaustion in the heat for humans and animals. Tests in exercising rats (Walter et al., 200), goats (Caputa et al., 1986) and humans (Nybo & Nielsen, 2001; Gonzalez-Alonzo et al., 1999) have shown that exhaustion is reached at a critical core temperature of approximately 40°C. This critical temperature seems to be a set point at which exercise ceases. Whether the participant is pre-cooled (Gonzalez-Alonzo, 1999) or preheated (Gregson et al., 2002) the temperature at which exhaustion if reached is approximately the same.

Trained individuals have an enhanced ability to tolerate elevated core temperature, attributable to higher levels of aerobic fitness which influences the ability to exercise during uncompensable heat stress. Core temperature can vary as much as 0.9°C between subjects with differing fitness levels matched for low body fatness (Selkirk & McLellan 2001), indicating that individuals with lower aerobic fitness fatigue at lower critical core temperatures. Untrained participants started at similar resting core temperature but fatigued at 38.7°C, whereas the final core temperature of trained participants reached 39.5°C regardless of body fatness.

It has been documented that high fit individuals generally terminate an exercise trial due to the attainment of the ethical limit for core temperature (as determined by research ethics boards) of typically 39.5 to 40.0°C whereas moderately fit participants cease exercising due to exhaustion (Cheung & McLellan, 1998).

5.4 Physiological effects of hyperthermia

5.4.1 Neuromuscular effects

The mechanisms, central or peripheral, responsible for the early onset of fatigue while exercising in uncompensable heat remain unclear. There is increased support for the theory that the decrease in force output during hyperthermia is the result of decreased central drive to the muscle (Nybo & Nielsen, 2001; Morrison et al., 2004). Nybo and Nielsen (2001) reported reduction in voluntary activation and force production following cycling to a core temperature of 40.0°C regardless of whether the muscle was exercised or not. A reduction in voluntary activation percentage was associated with the impaired ability to generate force (Fig. 2.1). However, there are several reasons that make it difficult to isolate the central nervous system in the development of hyperthermic fatigue. Namely, the length of time required to induce a significant elevation in core temperature leads to the development of confounding factors such as dehydration, electrolyte imbalances and cardiovascular strain, all of which may induce fatigue.

Passively induced hyperthermia has been found to be a main factor attenuating force development. Passive heating to a core temperature of 39.4°C had a significantly negative effect on voluntary activation and force production. Although cardiovascular strain was significantly reduced with the addition of skin cooling, force production remained decreased until core temperature returned to normal values (Morrison et al., 2004).

Two theories have been proposed to explain the decrease in central drive in hyperthermic conditions. First, the descending message from higher brain centers to the motor neurons may be compromised. On the other hand, there may be a reduction of the excitability of the motor neurons at a spinal level due to sensory feedback from type III and IV afferent fibers (Cheung and Sleivert, 2004).

5.4.2 Brain activity

Studies on mammals have revealed that exhaustion during exercise occurs with a brain temperature of 42.5°C in goats (Caputa et al., 1986) and 40.2°C in rats (Fuller et al., 1998). Although, the brain is the most likely site for critical temperature effects, direct human studies have yet to be performed. However, brain activity during hyperthermia has been explored in humans. A rise in core temperature in trained athletes cycling to exhaustion has been related to changes in EEG (Nielsen et al., 2001). EEG frequencies shifted toward lower frequency α-waves indicating a lower state of arousal while EMG amplitude and frequency of the exercising muscle remained unaltered during exercise with progressive hyperthermia. This indicated that hyperthermia does not affect the electrical patterns of active skeletal muscles but may affect cerebral function (Nielsen et al, 2001).

5.4.3 Muscle function and metabolism

The balance of substrate utilization may also change as a result of elevated core body temperature, resulting in a decrement of exercise performance. Hyperthermia results in a shift towards increased carbohydrate utilization and reduced fat metabolism during exercise. Lipolysis takes a longer time to begin than carbohydrate metabolism. As a result, the rate of energy delivery from fats is less than carbohydrates. Therefore, carbohydrates can become the rate-limiting step in metabolism. Exercise can continue for a longer period of time if a smaller fraction of carbohydrates are metabolized during exercise. Jentjens et al., (2002) demonstrated that more muscle glycogen and less ingested carbohydrates are utilized during sub-maximal exercise in a heated environment compared with that of a cooler environment. Subjects exercised at 55% of their VO_{2max} on a cycle ergometer for a period of 90 minutes while consuming 8% glucose solutions standardized to body weight. The study found a 25% increase in muscle glycogen utilized in the heat trial (35.4 ± 0.2°C) compared to the cool trial (16.4 ± 0.2°C) during the period from 60 to 90 minutes. It was concluded that muscle utilization of free glucose may be directly impaired at elevated temperatures (Jentjens et al., 2002). These findings provide evidence that increased temperature may play a role in fatigue through changing substrate utilization properties. Prolonged exercise with a corresponding increase in core temperature could lead to substrate-related fatigue.

There are two mechanisms that have been suggested to explain the alterations in metabolism associated with hyperthermia. First, epinephrine concentrations can be markedly increased two fold from resting levels during exercise induced hyperthermia (Parkin et al., 1999). Second, because elevation of muscle temperature, increased glycogenolysis and lactate accumulation have been observed in the absence of changes in core temperature or plasma catecholamine levels.

It has been proposed that the increases in anaerobic glycolysis may be due to the Q10 effect which is the factor by which any chemical or biological reaction rate increases or decreases when exposed to a temperature change of 10°C (Febbraio, 2000). This indicates that muscle temperature alone may play a role in metabolism during heat stress.

5.4.4 Cardiovascular function

Exercise induced hyperthermia is associated with high levels of cardiovascular strain (Nybo & Nielsen, 2001). Redistribution of blood to peripheral tissues due to cutaneous vasodilation during hyperthermia results in an inability to sustain adequate cardiac output, blood pressure and critical blood flow to the brain (Nybo et al., 2002). To increase cooling, blood is shunted to the skin and away from working muscles. The blood shunted to the peripheral tissues can exchange heat with the surroundings, and then returned as venous blood to the heart to decrease overall core body temperature. However, Neilson et al., (1990) proposed that the increase in peripheral blood flow may limit the blood supply to the working muscles and, therefore, reduce their ability to perform in the heat. In subsequent tests it was determined that there is no reduction in blood flow to the exercising limbs when subjects exercise in a heat stress environment with an elevated core temperature of approximately 40°C.

The effects of manipulating starting core temperature in trained cyclists revealed that increases in heart rate and decreases in stroke volume paralleled the rise in core temperature from 36 to 40°C (Gonzalez-Alonzo et al., 1999). Skin blood flow reached a plateau at 38°C, suggesting that the elevated heart rate was the primary contributor to decreased stroke volume. This was due to reduced cardiac filling time, with the net result being a decrease in cardiac output during hyperthermia.

5.5 High Intensity Intermittent Exercise

Exercise intensity has a significant effect on heat storage because core temperature (Tc) increases exponentially as a function of the percentage of maximal oxygen uptake (ACSM, 1996; Davis et al., 1976). Although the total heat production during a single bout of high-intensity exercise may not be enough to produce hyperthermia due to the high rates of heat gain (0.158°C per minute; Nadel, 1979), when multiple bouts of high-intensity exercise are performed under uncompensable conditions, substantial heat storage can occur. It has been shown that even when intensity is moderate, intermittent exercise produces greater elevations in Tc than continuous activity (Kraning & Gonzalez, 1991). In sports where competitors engage in a series of high-intensity bursts of activity without adequate recovery to allow heat dissipation, rates of heat gain as great as 0.158°C per minute will rapidly lead to hyperthermia. When training sessions and competitions are conducted in hot, humid environments, the heat storage would be accentuated.

In fact, hyperthermia has been noted in a variety of sports that involve high intensity, intermittent exercise (Bergeron et al., 1995; Francis et al., 1991; Locke et al., 1997). Although elevations in Tc may be a problem during activity of this kind, the rest periods also provide an opportunity to implement external cooling, thus possibly reducing heat storage and concomitant hyperthermic fatigue.

5.6 Strategies to improve performance in the heat

A variety of cooling units are now in use in competitive athletic settings, however, their effectiveness has not been thoroughly examined. The majority of the work designed to investigate post-exercise cooling methods has focused on the treatment of individuals suffering from hyperthermia and/or heat stroke. Cooling methods involving air flow, water spraying, water immersion, application of ice packs, and combinations of the aforementioned have produced differing results (Armstrong et al., 1996; Kielblock et al., 1986). Some researchers have found that warm air flow in combination with water spraying was effective (Poulton & Walker, 1987), whereas others have reported the fastest rates of cooling with cold water immersion (Armstrong et al., 1996; Armstrong et al., 1994). Because of the high thermal conductivity of water, water immersion may be highly effective in medical situations; however, it is probably not of practical value in settings where the intent is to return to physical activity. Regardless of these issues, research has not been conducted to study the thermoregulatory responses when post-exercise cooling is used in conjunction with multiple, high-intensity exercise sessions.

5.6.1 Rapid Thermal Exchange System

As previously stated, a new cooling device [Rapid Thermal Exchange (RTX), AVAcore Inc., Palo Alto, CA] has been shown to be effective in manipulating core body temperature (Grahn et al., 1998; Soreide et al., 1999). The body dissipates excess heat largely through hairless skin areas that are underlain by arteriovenous anastomoses (AVAs) and the subcutaneous venous plexuses. These specialized hairless surfaces include the palms of the hands and soles of the feet, as well as the face and ears (Grahn et al., 1998). The RTX cooling device relies on manipulation of the specialized vessels underlying the palm of the hand (AVAs). These specialized vessels constrict and dilate as a response to higher and lower core body temperatures, respectively (Bergersen et al., 1997; Grahn et al., 1998; Hales et al., 1985; Midttum et al., 1998; Soreide et al., 1999). The result is a change in the temperature of venous blood returning to the heart, impacting the core body temperature. This device creates a thermal gradient using a water-perfused matrix underlying a metal plate that is designed for the curvature of the palm of the hand. The metal heat exchanger is enclosed in a plastic cover with a pressure-sealed cuff around the wrist. The vacuum creates a pressure gradient below atmospheric pressure within the chamber enclosing the hand. The negative pressure promotes a greater volume of blood to enter the hand for heat exchange.

5.7 Exercise in Water

The thermal properties of water differ from those of air by a 20-fold higher heat conductivity and a specific heat approximately 1000 times greater than air (Blatteis, 2001). Therefore the average skin temperature in a water environment will be very close to water temperature. In warm water the ability of the body to dissipate heat through blood flow to the skin becomes paramount. The heat transfer by the blood can vary 6-10 times above minimal value, and the blood flow can provide a maximal heat transfer of about 100 $W \cdot m^{-2} \cdot {}^{\circ}C^{-1}$. From this it can be calculated that a subject swimming with a rate of oxygen consumption of 3 $L \cdot min^{-1}$ cannot sustain a steady body temperature if the water is warmer that 32°C (Nielsen, 1978). Therefore, there is concern of the possibility of exercise induced hyperthermia for swimmers training at a high intensity in warm pools with hot ambient conditions.

5.8 The Hand

5.8.1 Hand Blood vessels and vascular innervations

Blood is supplied to the hand mainly by the radial and ulnar arteries. These arteries exist in the deep palmar arch and to a less extent in the superficial palmar arch (Gray, 1989). The finger arteries arise mainly from these arches. Dorsal and palmar digital arteries run parallel to the phalanges on both sides. The palmar digital arteries are the main supply vessels, the dorsal digital arteries being very small. The veins of the hand are also divided into superficial and deep. The palmar digital veins open mainly into superficial arches and the palmar metacarpal veins into deep arches. The superficial arches continue in the cephalic, basilica and three median antebrachial veins. The deep arch drains into the radial and ulnar veins, which unite in the brachial vein (Rohen & Yokochi, 1988). The blood flow is regulated by opening and closing of the ateriovenous anastomoses (AVA) in the hand. When the hand is warm, blood flows into the hand where the AVA will be open. Blood flows in relatively large quantities from the arteries through the AVA to the superficial veins (Havenith et al., 1995). The blood vessels of the hand skin are normally subjected to a high degree of vasoconstrictor tone, even though the subject is comfortably warm. Johnson et al.,(1995) indicated that active vasodilation occurs in the back of the fingers and hands. The mechanism of active vasodilation is still subject to debate.

5.8.2 Cold induced vasoconstriction

A strong vasoconstriction in the skin of the hand that is in contact with cold materials is observed in the first minutes of cold exposure. This strong vasoconstrictor response in skin and muscle is caused by several factors. The most important mechanism is a reflex excitation of vasoconstrictor fibres (Folkow *et al.,* 1963). The thermoreceptors in the cooled skin transmit afferent signals to the thermoregulatory centre in the brain. The centre increases the vasomotor tone and transmits signals to the periphery via the sympathetic nerves. Increased sensitivity of the vascular smooth muscle cells to norepinephrine may contribute to the neutrally mediated vasoconstriction (Shepherd & VanHoutte, 1981). The cold can also act directly on the smooth muscle surrounding the blood vessels (Keatinge, 1970). The local blood flow is not only affected by the vascular lumen but also by the intrinsic properties of the circulating blood.

5.8.3 Peripheral circulation

Normally, a connection between the arterial and the venous circulation occurs by the capillaries. In some parts of the human body, such as fingers, lips, cheeks, nose and elbows, there are direct connections between the arterial and venous network (Hale & Burch, 1960). These connections are called ateriovenous anastomoses (AVA's). Grant and Bland (1931) found a relation between the number of the AVA's in a body part and the occurrence of cold induced vasodilation. Since this discovery, some researchers (Livingstone et al., 1989a) have stressed the importance of the AVA's for local temperature regulation. Evidence, however, is hard to find because blood flow through the AVA's cannot be measured in a simple way. The circulation pattern can be changed by a different distribution of blood flow through the AVA's and capillaries. Because the AVA's have a relatively large diameter, the total blood flow in that skin part will increase, and so will the heat transfer to the surrounding tissue and eventually the environment.

5.9 Limitations in the Literature

The majority of studies to date on the impact of cooling on performance have tested exclusively males. However, women make up a large percentage of high performance athletes, so their response to cooling strategies should also be investigated despite the challenges of fluctuating core temperature due to menstrual cycles. It is not known if there are specific gender responses to cooling and what the impact may be on performance.

Another limitation of previous research in cooling is that most studies have been conducted in the laboratory setting and have failed to take into account heat gain from solar radiation, which would typically contribute a significant thermal load during outdoor sport events. For swimmers, with the addition of warm water temperature, an uncompensable heat stress environment may be created. Another challenge of using cooling strategies in the field is portability and access to freezers and power sources. Both of these factors must be taken into consideration prior to use of cooling for athletic competitions. The RTX device addresses both of these last concerns as it is fully portable; however it has yet been tested in the field.

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

5.10 Summary

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

One strategy for dealing with performance in uncompensable heat during training is intermittent cooling. Although there are currently no studies available, the Rapid Thermal Exchange System may be an efficient and economical method to rapidly cool the body core.

Further research must be conducted using the RTX to determine its effectiveness in the athletic field.

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TABLE OF APPENDICES

Appendix A - Informed Consent Form- this document was read and signed by each participant prior to beginning the study to ensure that each individual understood their personal rights when participating in the study.

University of Victoria

Participant Consent Form

Department of Physical Education

You are being invited to participate in a study entitled "The effect of hand cooling on thermal and psychophysical strain and performance during high intensity intermittent training of elite swimmers." that is being conducted by Thomas Zochowski (MSc: Kinesiology Candidate)

Introduction

Thomas Zochowski is a Graduate student in the Master of Science program in the department of Physical Education at the University of Victoria and you may contact him if you have further questions by
Phone: 250-661-6410
Email: tommyz@uvic.ca

As a Graduate student, I am required to conduct research as part of the requirements for a degree in Kinesiology. It is being conducted under the supervision of Dr. Gordon Sleivert and Dr. David Docherty. You may contact either of my supervisors at:

Dr. Gordon Sleivert
250-744-5536
gsleivert@pacificsport.com

or

Dr. David Docherty
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docherty@uvic.ca

Project Funding

This research is being funded in part by the Michael Smith Foundation for Health Research / University of Victoria Support for Graduate Students.

Purpose

The purpose of this study is to examine the thermoregulatory, performance and psychophysical effects of using intermittent hand-cooling during high intensity, intermittent training in elite swimmers in competition (~27°C) versus warmer pools (~30°C).

Research Contributions

Research of this type is important because athletes regularly train and compete in thermostressful environments that amplify physiological strain and accordingly can impair performance and/or the efficacy of training. For example, the environmental conditions during the 2004 Olympic Games in Greece ranged from 35°C to 40°C. Not only do these conditions effect athletes performing in land based activities but also athletes in water sports. Typically, outdoor swimming pool temperatures range from 29oC to 33oC. A significant amount of endogenous heat is produced by working muscle during exercise and consequently core temperature is usually elevated above the resting level of 37°C, even in moderate temperatures. Hot, humid climates as well as warm swimming pools limit the body's ability to transfer heat to the environment. In these cases exercise may be accompanied by adverse physiological effects, psychophysical responses, decreases in performance and heat illness. This research will add to the depth of knowledge in the thermoregulatory field and further understanding of athletic performance in a hyperthermic state.

Participation

You are being asked to participate in this study because you are an elite swimmer between the ages of 16 and 26.

If you agree to voluntarily participate in this research, your participation will include attending five sessions at the Saanich Commonwealth Place swimming facility. You will participate in one anthropometric / familiarization session and four experimental sessions.

Session one will include:

- Height, Weight
- Body composition measurement through skin fold protocols
- Familiarization with the cooling mechanism (RTX, AVACore Technologies, Palo Alto, California).

Four testing sessions will include:

- Standardized warm-up protocol followed by one of four experimental conditions. You will perform a test set of 8x100 freestyle with a one minute rest interval. Then, you will swim in either a cool swimming pool (27oC) or a warm swimming pool (30oC) either with sham cooling (RTX with 33oC water) or actual cooling (RTX with 22oC water).
- During the rest interval you will be cooled using the Rapid Thermal Exchange Unit (RTX, AVACore Technologies, Palo Alto, California).
- Your heart rate will be examined using a Polar heart rate monitor (Polar Electro Inc., Port Washington, NY, USA).
- During the experimental session, after each repetition, perceived exertions, thermal comfort and thermal sensation will be assessed using valid scales (Appendix).

- Core body temperature will be monitored continually via a thermal monitoring capsule, Jonah (Vital Sense, Mini Mitter Co. Inc., Bend, OR) which you will ingested 6-12 hours before reporting to the swimming pool for testing.

Inconveniences

The testing in this study will be completed in the time frame of your regular training program. Although you would not, normally, complete test protocol on such a regular basis it would be part of your normal training routine. You will not be asked to contribute more time than would regularly be required of you during an everyday training session.

Risks

There are some potential risks to you by participating in this research. You will be performing a test set of 8x100 freestyle at maximum effort at a one minute rest interval. This is a fatiguing protocol. Additionally, when exercising in a hot environment there is a risk of heat injury.

To prevent or to deal with these risks the following steps will be taken. Although this is a fatiguing protocol you are an elite swimmer and are accustom to this type of training and the fatigue in this testing session will not exceed the fatigue that you typically undergo during regular training. Additionally, when exercising in a hot environment there is a risk of heat injury. Thus, core temperature will be measured continuously throughout the test, and if it exceeds 39.5°C the test will be stopped. Core temperature will be monitored using a VitalSense ® capsule. You will be screened regarding any contraindications to swallowing a telemetric capsule using a series of questions prepared by a physician. You will be screened verbally and will be referred to a physician before proceeding with the study.

Testing will be stopped immediately if your core temperature exceeds 39.5°C. A core temperature of 39.5°C is a conservative cut-off limit that is used repeatedly in thermoregulation research in Canada. Dr. Sleivert has extensive experience using thermal monitoring techniques. Should the core temperature reach 39.5°C, the trial will immediately stop and cooling will be implemented by placing an ice vest on you and removing you from the swimming pool. This will ensure that your body temperature begins declining immediately.

In case of emergency (i.e. if body temperature does not decline immediately) EMS will be contacted.

Benefits

The potential benefits of your participation in this research include expanding the pool of knowledge in the area of thermoregulation. The results of this study may be used in future training situations held in hot, humid conditions to enhance performance in these extreme environments.

Voluntary Participation

Your participation in this research must be completely voluntary. If you do decide to participate, you may withdraw at any time without any consequences or any explanation. If you do withdraw from the study your data will be removed from the data base and not used for analysis.

To make sure that you continue to consent to participate in this research, you will be informed before each test session that your participation is voluntary that that you may withdraw at any time without penalty.

Anonymity

Your anonymity will be only partial since the other participants and I will know your participation. In terms of protecting your anonymity, your name, e-mail address and phone number will be collected for contact purposes. Results of this project may be published but any data included will in no way be linked to you specifically. Additionally you will be assigned a personal identification number to ensure anonymity in the analysis and documentation of results. I will be the only one that will access the data collected in this study.

Your confidentiality and the confidentiality of the data will be protected. The data collected and the coded identifications will be securely stored in separate locked cabinets in such a way that I will be the only one able to gain access to it. Data will be stored at the Pacific Sport National Sport Centre Victoria in Dr. Sleivert's office.

Dissemination of Data

It is anticipated that the results of this study will be shared with others in the following ways: The data will be disseminated directly to you, will be used as part of a Master's Thesis and be published in a scientific journal.

Data Disposal

At the end of the project any personal information will be destroyed immediately except that, as required by the University's research policy, any raw data on which the results of the project depend will be retained in secure storage for five years, after which it will be destroyed.

Contact

In addition to being able to contact the researcher and supervisor at the above phone numbers, you may verify the ethical approval of this study, or raise any concerns you might have, by contacting the Associate Vice-President, Research at the University of Victoria (250-472-4545).

Your signature below indicates that you understand the above conditions of participation in this study and that you have had the opportunity to have your questions answered by the researchers.

Name of Participant	*Signature*	*Date*

A copy of this consent will be left with you, and a copy will be taken by the researcher.

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

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Appendix B –Contraindications for use of telemetric capsules- All participants were screened regarding any contraindications to swallowing a telemetric capsule using a series of questions prepared by a physician. If any contradictions had been indicated the participant would have been referred to a physician before proceeding with the study.

Contraindications for use of telemetric capsules:

- Any individual whose body weight is less than forty (40) kg.
- In the presence of any known or suspected obtrusive disease of the gastrointestinal tract, including, but not limited to diverticulitis and inflammatory bowel disease.
- Any individual having or suspected to have any inflammatory bowel disease.
- Any individual exhibiting or having a history of disorders or impairment of the gag reflex.
- Any individual with previous gastrointestinal surgery.
- Any individual who might undergo nuclear magnetic resonance (NMR) scanning during the period that the thermistor is within the body.
- Any individual with hypomotility disorders of the gastrointestinal tract including but not limited to Illus.

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

Ratings of Perceived Exertion

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

(Borg, 1982)

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

Thermal Comfort Scale

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

(Gagge et al., 1967)

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

Thermal Sensation

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

(Gagge et al., 1967)

Appendix F – Preliminary Data Collection

Purpose

Preliminary data was collected in order to determine the effect of performing the 8x100 meter test in the warm pool (29.7°C) versus the cold pool (27.2°C).

Experimental Design

8 elite participants were selected from the Victoria Amateur Swim Association. They each performed the testing protocol including the standard warm-up once in each pool condition in a counter balanced order separated by one week. At the completion of each 100 meter effort the final time and heart rate were recorded.

Results

According to figure 4.1 each condition demonstrated a peak performance during the sixth repeat with the final 100 meter time significantly less in the warm pool than the cool pool ($p<0.05$). Similarly, according the figure 4.2 each condition showed a gradual heart rate increase throughout the test set with the cool pool heart rate significantly less than the warm pool ($p<0.05$).

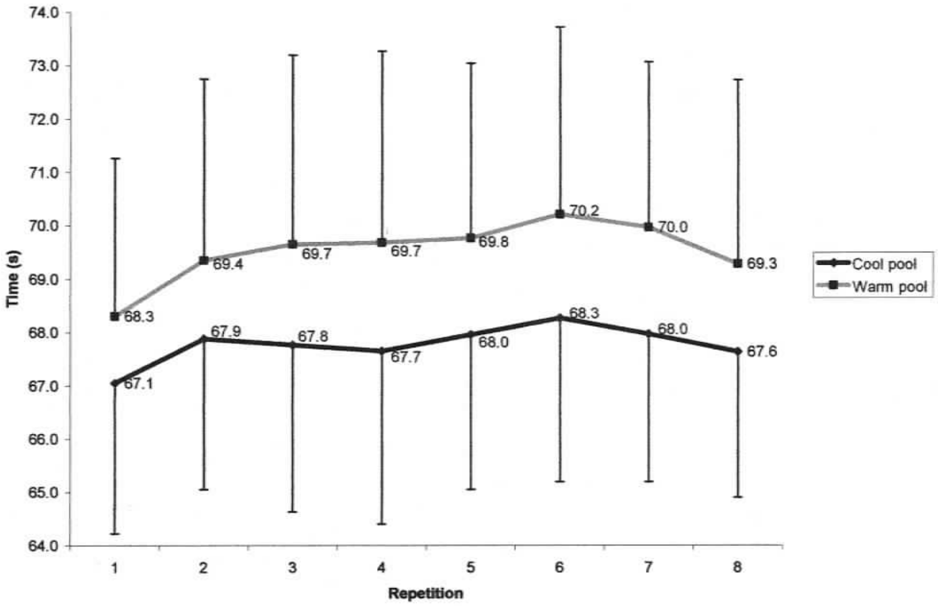

Figure 4.1 Mean final 100 meter time following each repletion in response to two experimental conditions. Significant difference between conditions (P<0.05).

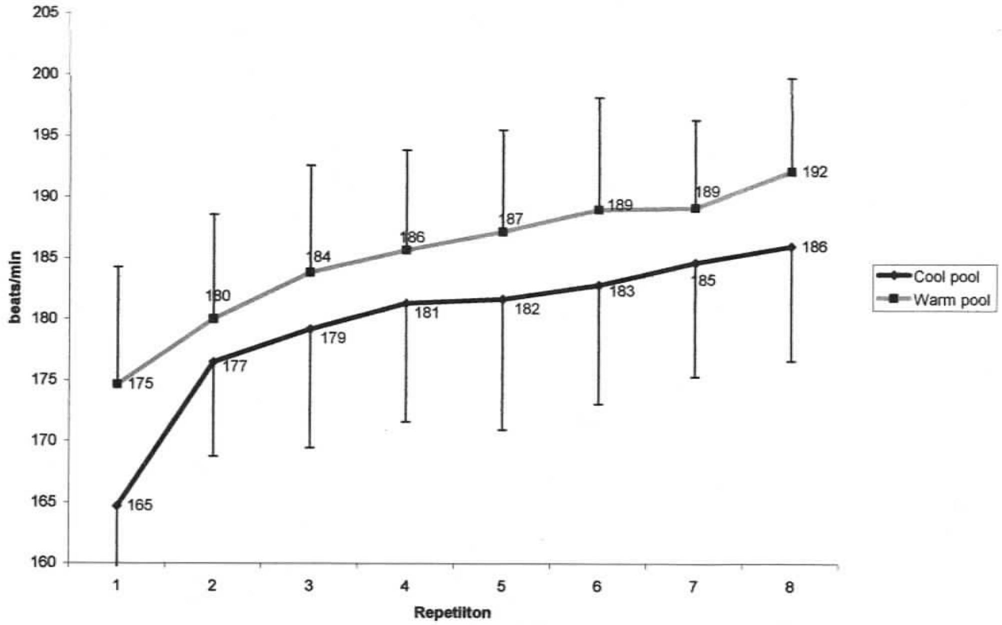

Figure 4.2 Mean final heart rate following each repletion in response to two experimental conditions. Significant difference between conditions (P<0.05).