Time Course Changes in Muscle Temperature and Performance Following Active Warm Up in Cool Environments

by

Megan Kidston
B.Sc., McGill University, 2009

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Supervisory Committee

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Dr. Lynneth Stuart-Hill, School of Exercise Science, Physical & Health Education
Co-Supervisor

Abstract

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Co-Supervisor
Dr. Lynneth Stuart-Hill, School of Exercise Science, Physical & Health Education
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The effect of active warm up (WU) and passive heating (HP) following WU on muscle temperature (Tm) and performance in cool (10°C) environments was studied. Eight male recreational athletes (29±5 y) with a minimum relative mean VO_{2peak} score of $50 mL\cdot kg^{-1}\cdot min^{-1}$ ($58.0 \pm 6.3\ mL\cdot kg^{-1}\cdot min^{-1}$) completed two 60-minute sessions in an environmental chamber (9.77˚C, 71%RH). Following 15 minutes of standardized WU on a cycle ergometer, heat was applied to the legs during 30 minutes of inactivity using heated pants in HP but not in control (CON). Core (T_c), skin (T_{sk}) and muscle temperature, heart rate (HR), and thermal comfort (TC) and sensation (TS) were monitored at 5-min intervals throughout test sessions. Muscle performance was assessed by countermovement (VJ) height measured pre- and post-WU and at 10-, 20-, and 30-minutes following WU, as well as by anaerobic power, capacity, and fatigue measures calculated from a 45-second Wingate anaerobic test (WAnT) completed at the end of the 30-minute inactivity phase. WU resulted in similar and significant increases in T_m and VJ from baseline to post-WU ($p<0.05$). T_{sk} showed a difference between HP and CON prior to, during, and at the end of WU ($p<0.05$). Compared to end-WU, T_m was lower in HP and CON at 20-, 25- and 30-minutes of inactivity; however, T_m remained higher in HP at all timepoints following WU compared to CON. This maintenance in T_m during HP was associated with a higher peak power output calculated from WAnT ($p<0.05$). No differences were seen in VJ performance, TC, or TS following WU ($p<0.05$). HP can be used to attenuate thigh T_m and peak power performance decline following active WU in cool (~10˚C) environments.

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Symbols and Abbreviations

CON	Control experimental condition
HP	Heated Pants experimental condition
HR	Heart Rate
PAR-Q	Physical Activity Readiness Questionnaire
T_c	Core Temperature
TC	Thermal Comfort
T_m	Muscle Temperature
T_{re}	Rectal Temperature
TS	Thermal Sensation
T_{sk}	Skin Temperature
VCO_2	Carbon Dioxide Production ($mL \cdot kg^{-1} \cdot min^{-1}$ or $L \cdot min^{-1}$)
VJ	Countermovement Vertical Jump
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 $L \cdot min^{-1}$)
VO_{2peak}	Peak Oxygen Consumption ($mL \cdot kg^{-1} \cdot min^{-1}$ or $L \cdot min^{-1}$)
WAnT	Wingate Anaerobic Test
WU	Warm Up
45sPP	Average of 5-second Peak Power segments over full 45-second WAnT
5sPP	5-second Peak Power

Acknowledgements

Thank you to my supervisor, Ben, for hiring the keen intern who wanted to move across the country to see what working in sport was about. Your passion for research, endless ideas and enthusiasm both challenged and inspired me. Thank you for your mentorship and patience throughout the time I've worked with you. We may not have done it the conventional way, but lessons were learned that went well beyond this project alone. Pretty safe to say I will avoid using Times New Roman going forward unless absolutely necessary!

I would also like to thank my co-supervisor, Lynneth, for giving time out of a busy schedule to answer questions and help me successfully complete my studies.

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I would also like to thank Rob, recruitment assistant extraordinaire - always willing to help out with "one more" session in the MET (I know your Bolton roots never prepared you for standing around at -10˚C!), and for always taking the time to answer my questions and offer advice.

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1. Introduction

Summer sport athletes naturally train and compete in warm and hot conditions that augment thermal strain and contribute to exertional heat stress, negatively influencing performance and recovery. However, the year-round training environment and international competition schedule mean that summer sport athletes must also cope with cool climates and cold temperatures. The definition of a cold environment varies with different activities and sports. Cooler temperatures (3˚C-11˚C) may have a beneficial effect on long-term, moderate-intensity performance (Galloway & Maughan, 1997; Parkin, Carey, Zhao & Febbraio, 1999) but are likely to detriment short-term, high-intensity performance (Dixon et al., 2010; Drinkwater, 2008; Sargeant, 1987).

Body temperature is regulated primarily in the hypothalamus which continually makes thermoregulatory adjustments to maintain core temperature (T_c) within a narrow range: 37°C ± 1°C (McArdle, Katch & Katch, 2010). Thermal mechanisms including radiation, conduction, convection and evaporation all contribute to heat gain and heat loss. Non-thermal effectors including baroreceptors and mechanoreceptors have been shown to modulate the rate of local sweating and skin blood flow after the onset of exercise and following exercise, affecting changes in T_c (Kenny et al., 2009; Mekjavic & Eiken, 2006). Heat transferred by blood flow between body core and skin is affected by temperature, humidity, wind chill, activity level, and insulative properties of body fat and clothing.

Known effects of cold muscle temperature (T_m) including lower cell metabolism, vasoconstriction, decreased nerve conduction velocity, decreased muscle contractility and decreased extensibility of collagen fibres can all increase risk of injury and reduce athletic performance (Dixon et al., 2010; Safran, Garrett, Seaber, Glisson, & Ribbeck, 1987). Low-intensity exercise in the cold may also increase oxygen consumption due to shivering, increasing the need of muscle glycogen stores to provide carbohydrate fuel. Despite an increased T_c resulting from moderately intense (~70% maximal) sustained exercise, drops in T_m affect performance in extremely cold conditions due to compromised muscle enzyme activity and neuromuscular recruitment (Nimmo, 2004). In lab conditions, temperatures of -10˚C and colder have elicited reduced oxygen consumption and a reduction in endurance capacity (Nimmo, 2004). During high-intensity exercise, subnormal T_m (<34˚C) has resulted in decreased dynamic performance during cycling and jumping, and reductions in optimal velocity for dynamic power output (Dixon et al., 2010; Nimmo, 2004). Muscle strength and power were decreased following cold water immersion at 12˚C as assessed by isokinetic leg extensions (Howard, Kraemer, Stanley, Armstrong, & Maresh, 1994) and countermovement vertical jump (VJ) (Dixon et al., 2010). Oksa et al. (1997) similarly found that plyometric (agonist and antagonist) VJ performance was reduced in a dose-dependent manner with cooling, as assessed by decreased flight time, average force production and take-off velocity. In this case, performance was affected under exposure to ambient temperatures of 20˚C – a moderate stress environment. Reduced oxygen delivery resulting from vasoconstriction and decreased blood flow, or increased energy demand caused by decreased efficiency are both possible explanations for increased fuel utilization during high-intensity exercise in the cold.

Pre-warming before exercise facilitates work through an increase in body temperature. Warm up (WU) is a widely accepted means of improving performance and decreasing the risk of injury (Bishop, 2003a; Fradkin, Zazryn, & Smoliga, 2010; Woods, Bishop, & Jones, 2007). Passive heating provides a means of improving muscle performance through an increase in T_m without depleting energy substrates; methods include heating pads, diathermy, hot showers, hot baths and saunas. Active WU involves dynamic exercise preceding performance; it can be more practical in certain sport situations, and may provide additional benefits over passive heating alone.

Temperature-related effects of warming up before exercise may improve performance by decreasing viscous resistance of muscles and joints, accelerating rate-limiting oxidative reactions, increasing nerve conduction rate, and facilitating the release of oxygen from haemoglobin and myoglobin with consequent increased oxygen delivery to muscles (Bishop, 2003a; Fradkin et al., 2010; McArdle et al., 2010). Non-temperature-related effects associated with a dynamic WU that may contribute to performance include increased blood flow to muscles, elevated baseline oxygen consumption, increased twitch potentiation, decreased muscle stiffness, and contribution to pre-performance routine including improved preparedness and an augmented mental activation state (Bishop, 2003a). Conversely, warming up can decrease performance if energy stores are sufficiently depleted, if WU contributes to thermoregulatory strain, or if WU accelerates onset of fatigue.

Timing, duration, intensity, and length of recovery before performance are all important considerations when structuring a WU. Short-term (<10s) performance improvements have been shown consistently following a quality WU (Bishop, 2003b). The evidence is less clear for intermediate- (>10s-5min) and long-term (>5min) performance; however, Bishop (2003b) postulated that inconsistencies of timing, intensity, and recovery period were likely attributable to these discrepancies. Performance was enhanced when the WU was of adequate intensity, fairly short, and the period between active WU and performance was appropriate (~5-10minutes).

One of the common challenges for many summer sports athletes competing in cool environments is dealing with the delays that occur prior to competition. Prolonged delays that occur following WU can have been shown to negatively affect subsequent performance (Sporer, Pethick, Johnson, & Sleivert, 2008; Zochowski, Johnson, & Sleivert, 2007). Sporer et al. found that 30 minutes of passive heating following a general 15 minute WU in a -10˚C environment resulted in ~50% maintenance of performance gains following WU, as assessed by VJ, compared to without passive heating. More recently, Faulkner et al. (2012) found that insulated trousers with integrated passive heating worn for 30 minutes in a 16˚C environment after a 15 minute intermittent WU attenuated T_m decline and resulted in a significant improvement in peak power (9.6%) and average power (9.1%), as assessed by a thirty-second maximal cycling sprint, compared to wearing standard track pants alone or insulated trousers without passive heating.

Using passive heating as a bridging mechanism appears to be a valuable and easily implemented strategy enabling maintenance in T_m and muscle performance in cool and cold environments. However, the research in this area is limited. Further studies need to be carried out to better understand the time course and effects of muscle cooling following WU in cool conditions and whether these effects can be reduced using passive heating. A better understanding of these time course changes will benefit athletes by contributing to optimal WU timing and strategies to maintain T_m if necessary prior to performance.

1.1 Purpose of Experiment

The purpose of the proposed research study was to investigate time course changes of T_m following WU in cool environments and to evaluate the effectiveness of passive heating on maintaining T_m and performance.

1.2 Research Questions

1) What were the effects of active WU on T_m and VJ performance in a cool environment (10˚C)?

2) What was the decay rate of T_m during a period of inactivity following an active WU during exposure to a cool environment (10˚C)?
3) What was the effect of inactivity following an active WU on short-term, high-intensity muscle performance in a cool environment (10˚C)?
4) Was the decay rate in T_m and performance attenuated using passive heat (heated WU leggings)?

1.3 Hypotheses

H1: Active WU will have no effect on T_m and short-term, high-intensity performance in a cool environment (10˚C)

H2: T_m will be maintained following inactivity during exposure to a cool environment (10˚C)

H3: Decays in T_m with inactivity following an active WU will have no effect on short- term, high-intensity performance

H4: Maintenance of elevated T_m following active WU using passive heating will have no effect on short-term, high-intensity performance

1.5 Operational Definitions

- **Muscle temperature (T_m):** intramuscular temperature, measured in the vastus lateralis muscle
- **Active WU:** General aerobic WU preceding performance
- **Passive heating:** Heated garment used to maintain or increase temperature of muscle
- **Short-term, high-intensity performance**
    - Explosive power
        - Peak power produced during countermovement VJ, measured as jump height
        - Anaerobic power
            - Peak power: highest average power over any 5 seconds (5sPP)
            - Mean power: average power maintained through the (9) 5-s segments (Avg45sPP)
            - Fatigue Index: amount of the decline in power during the test expressed as a percentage of peak power

1.4 Delimitations

The study was delimited to male recreational athletes between the ages of 19 and 35 with a history of athletic training. Inclusion criteria included a minimum relative VO_{2peak} score of $50ml \cdot kg^{-1} \cdot min^{-1}$; athletes were informed of this criteria cut-off during the information session prior to participation.

1.5 Limitations and Assumptions

Participants who meet recruitment criteria are representative of the largest group from which individual responses are expected to be similar to those of athletes, particularly summer sport athletes. It was not possible to maintain a consistent level of training throughout the study; however, the counterbalance design has been chosen to help protect from systematic effects of training and differences in fitness. Anthropometric measures and a peak oxygen consumption test (VO_{2peak}) were used as descriptor variables to help recognize differences in body composition and fitness. There was a danger of testing effect due to the specificity and intensity of the testing; however, participants had previous related experience to the exercise modes and tests. They were familiarized with all the testing protocols and had a chance to practice the tests before data were collected during experimental sessions. Athletes were instructed to try to maintain a consistent level of training for the duration of their involvement in the study.

Ideally, a third experimental trial using a similar garment as the HP condition but without an external heat load (i.e. a sham condition) would have been included in the study design to better compare T_m and muscle performance responses representative of the competitive environment at 10˚C. However, pilot testing trials using a sham condition showed similar T_m and performance responses to CON. Therefore, it was decided to exclude a third experimental session that would increase the commitment of each participant in terms of number of sessions to attend, overall duration of study participation, and number of muscle temperature insertion protocols required.

Finally, limiting the analysis to those participants that met the T_m maintenance inclusion criterion may have decreased the potential statistical power of the findings. However, due to technical difficulties with the heated garment itself resulting in sometimes insufficient and inconsistent heat application to the leg muscles (see section 4.3), this criterion established parameters for the HP condition and therefore for analysis of T_m and muscle performance responses before, during and following WU in a cool (10˚C) environment when the garment was able to maintain T_m.

1.6 Controls

Participants were asked to avoid vigorous exercise 4 hours prior to testing, and food and caffeine 3 hours prior to testing. Although a food and training log was not required, athletes were encouraged to follow a similar diet and a consistent training program throughout their participation in the study and to arrive ready for testing well-hydrated. Participants were instructed to wear the same attire on both days to control variations in clothing warmth and weight (for performance trials).

Participants performed both experimental conditions in pseudorandom balanced order, thereby acting as their own controls. Testing sessions were scheduled at least 48h apart to allow for sufficient recovery and to minimize interference from fatigue, and sessions were scheduled at the same time of day to minimize the effect of diurnal variations in body temperature and heart rate (HR). All three sessions were scheduled within a 2-week period to avoid interference from other training or lifestyle effects.

2. Methods

2.1 Participants

Sixteen male, physically active, recreational athletes with a history of athletic training volunteered to participate in this study. All participants were between the ages of 19 and 35. These characteristics were chosen so as to recruit participants that represented the largest group from which individual responses are expected to be similar to those of summer sport athletes. Of the sixteen who volunteered to take part, one participant did not meet the minimum fitness criteria, one was non-compliant to the training control guidelines, and one chose to withdraw after session 1 due to discomfort following the muscle probe insertion protocol.

Recruitment posters were posted in Canadian Sport Institute Pacific facilities and around the University of Victoria campus and via word of mouth following the initial advertisement of the project; participants were then responsible for contacting the PI or recruitment assistant for any clarifications needed and to express their interest in taking part in the study. Interested participants were sent a copy of the informed consent form, a participant information sheet, the testing schedule, and a copy of the Physical Activity Readiness Questionnaire (PAR-Q) (see Appendices B, C, D and E). Participants were encouraged to bring up any questions, concerns, or clarifications by email or phone and were required to sign the informed consent and the PAR-Q prior to participating in the study. The project received approval from the Canadian Sport Institute Pacific and University of Victoria Biosafety committees, and the University of Victoria Human Research Ethics Board.

2.2 Experimental Design

A counter-balanced repeated measures design was implemented for this study (Figure 1). Each participant attended three sessions. The first session included familiarization with the laboratory, testing equipment and procedures. During session one, anthropometric measures including height, weight, and skinfolds were recorded, and a maximal aerobic power test was performed on a cycle ergometer to determine peak VO_2 and HR. Familiarization with the countermovement vertical jump (VJ) and Wingate anaerobic test (WAnT) cycle protocols and equipment was also carried out at the end of session one. The second and third sessions comprised of experimental trials under two different conditions an environmentally controlled chamber (9.77±0.22˚C, 71.41±6.20%RH). In the control (CON) condition, participants wore shorts only. In the heated pants (HP) condition, participants wore a customized pair of long-johns that had electric heating panels built into the front and back of both thighs which were inactive during baseline and WU, and activated (connected to a power supply and turned on) immediately following WU and for the 30 minutes following WU. Experimental conditions were performed in pseudorandom balanced order, allowing participants to act as their own controls. Participants were instructed to wear typical upper-body clothing for cool weather conditions: long-sleeved shirt, sweater, or jacket; this was replicated in their second experimental session. Testing sessions were scheduled a minimum of 2 days apart to ensure sufficient recovery and avoid interference from fatigue. All three sessions were scheduled within a 2-week period to avoid interference from other training or lifestyle effects. Testing sessions took place at approximately the same time of day to minimize the effects of circadian rhythms on HR and T_c. Experimental design is shown in Figure 1.

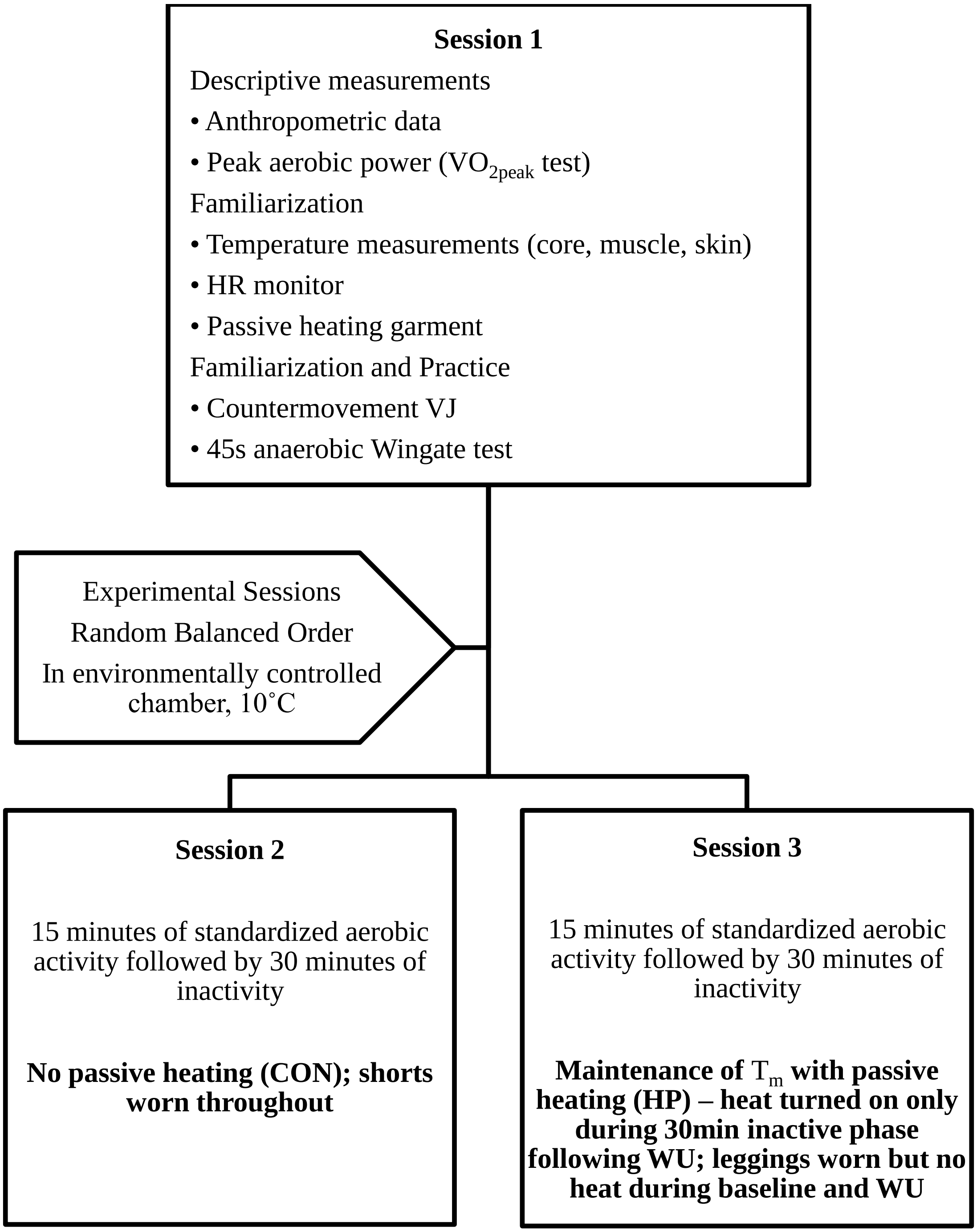

Figure 1. Experimental Design.

2.3 Initial Session and Descriptive Measures

Anthropometric data. Anthropometric data were used as a descriptor of participants and to account for inter-individual variations in body composition between participants. It was also used to gauge participants' relative representation of an athletic population. Skin fold thicknesses were measured with a caliper (model SFC-1000 Harpenden Skinfold Calipers, Baty Intl., West Sussex, England) at eight sites on the right-hand side of the body: tricep, bicep, subscapula, suprailiac, supraspinale, abdomen, thigh, and medial calf.

Peak aerobic power. Maximal oxygen uptake (VO_{2max}) was used to define aerobic power. Because athletes were limited to one maximal incremental exercise test, a true max was not defined; therefore, a peak VO_2 was determined. The VO_{2peak} test was performed on a cycle ergometer (Velotron cycle ergometer and Velotron Coaching Software, RacerMate, Seattle, WA) using SRM cranks (Jülich-Welldorf, Germany) to determine power output during session 1. The participant was instrumented with a HR monitor and watch (Polar Electro, Finland). Expired air was breathed into a Rudolph valve mouthpiece, which was held in place with a headpiece and attached to a hose that connected to a metabolic cart for gas analysis through the accompanying computer software (TrueOne® 2400 Metabolic Measurement System, Parvo Medics, Sandy, UT) during testing. This enabled real-time direct analysis of expired gases to determine oxygen consumption (VO_2), minute ventilation (VE), production of carbon dioxide (VCO_2), and respiratory exchange ratio (RER).

VO_{2peak} was determined using a cycle ergometer protocol involving incremental increases in power output. Participants began the test with a ten minute self-selected WU, trying out different intensities. The test began at 0 W and power output was increased by 1 W every 2 seconds in a 30W/min ramp protocol until exhaustion. The test took approximately 10-15 minutes depending on the fitness level of each individual participant. Verbal encouragement was provided during the later stages of this test. The test was terminated at the participants' discretion usually due to volitional exhaustion; this usually coincided with a plateau in HR or a decrease in VO_2 with an increase in workload.

VO_{2peak} was used to describe the sample population, as a general comparison between the sample population and the intended target population for this research (i.e. elite cyclists and triathletes), and to control for the potentially confounding effect of varying fitness levels amongst participants. Participants were required to meet a minimum relative VO_{2peak} value of

$50mL\cdot kg^{-1}\cdot min^{-1}$ for inclusion in the study. Peak HR attained was recorded and used to customize the WU in the experimental sessions for each participant.

2.4 Experimental Sessions

Testing took place at the Canadian Sport Institute Pacific Performance Lab and Mobile Environmental Trailer (MET), located at the Pacific Institute for Sport Excellence (PISE) in Victoria, BC. Participants arrived at the Performance Lab, changed into their cycling clothing, had their weight recorded, and were instrumented with a HR monitor. Core, muscle, and skin temperature instrumentation followed (see section *2.5 Temperature Measurements*). The participant walked to the MET with testers to begin the trial. The MET was controlled at 9.77±0.22˚C, 71.41±6.20% humidity. Each participant entered the MET and remained inactive for 15 minutes to establish baseline measures before performing a 15 minute active WU on the cycle ergometer at a standardized intensity of 70% of the peak HR recorded during VO_{2peak} testing (session 1). A 30 minute period of inactivity followed under two experimental conditions in which lower-body garments were controlled: a control (CON) condition where participants wore shorts and a passive heating (HP) condition where participant wore a garment with heating panels built in over the quadriceps and hamstring muscle areas. These pants were connected to a power supply and were designed to maintain a surface temperature of ~33-36˚C. From pilot testing and previous research (unpublished data) using these pants, this temperature was associated with T_{sk} and T_m maintenance following WU while minimizing discomfort and taking safety into consideration. Therefore, this heat output was applied over the quadriceps, hamstring, and gluteus muscle groups as a method of maintaining T_m following active WU. Inconsistent and uneven heat distribution to these muscle groups due to technical difficulties with the heated garment, as seen through data collected and general observation, resulted in a greater decline in T_m in some participants compared to others. Therefore, participants whose T_m was maintained within 1˚C of post-WU value (n=8) were used in the analysis of results to better understand the practical effect of T_m maintenance following active WU on high-intensity, short-term performance.No passive heating was applied to the legs during baseline and WU; external heat was applied only for the 30min inactive period following the WU.

HR, T_c, T_m, and T_{sk} were measured continuously and recorded every 5 minutes. Performance was measured using VJ height and a 45s maximal sprint cycling test (see section *2.6 Performance Measures*). VJ was performed following the initial baseline measure, following active WU, and at 10 minute intervals during the 30 minutes of inactivity. The 45s anaerobic WAnT was performed 2 minutes after the final VJ trial at the end of the 30 minutes of inactivity. The time course of events and measurements taken in the experimental sessions is shown in Figure 2.

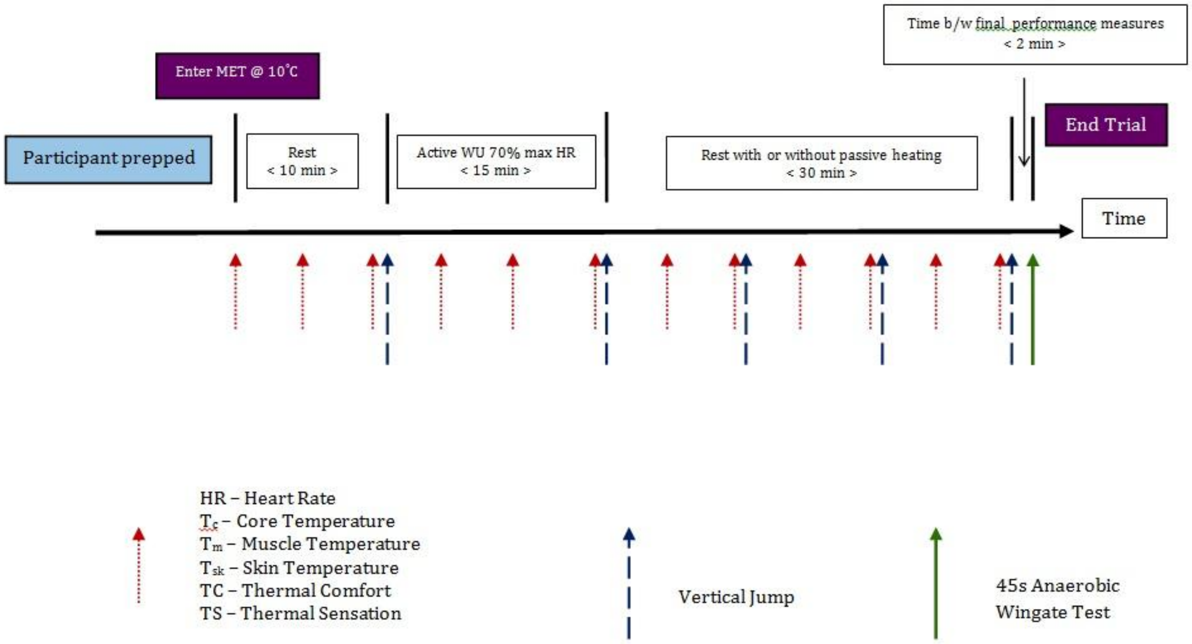

Figure 2. Time course of events during experimental sessions.

2.5 Temperature Measurements

Muscle Temperature. Using an approved, sterile, and practiced procedure, Canadian Sport Institute Pacific’s lab technician used an 18-gauge hypodermic needle (model IT-18, Physitemp Instruments Inc., Clifton, NJ) to insert a sterile intramuscular temperature probe (T Copper-constantan Custom IT-18 implantable probe, Physitemp Instruments Inc., Clifton, NJ) ~3.5cm into the right vastus lateralis muscle. Prior to the insertion procedure, the site was measured at the mid-point between the inguinal fold and the most superior aspect of the patella on the superior-lateral surface of the vastus lateralis muscle. This enabled the lab technician to repeat the insertion site during the second experimental session. The lab technician cleaned the site thoroughly before and after, and wore sterile gloves during the procedure. The needle was removed following insertion of the probe. A loop was made with the probe wire where it exited the skin, and the loop was secured with Opsite sterile dressing (Smith & Nephew Medical Ltd., Hull, England). The lead of the probe was connected to a portable thermometer (model Thermalert TH-5 Reader, Physitemp Instruments Inc., Clifton, NJ) for real time data display.

Core Temperature. Rectal temperature was monitored as an index of T_c and was measured using a disposable rectal temperature probe (NovaMed USA, Rye, NY) connected to a Smart Reader Data Logger and SRP Display Module (ACR Systems Inc., Surrey, BC) for instantaneous real time data display. Participants were required to insert the rectal probe into the anal canal to a depth of 10 cm. Each participant had their own temperature probe that they used for both experimental conditions. Probes were sterilized using bleach solution and kept in clearly labeled zip-lock bags between trials.

Skin Temperature. Participants were instructed to bring and wear a long-sleeved shirt, sweater or jacket similar to what they would wear prior to competition in a cool (~10˚C) environment, and to wear the same clothing for both experimental sessions. This enabled a realistic representation of participants' pre-competition attire while also controlling for differences between sessions. Since upper body clothing was not standardized across participants, T_{sk} was only measured on the lower body at 4 sites on the right leg (2 placements over each of quadriceps and hamstring muscles) and 2 sites on the left leg (1 placement over each of the quadriceps and hamstring muscles) using electrical NTC (Negative Temperature Coefficient) thermistors (Cantherm Model MF51E103E3950, Digi-Key Corp., Thief River Falls, MN), attached using 25mm Transpore tape ($3M_{TM}$). Thermistors were connected to a SmartReader7 data logger (ACR Systems Inc., Surrey, BC) and SRP Display Module (ACR Systems Inc., Surrey, BC) which displayed instantaneous temperature measurements. Placement of the superior thermistor was consistently ~2cm to the right of the dressing covering the T_m probe, and in-line with the T_m probe insertion point. The second thermistor over the quadriceps muscle was attached in a medial and inferior location to the first. This placement was replicated on each subject on their two experimental sessions; it was also attempted to keep these placements relatively consistent across participants despite differences in thigh length and girth.

Left and right hamstring, left and right calf, and left quadriceps T_{sk} were recorded every 5 minutes to monitor heat magnitude and distribution of the passive heating garment for consistency and safety reasons. For data analysis, a calculated mean value of the two skin thermistors over the right quadriceps muscle was used since these were the most relevant to the heat regulation and dissipation in the right vastus lateralis muscle (site of T_m insertion). Values given in results and discussion therefore refer to mean (right) thigh T_{sk}.

2.6 Performance Measures

Countermovement Vertical Jump. The VJ was performed on a jump mat (Just Jump, Probiotics Inc., Huntsville, AL), which measures jump height based on flight time. The timing mat system consisted of a contact mat connected by a cable to a digital timer. The timer, which measured flight time, was triggered when the participant's feet left the mat and stopped when they made contact with the mat. This method of calculation assumed that the takeoff and landing positions were on the mat. To control for a learning effect of technique, participants were given a training session with feedback on jump technique during the initial testing and familiarization session. The participant stood in the middle of the mat with feet shoulder width apart, and performed a VJ (i.e. starting standing upright, bend knees and then jump off the mat as high as possible using full arm swing). The participant was encouraged to jump for maximum height and to stay centered over the jump mat. In the experimental sessions, three repetitions were attempted before and after WU, and at 10 minute intervals during the inactivity phase; no feedback was given, and the best of the three jumps was used for results analysis.

Wingate Anaerobic Test (WAnT). The 45-second WAnT was an all-out cycle effort performed on a mechanically braked cycle ergometer (Ergomedic 894E, Monark Exercise AB, Varberg, Sweden). The test objective was to complete as many revolutions as possible at the given workload without pacing. The number of revolutions of the flywheel was recorded per 5-second interval; these data were integrated with the calculated workload and analyzed through Monark Anaerobic Test Software Version 2.2 (Monark Exercise AB, Varberg, Sweden). The workload placed on the weight basket was individualized for each participant at 0.8kg/kg body weight (Bar-Or, 1987). Peak power was the highest mechanical power elicited from the test taken as the average power over any 5 seconds (5sPP), mean power was the average power maintained over the 45 second test (Avg45sPP), and fatigue index was the amount of the decline in power during the test expressed as a percentage of peak power. Fatigue index was calculated using the following equation:

$$\text{Fatigue Index (\%)} = \frac{(\textbf{\textit{Peak Power Output}} - \textbf{\textit{Minimum Power Output}})}{\textbf{\textit{Peak Power Output}}} \text{x}100.$$

Seat and handlebar height were adjusted, recorded, and repeated for each participant, and feet secured with toe clips and straps. When ready to begin the test, the participant was given a 1-minute lead in, where the participant had to maintain a pedaling cadence of 60 rpm; there was no resistance on the flywheel during this time. The test administrator gave a 10 second warning and then counted down into the test "3, 2, 1, GO"; at "GO" the tester simultaneously manually dropped the weight basket. The participant cycled all-out as fast as possible for 45s with verbal encouragement from the principal investigator. During the test the participant was informed when they had 15 seconds remaining in the test, 5 seconds remaining in the test, and were counted down to the end of the test from 3 seconds. At the end of the test, the principal investigator immediately re-set the weight basket to remove the resistance from the flywheel so the participant could spin easily and recover.

2.7 Psychophysical Variables

Every 5 minutes, participants were asked to give a subjective score of overall thermal comfort (TC) and thermal sensation (TS) based on a 1-5 point scale and 0-9 point scale, respectively (Gagge, Stolwijk, & Hardy, 1967). See Appendix F for TC and TS scales.

2.8 Statistical Analysis

Temperature, performance variables and psychophysical variables (T_c, T_m, T_{sk}, VJ, TC, and TS) were analyzed using 2-way repeated measures ANOVA (condition x time) using SPSS IBM Statistics 20 software for windows. These analyses were run separately for the WU and post-WU phases to better examine the results over time and between conditions while considering the slight variation in HP during WU (pants, no passive heating) and post-WU (passive heating turned on) compared to CON (shorts). *Post-hoc* paired-sample t-tests and Bonferroni corrections were used where significant effects were found. Paired sample t-tests were used to compare WAnT scores (5s Peak Power, Average 45s Peak Power, and Fatigue Index). Type I error was protected at 5% ($p<0.05$). Boxplots for outliers, Shapiro-wilks for normality and Mauchly's test of sphericity were used to test for assumptions of normally distributed data. Rare outliers and violations of normality were considered and corrected where necessary.

In addition to standard testing using repeated measures ANOVAs, performance data (VJ and WAnT) were analyzed using Hopkins' approach for reporting statistical findings which combines information on the magnitude of the estimate of the effect, the degree of imprecision about that effect, and the smallest difference that has a real world (clinical) meaning (Hopkins, 2000). Data analysis was run after entering the raw values in Will Hopkins' spreadsheets for pre-post crossover (VJ) and post-only crossover effects (VJ and WAnT) for HP and CON (Hopkins, 2006). Threshold %improvement was set at 3% for VJ based on a 1.5% change (relevant improvement for athletes) multiplied by the coefficient of variation (CV) of the VJ test (2.0) (Hopkins, Schabort, & Hawley, 2001). Since the test-retest variation in 30-90s WAnT tests is between 0.8 and 2.0CV, the set threshold for % improvement in the 45s WAnT test was defined at 1.5%. This technique is especially appropriate for applied sport physiology, as a clinical effect can result in a meaningful performance enhancement in elite populations. Although there is greater variance around performance variables of recreational athletes compared to elite athletes, this method is still relevant for analysis of results using levels of confidence and taking into consideration the physical descriptor measures of the participants.

3. Results

3.1 Subject Characteristics

Sixteen males volunteered to participate in the study. Two participants completed only the initial testing session: one did not meet the relative $V0_{2peak}$ minimum score of 50.0mL·kg^{-1}·min^{-1}, and one felt nauseous and numbness following the T_m thermistor insertion on the first experimental session; this participant voluntarily withdrew from the remainder of the study. Fourteen volunteers therefore completed all three sessions, but one was non-compliant to the training control guidelines and was dropped from consideration for analysis. Of the remaining thirteen, five participants did not meet the inclusive criterion for data analysis: T_m maintenance within 1˚C of post- WU temperature. This inclusion criterion was established due to technical difficulties encountered with the heated garment itself. See section 4.3: Sources of Error/Reasons for Inability to Maintain T_m for further discussion. Therefore, only the mean data of eight participants' T_m responses and performance measures were analyzed (n=8). Mean descriptive data of participants including anthropometric and VO_{2peak} data can be seen in Table 1. For raw scores of key variables of included participants (n=8), see Appendix G. For raw scores of key variables of excluded participants (n=5), see Appendix H.

Table 1

Physical Characteristics of Participants (n=8)

	Age (yrs)	Height (m)	Weight (kg)	Thigh girth (mm)	BMI (kg·m^2)	Sum of 8 (mm)	Calc. fat (%)	Relative $V0_{2peak}$ (mL·kg^{-1}·min^{-1})
Mean	29	1.843	80.05	55.2	23.6	77.8	12.2	58.0
SD	5	0.061	8.34	4.1	2.4	20.3	3.1	6.3

BMI = Body Mass Index

Calc. fat = % Body Fat calculated using Yuhasz regression equation

3.2 Temperature Variables

Muscle Temperature. There was no difference in Tm between experimental conditions CON and HP at the end of baseline, during WU, or at the end of WU. T_m increased steadily during the 15 minute active WU by 3.6°C and 3.9°C for HP (heat turned off during WU) and

CON, respectively. T_m was significantly higher in both conditions following 5-, 10-, and 15-minutes of WU compared to baseline ($p<0.001$).

Overall T_m post-WU showed a significant effect of condition ($p=0.001$), time ($p=0.010$), and condition*time interaction ($p=0.036$). As shown in Figure 3, T_m declined in CON by 2.9(±0.4)°C, and was significantly lower at every 5-minute measurement of inactivity compared to end-WU ($p<0.01$). In contrast, T_m was maintained for 20 minutes, with a mean decline of 0.2°C, but was lower at 25- and 30-minutes post-WU compared to end-WU values ($p<0.01$). Overall, T_m fell 0.6(±0.4)°C in HP, a maintenance of 2.3°C compared to CON at 30 minutes post-WU. T_m trends and effects can be seen in Figure 3.

Core Temperature. T_c fluctuated minimally within each condition, with a minimum-maximum range of 36.76(±0.52)-37.13(±0.50)°C for HP, and 36.35(±1.33)-36.74(±0.56)°C for CON (see Figure 4). There was no difference in T_c between conditions, and no interaction effect was seen during WU or post-WU. There was an effect of time post-WU ($p=0.003$), with T_c being warmer at 10- ($p=0.049$) and 15-minutes ($p=0.001$) into WU compared to end-baseline. Post-Wu there was also an effect of time ($p=0.029$); T_c was cooler 30-min post-WU compared to end-WU ($p=0.016$). T_c trends and effects can be seen in Figure 4.

Skin Temperature. Prior to WU, T_{sk} was lower in CON at 26.39±(1.01)°C than HP (heat turned off during baseline and WU) at 29.97(±0.79)°C ($p<0.001$). As seen in Figure 5, both CON and HP T_{sk} declined in the first 5 minutes of WU before increasing to 25.03(±1.36)°C and 31.85(±1.36)°C, respectively. WU had a time effect on T_{sk} following 5-, 10-, and 15-min of cycling in both CON ($p<0.001$, $p=0.004$, $p=0.041$) and HP ($p=0.003$, $p=0.002$, $p<0.001$). HP remained significantly higher than CON at each 5-min interval throughout the WU ($p<0.001$).

T_{sk} remained higher compared to end-WU at all 5-minute intervals throughout the inactivity phase in both CON and HP ($p<0.001$). T_{sk} increased to a maximum of 27.45(±1.41)°C at 10 minutes, then steadily fell to 26.62(±0.90)°C in CON. With the application of passive heat to the legs immediately following WU, T_{sk} increased by 2.76°C after 5min, and was 3.22-4.10°C above end-WU value for the remainder of the inactivity phase following warm up, with a maximum value of 35.95(±1.55)°C. T_{sk} remained elevated in both CON and HP compared to end-WU for the duration of the inactivity phase ($p<01$). T_{sk} trends and effects can be seen in Figure 5.

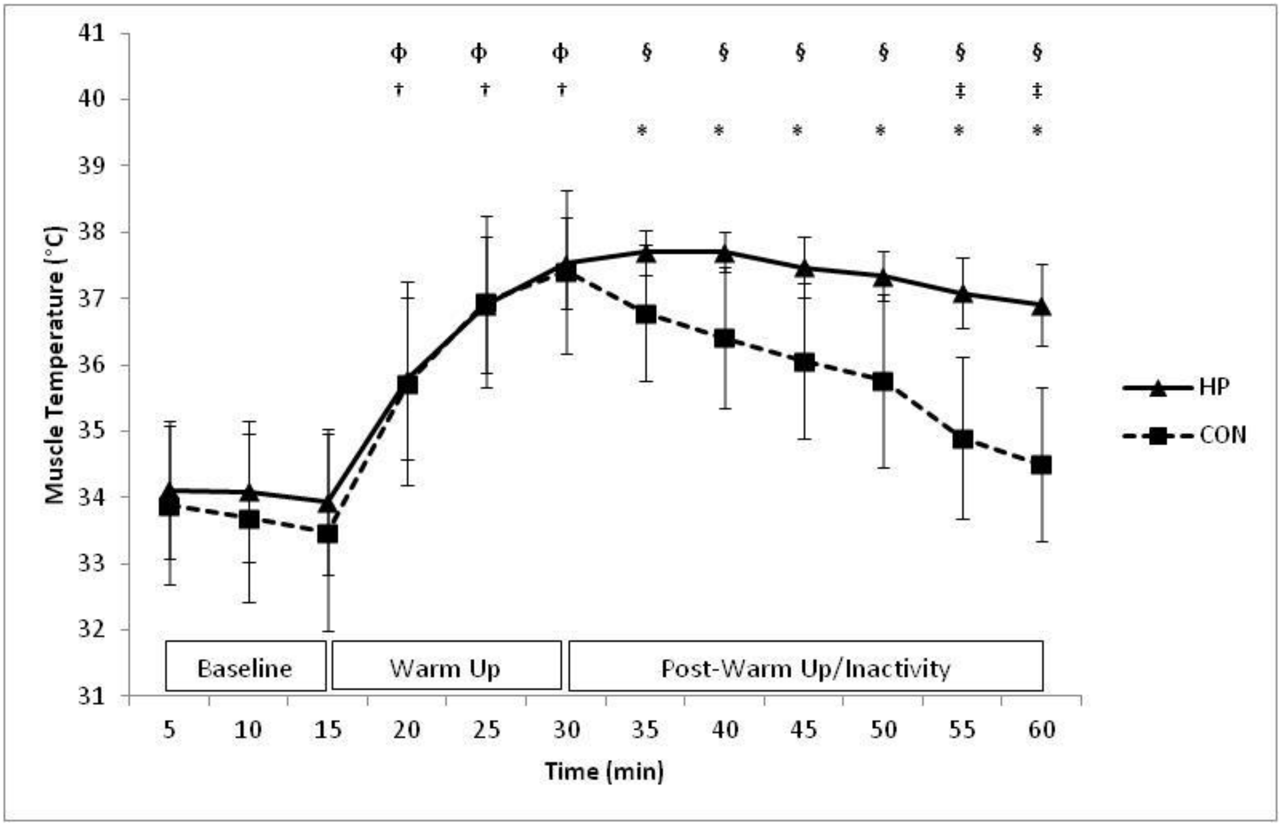

Figure 3. Muscle temperature (T_m) of 8 participants during a 15 minute seated baseline, 15 minute standardized active warm up (WU) on a cycle ergometer, and 30 minute inactivity phase following WU in an environmentally controlled chamber (9.77°C, 71.41% RH) in response to two experimental conditions: heated pants (HP, ▲) and control (CON, ■).

Φ indicates a significant time difference in T_m compared to end-baseline for CON only ($p<0.05$).

† indicates a significant time difference in T_m compared to end-baseline for HP only ($p<0.05$).

§ indicates a significant time difference in T_m compared to end-WU for CON only ($p<0.05$).

‡ indicates a significant time difference in T_m compared to end-WU for HP only ($p<0.05$).

* indicates a significant difference in T_m between HP and CON ($p<0.05$).

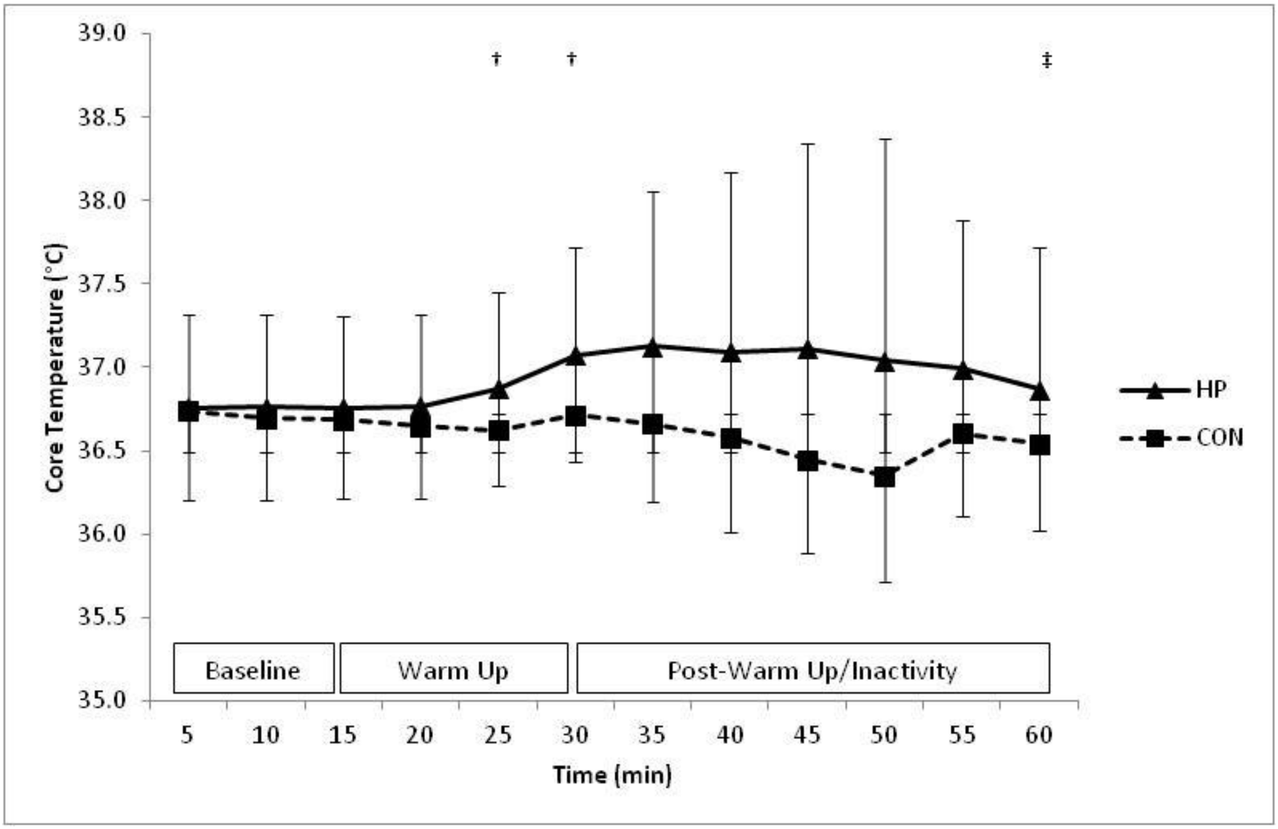

Figure 4. Core temperature (T_c) of 8 participants during a 15 minute seated baseline, 15 minute standardized active warm up (WU) on a cycle ergometer, and 30 minute inactivity phase following WU in an environmentally controlled chamber (9.77°C, 71.41% RH) in response to two experimental conditions: heated pants (HP, ▲) and control (CON, ■).

† indicates a significant time difference in T_c compared to end-baseline for HP only ($p<0.05$).

‡ indicates a significant time difference in T_c compared to end-WU for HP only ($p<0.05$).

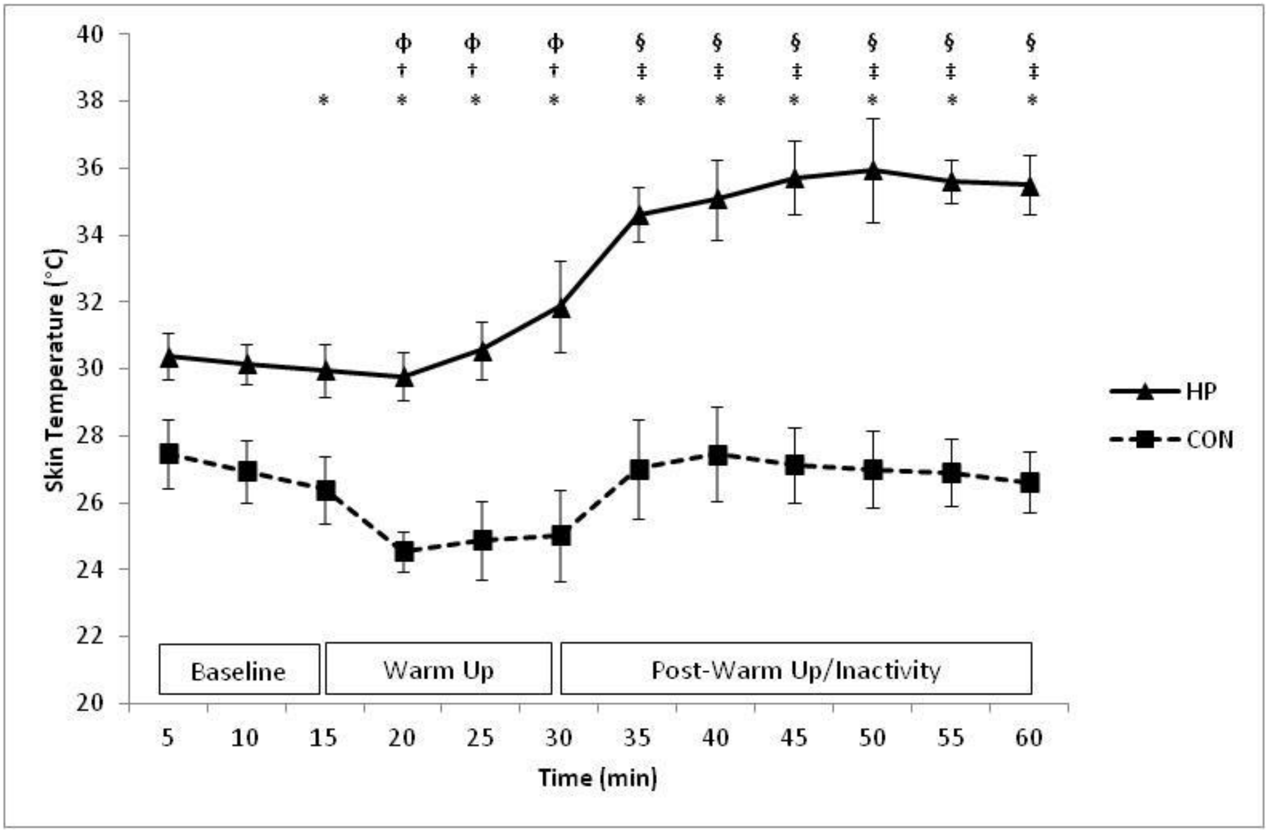

Figure 5. Thigh skin temperature (T_{sk}) of 8 participants during a 15 minute seated baseline, 15 minute standardized active warm up (WU) on a cycle ergometer, and 30 minute inactivity phase following WU in an environmentally controlled chamber (9.77°C, 71.41% RH) in response to two experimental conditions: heated pants (HP, ▲) and control (CON, ■).

Φ indicates a significant time difference in T_{sk} compared to end-baseline for CON only ($p<0.05$).

† indicates a significant time difference in T_{sk} compared to end-baseline for HP only ($p<0.05$).

§ indicates a significant time difference in T_{sk} compared to end-WU for CON only ($p<0.05$).

‡ indicates a significant time difference in T_{sk} compared to end-WU for HP only ($p<0.05$).

* indicates a significant difference in T_{sk} between HP and CON ($p<0.05$).

3.3 Performance Variables

Countermovement Vertical Jump. VJ performance was analyzed using a percent change from baseline calculation to enable comparison of relative values of jump height between individuals. End-baseline values are therefore presented as 100. There was a significant improvement in VJ performance after 15 minutes of cycling (WU), with a mean increase of 16(±4)% in HP ($p<0.001$), and 18(±6%) in CON ($p<0.001$), but no significant difference between conditions (see Figure 6).

Following WU, there was an overall effect of time ($p=0.001$), but no difference between conditions. VJ performance declined in both CON and HP following 10- and 20-minutes of inactivity compared to WU ($p<0.01$) (see Figure 6). Between 20 and 30 minutes of inactivity, VJ performance was maintained in HP but continued to decline in CON; both VJ performance values at 30 minutes were lower than end-WU ($p<0.001$).

Applied statistical analysis for elite populations. A 3% set threshold improvement based on the maintenance of VJ performance at the end of 30 minutes of inactivity compared to immediately post-WU in CON and HP yielded the following results: using HP was possible (26%) to have a substantially positive effect, possible (72%) to have a trivial effect, and very unlikely (2%) to have a substantially positive negative effect on VJ performance compared to CON.

Wingate Anaerobic Test. Absolute 5-second Peak Power (5sPP, W), 45-second average Peak Power (45sPP, W), and Fatigue Index (%) were higher in the HP condition than the CON condition by a mean of 1.3%, 1.7%, and 0.2%, respectively. The difference in 5sPP was significant ($p<0.05$). See Figure 7 for WAnT comparisons and differences.

Applied statistical analysis for elite populations. Based on a set 1.5% improvement for applied sport, the HP intervention is very likely (92%) to have a trivial (40%) or substantially positive (52%) effect on 5s peak power performance, almost certain (100%) to have a trivial (41%) or substantially positive effect (59%) on 45s anaerobic capacity, and possible (71%) to have a trivial (42%) or substantially positive (29%) effect on fatigue index compared to CON (Hopkins, 2006).

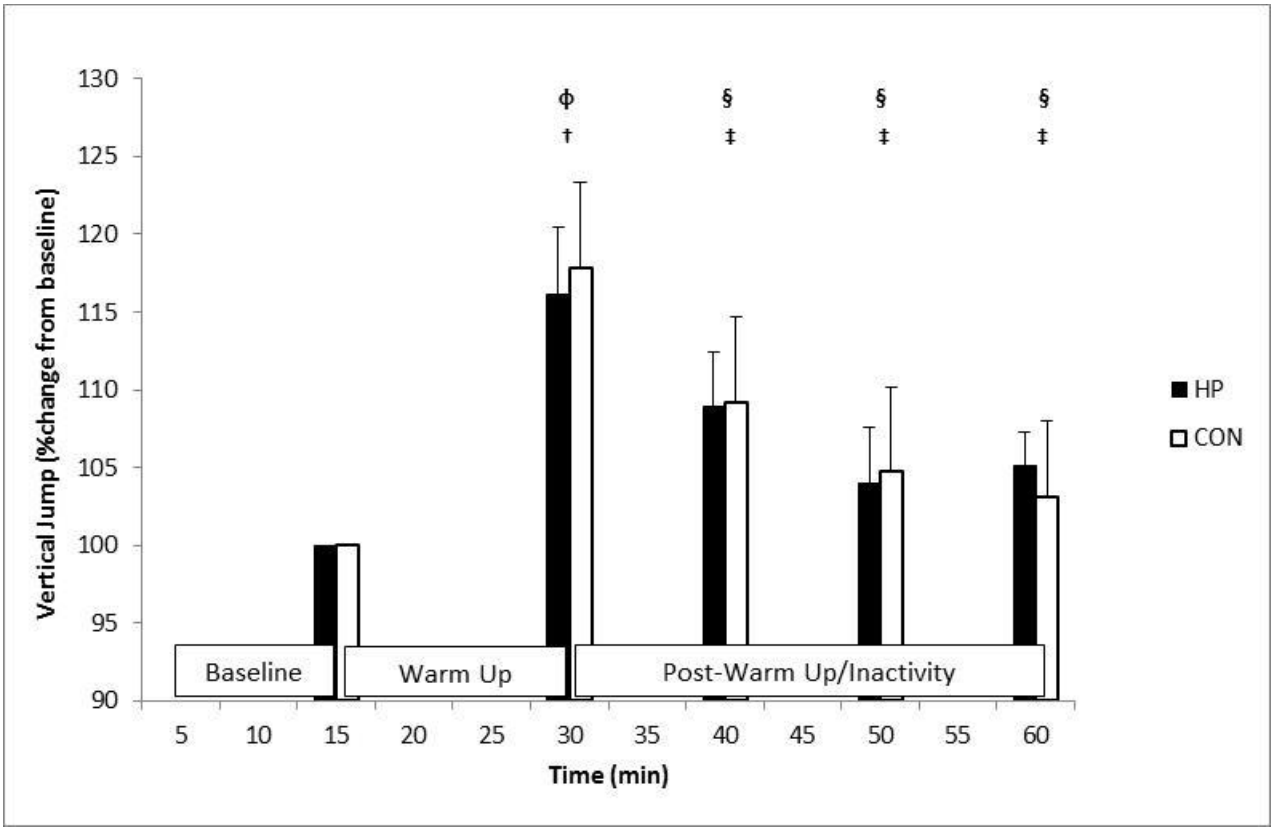

Figure 6. Countermovement vertical jump performance (presented as %change from baseline) of 8 participants during a 15 minute seated baseline, 15 minute standardized active warm up (WU) on a cycle ergometer, and 30 minute inactivity phase following WU in an environmentally controlled chamber (9.77°C, 71.41% RH) in response to two experimental conditions: heated pants (HP, ■) and control (CON, □).

Φ indicates a significant time difference in VJ performance compared to end-baseline for CON only ($p<0.05$).

† indicates a significant time difference in VJ performance compared to end-baseline for HP only ($p<0.05$).

§ indicates a significant time difference in VJ performance compared to end-WU for CON only ($p<0.05$).

‡ indicates a significant time difference in VJ performance compared to end-WU for HP only ($p<0.05$).

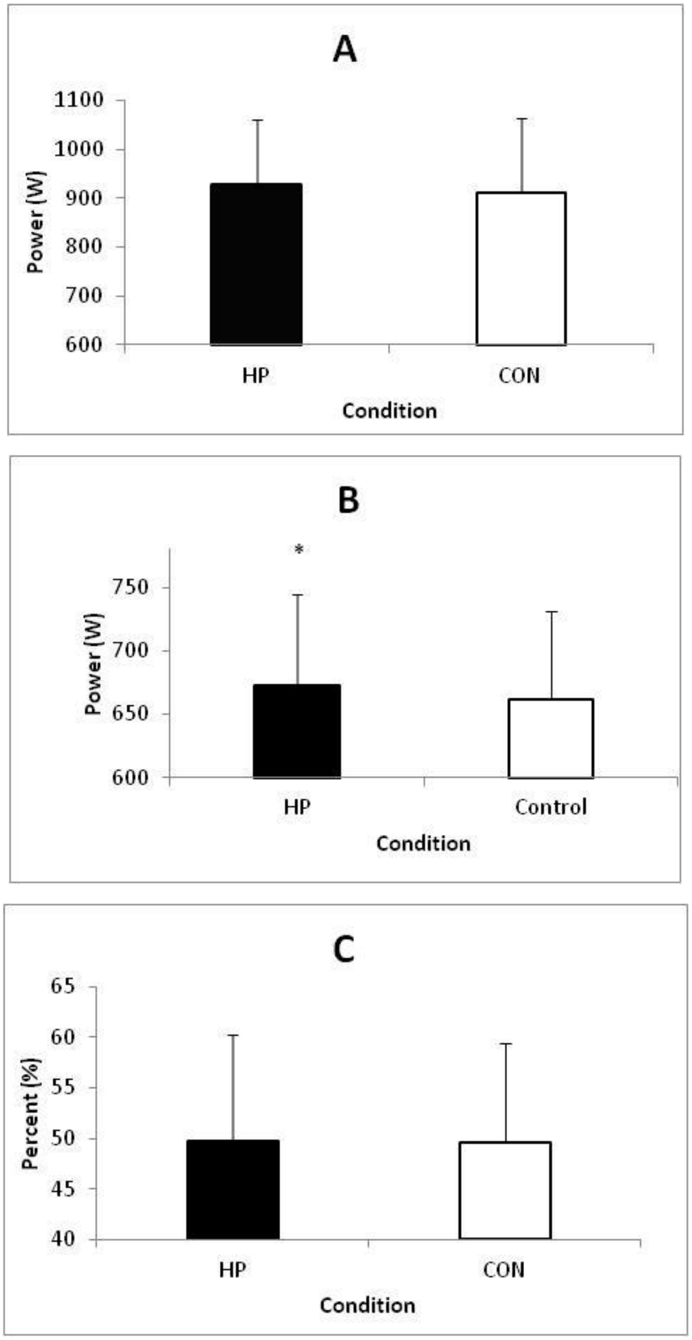

Figure 7. A) 5-second peak power (5sPP), B) average 45-second power (45sPP), and C) fatigue index measures of a 45s maximal sprint cycling performance following 30-minutes inactivity post-warm up in two conditions: heated pants (HP, ■) and control (CON, □) in an environmentally controlled chamber (9.77°C, 71.41% RH).

* indicates a significant difference between HP and CON ($p<0.05$).

3.4 Psychophysical Variables

Thermal comfort. As seen in Figure 8, TC scores remained relatively stable through the experimental session. Overall, participants reported scores between 1 and 1.5 during HP, and between 1.5 and 2 during CON, where 1 is “comfortable” and 2 is “slightly uncomfortable”. No differences in TC were seen with time or between HP and CON before, during, or at the end of WU.

In the 30 minutes following WU, there was an effect of condition ($p=0.010$) but no effect of time on TC. TC was higher with HP at 20- and 30-minutes of inactivity compared to CON ($p<0.05$).

TC and TS were similar in both conditions at the end of WU, with participants reporting feeling “slightly warm” and between “comfortable” and “slightly uncomfortable” at the end of WU. Following 30 minutes of inactivity post-WU, CON participants overall reported feeling “cool” and “slightly uncomfortable”; HP participants reported feeling “neutral” and “comfortable”.

Thermal sensation. Participants reported feeling “cool” at end- baseline in CON and “slightly cool” at end-baseline in HP; participants in both conditions reported feeling “slightly warm” at the end of WU. As seen in Figure 9, TS had an overall time effect during WU, but there was no differences between conditions. TS was higher in CON after 5-, 10- and 15-minutes of WU compared to baseline ($p<0.01$). TS was higher in HP after 10- and 15-minutes of WU compared to baseline ($p<0.01$).

Participants remained “slightly warm” for 5 minutes in CON before falling to “slightly cool” after 10 minutes of inactivity, and remaining between “slightly cool” and “cool” for the final 20 minutes of inactivity. With HP, participant remained feeling “slightly warm” following 10 minutes of inactivity, and “neutral” for the remaining 20 minutes of inactivity. TS remained higher in CON compared to baseline throughout the inactivity phased following WU ($p<0.05$). There was no difference between conditions at the end of WU, but TS was higher than CON at 10-, 15-, 20-, 25-, and 30-minute of inactivity compared to end-WU ($p<0.05$). TS trends and effects can be seen in Figure 9.

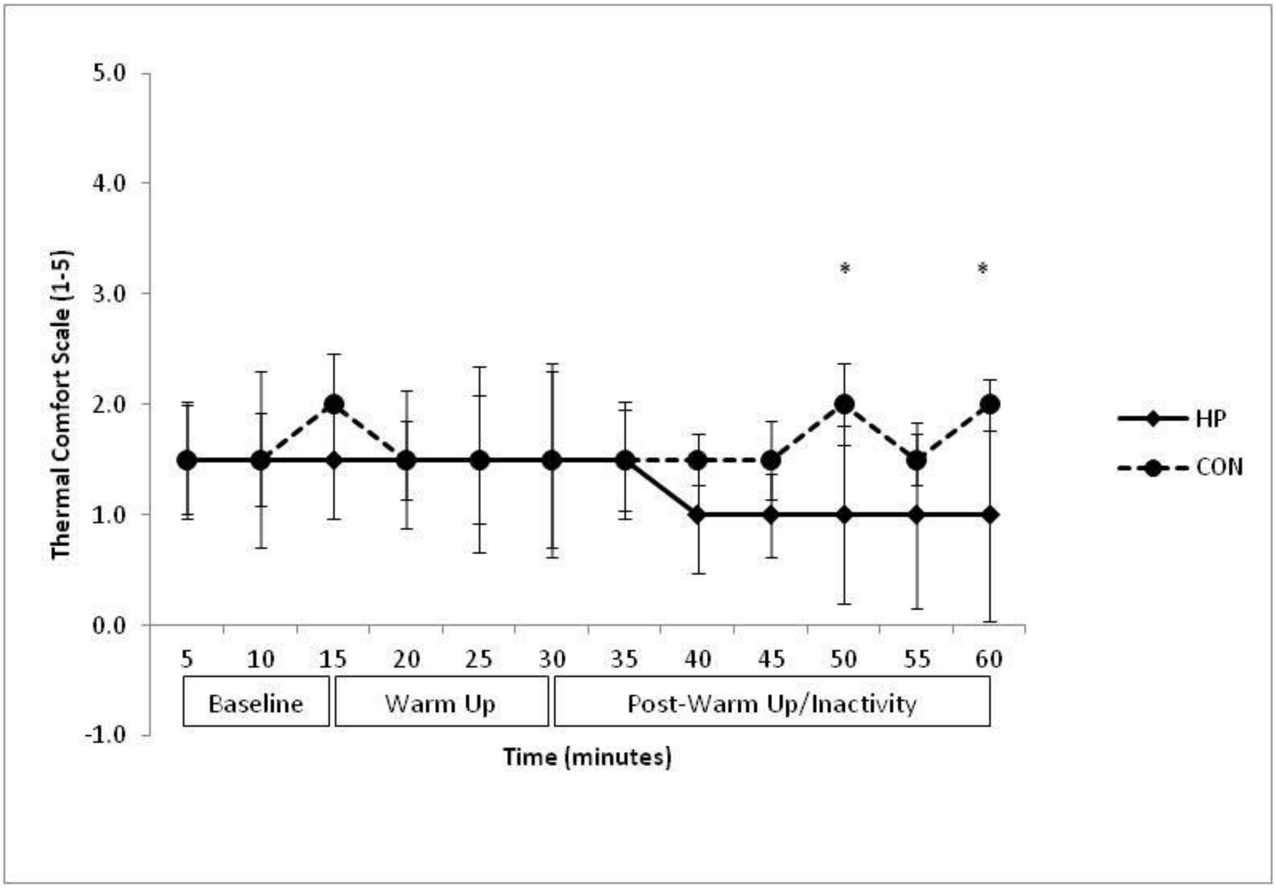

Figure 8. Psychophysical variable thermal comfort (TC) based on a 1-5 point scale during a 15 minute baseline, 15 minute standardized active warm up on a cycle ergometer, and 30 minute inactivity phase in an environmentally controlled chamber (9.77°C, 71.41% RH) in response to two experimental conditions: heated pants (HP, ♦) and control (CON, ●).

* indicates a significant difference in TC between HP and CON ($p<0.05$).

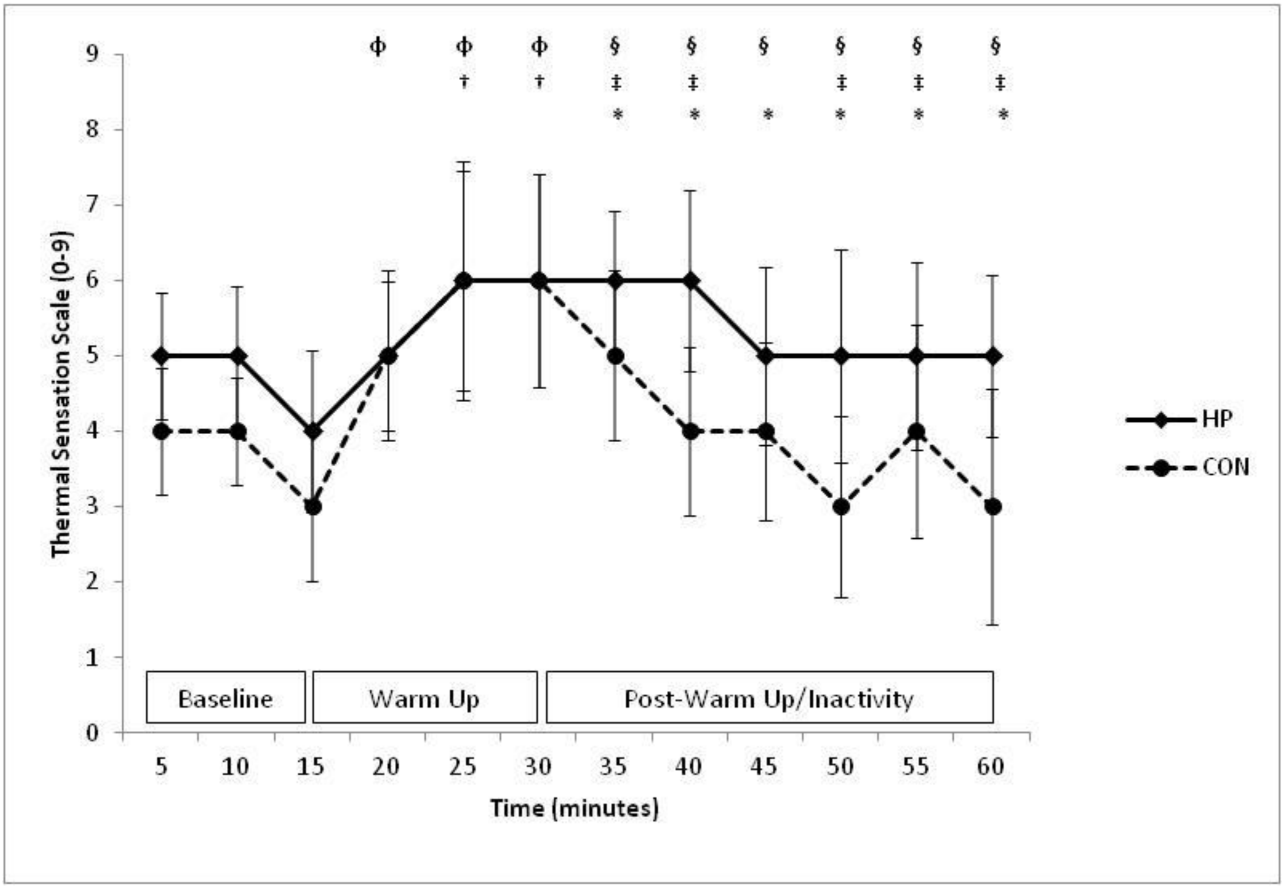

Figure 9. Psychophysical variable thermal sensation (TS) based on a 0-9 point scale during a 15 minute baseline, 15 minute standardized active warm up on a cycle ergometer, and 30 minute inactivity phase in an environmentally controlled chamber (9.77°C, 71.41% RH) in response to two experimental conditions: heated pants (HP, ♦) and control (CON, ●).

Φ indicates a significant time difference in TS compared to end-baseline for CON only ($p<0.05$).

† indicates a significant time difference in TS compared to end-baseline for HP only ($p<0.05$).

§ indicates a significant time difference in TS compared to end-WU for CON only ($p<0.05$).

‡ indicates a significant time difference in TS compared to end-WU for HP only ($p<0.05$).

* indicates a significant difference in TS between HP and CON ($p<0.05$).

4. Discussion

The purpose of the proposed research study was to investigate time course changes of T_m following WU in cool (10˚C) environments and to measure the effect of passive heating on T_m and performance. Pre- and post-WU T_m (see Figure 3) and VJ performance (see Figure 6) results were the same between conditions (HP, heat turned off during WU, and CON, $p>0.05$). A 15 min standardized aerobic WU performed at 70% HR_{peak} was sufficient to increase T_m in both experimental conditions by an average 3.8˚C and improve VJ by 17% compared to baseline ($p<0.001$). Compared to end-WU, T_m declined throughout the 30min inactivity period to a final difference of 3°C during CON; T_m was significantly lower at every 5-minute measurement of inactivity compared to end-WU ($p<0.01$).Conversely, HP maintained T_m for 20 minutes post-WU with a mean decline of 0.2°C before T_m fell below end-WU values at 25- and 30-minutes ($p<0.01$) to a mean decline of 0.6°C from end-WU. Moreover, HP resulted in elevated T_m compared to CON throughout the post-WU inactivity phase ($p<0.05$, see Figure 3); T_m was 2.3°C higher at 30minutes post-WU when HP was applied. VJ declined from end-WU in both conditions. No differences were seen in VJ performance between HP and CON, but maintenance in T_m during HP was associated with a higher VJ at 30-minutes post-WU compared to CON. Average 45s power was higher in HP than CON as assessed by a 45s WAnT performed following 30 minutes of inactivity post-WU ($p<0.05$, see Figure 7).

4.1 Effect of WU

Previous research has demonstrated that a proper WU of sufficient length and intensity is needed to increase T_m and consequent muscle performance (Stewart & Sleivert, 1998). Despite common acceptance that proper WU prior to competition is beneficial (Fradkin et al., 2010; Gray, De Vito, Nimmo, Farina, & Ferguson, 2006; Racinais, Blonc, & Hue, 2005), many athletes are still not implementing an adequate WU before training or competition (Cook, Holdcroft, Drawer, & Kilduff, 2013; Sporer, Cote, & Sleivert, 2012). This may be due to poor timing, insufficient intensity or duration, or a prolonged recovery period following WU resulting from a number of factors including environmental conditions, delays, sport culture, and athletes' inability to self-determine an adequate WU protocol (Sporer et al., 2012; Zochowski et al., 2007). As seen in Figure 10, there was no difference in T_m or jump height between conditions at the end of resting baseline or at the end of WU. However, a 15 minute standardized aerobic WU on a cycle ergometer at 70% HR_{peak} was of sufficient duration and intensity to increase T_m and muscle performance, as measured by VJ, in both HP and CON. These results are not surprising knowing that T_m is directly related to contraction properties and power (Bennett & Albert, 1985; Racinais & Oksa, 2010). The WU routine used was in accordance with recommended guidelines for duration and intensity prior to short-term activity (Bishop, 2003b; Stewart & Sleivert, 1998). Stewart and Sleivert found that a task-specific 15-minute WU performed at 60-70% VO_{2max} increased HR, body temperature, ankle dorsiflexion and knee extension and resulted in higher anaerobic capacity during a maximal run to exhaustion. In the present study, a 15-minute standardized WU performed at 70%HR_{peak} with ~2min post-WU recovery period resulted in a T_m increase of 3.6°C during HP (heat turned off during WU) which was associated with a 16% increase in VJ, and an increase of 3.9°C during CON which was associated with an 18% increase in VJ (refer to Table 2 for an overview of T_m and VJ changes with WU). Dixon et al. (2010) found that a 15 minute dynamic WU was effective in both offsetting the negative effects of cold exposure (12°C lower body water immersion for 45 minutes) and improving lower body power compared to baseline in ambient conditions ($p<0.05$). Gray et al. (2006) found similar improvements in muscle performance during a 6-second maximal sprint when both warm water immersion and electrical heating were used to elevate T_m above resting baseline at room temperature; a 3.3°C elevated T_m resulted in increased muscle fiber conduction velocity, maximal power output, and pedal rate compared to baseline ($p<0.05$). In 2001, Church, Wiggins, Moode and Christ found that VJ performance in 40 NCAA Division 1 female athletes improved significantly following a general 5 minute WU incorporating intermittent 10-s exercises.

As shown in Figure 4, T_c fluctuated within a narrow and normal range throughout both experimental sessions. As expected, there was a general increase in T_c following WU in both conditions, with T_c showing a greater increase during HP (heat turned off during WU) than during CON (0.32°C and 0.02°C, respectively). The benefit of increased body temperature following exercise on subsequent performance has been well documented (Assmussen & Bøje, 1945; Bergh & Ekblom, 1979; de Bruyn-Prevost & Lefebvre, 1980; Stewart & Sleivert, 1998). However, it is difficult to assess the effect of WU on T_c without considering its role on local muscle warming; consequently, T_c alone seems to be a poor indicator of muscle temperature and readiness prior to performance. The change in T_c in both HP and CON would not be considered significant from a practical perspective in that it likely has no real effect on performance and is well within expected daily fluctuations. In conclusion, a well-structured WU needs to consider optimal timing, intensity, duration, and recovery for the specific activity, environment, and schedule of the athlete or team to generate important temperature- and non-temperature related benefits to performance (Bishop, 2003b; Cook et al., 2013; Sporer et al., 2012; Zochowski et al., 2007).

T_{sk} showed the greatest fluctuation throughout the experimental sessions; this is not surprising as it is the most superficial measure and therefore the most influenced by environmental conditions. T_{sk} outside of its “normal” range (~33-35°C) leads to initiation of heat loss or heat retention thermoregulatory mechanisms (Mekjavic & Eiken, 2006). Participants wore only shorts during CON and therefore heat was easily lost to the environment, even as muscle and core temperatures increased during active WU. In addition to superficial skin temperature and circulation cooling from environmental stimulus, T_{sk} has been shown to decrease temporarily at the onset of exercise as blood flow to muscle increases (vasodilation) and therefore blood flow to skin decreases (vasoconstriction) (J. M. Johnson & Rowell, 1975; J. M. Johnson, 2010). As seen in Figure 5, both CON and HP T_{sk} declined in the first 5 minutes of WU before increasing to 25.03(±1.36)°C and 31.85(±1.36)°C, respectively. However, as T_m increased above T_c between 5 and 10 minutes of WU, the heat distribution pattern changed likely due to heat loss responses activated in the hypothalamus to accommodate the body’s need to dissipate heat from the core to the periphery. Therefore, the increase in T_{sk} values from end-baseline at 10 and 15 minutes of WU were likely due to vasodilation in skin blood vessels. These trends suggest that the body’s convective cooling system was facilitated in CON (shorts only) but hindered in HP (pants covering the legs), contributing to lower and higher T_{sk}, respectively. Figure 10 shows a summary of all temperature and VJ variables over the 60 minute experimental sessions.

Participants did not report any significant differences in TC or TS between conditions during the WU. Although participants in CON started to feel “slightly uncomfortable” at the end of baseline, mean values returned to “comfortable” after 5 minutes of cycling and remained “comfortable” to the end of the WU (see Figure 8). During steady state exercise, Gagge, Stolwijk and Saltin (1969) concluded that TC was primarily governed by thermoregulatory effector mechanisms (sweating and skin blood flow), and that participants remained “comfortable” when skin sweat was zero or low. In the present study, participants perceived WU, overall, as "comfortable"; however, rating variability was higher at the end of WU when participants were sweating most. Some participants reported feeling "uncomfortably warm" with the onset and maintenance of sweating, whereas others rated themselves as "comfortable" while sweating. This response was likely influenced by the compensation of WU offsetting the feeling of "slight discomfort" after sitting in ~10°C for 15 minutes prior to WU (baseline). TS showed a mean increase from "slightly cool" (HP) and "cool" (CON) to "slightly warm" at 10 and 15 minutes of the WU compared to end-baseline (Figure 9). Gagge et al. (1969) found that participants' ratings of TS during steady state exercise were governed by sensory mechanisms in the skin based on T_{sk} and air temperature, and that TS was more sensitive to ambient temperature than to work level. In the present study TS responses did seem to correspond to T_{sk} trends but also responded to work rate as T_m and T_{sk} increased throughout WU at the set 70%HR_{peak} intensity. However, since no significant differences were seen in TC and TS perceptions between pre- and post-WU, but mean performance (VJ height) improved following WU, it is important to note that perceptions of TC and TS should not be relied on as feedback for athletes to judge their physiological preparedness for improved performance.

4.2 Time Course of Changes in T_m Following WU

During CON, T_m declined continually from a post-WU value of 37.4(±1.2)℃. T_m fell 1.0℃, 1.6℃, and 2.9℃ following 10-, 20-, and 30-minutes of inactivity post-WU, respectively. Similarly, Kenny et al. (2003) found that post-exercise (15 minutes of isotonic knee extensions at 22℃ room temperature) T_m (38.23℃) decreased continuously during 30 minutes of recovery; however, decay rate dropped for the remaining 30 minutes of a 60-minute recovery period. Final T_m was 1.32℃ lower than post-exercise, which meant that T_m remained significantly higher compared to baseline (by 1.05℃). In the current study, final T_m following 30 minutes of inactivity remained 1.0℃ above baseline. Kenny et al. (2003) further concluded that non-evaporative heat-loss and T_{sk} were affected by elevated T_m of the lower limbs through muscle to periphery heat flow; therefore, the lower limbs were less effective at dissipating heat than the upper less active limbs. In hot conditions (29℃, 50%RH), it was similarly suggested that a sustained elevation in post-exercise esophageal (core) temperature was defined by the core-to-periphery heat gradient and resulted from convective transfer of residual heat from previously active muscles (Thoden, Kenny, Reardon, Jetté, & Livingstone, 1994). However, cold temperatures will substantially affect skin, muscle, and eventually core heat loss post-exercise as warm blood circulating to cool at the skin-environment interface quickly cools. Since cooling has been repeatedly shown to decrease muscle strength and power in the literature (Comeau, Potteiger, & Brown, 2003; Dixon et al., 2010; Racinais, Blonc, Oksa, & Hue, 2009), it follows that rapid cooling of muscles post-exercise will negatively affect subsequent short-term performance. Excessive post-WU recovery time even in ambient conditions (indoor pool) has also been shown to decrement subsequent performance (Zochowski et al., 2007). Intermittent and dynamic WU protocols in cold (below freezing) temperatures followed by time delays prior to performance have resulted in an accumulated drop in performance (Cook et al., 2013; Faulkner et al., 2013; Sporer et al., 2008). Cook et al. found that athletes were unwilling to adopt certain WU routines even though they resulted in the best performance results; it was therefore concluded that practicality and willingness to comply with the WU routine in the competitive environment are important aspects of WU design.

4.2 Effect of Passive Heating

HP applied to the legs following WU maintained T_m for 20 minutes following WU; a decline in T_m was not seen until 25- and 30-minutes post-WU. Even though a drop in T_m was seen in the final 10 minutes of the inactivity phase, T_m remained significantly higher (~2˚C) than CON (Figure 3). As seen in Table 2 and Figure 7, results from the 45-second WAnT showed a higher (1.7%) average power output following 30 minutes of inactivity with HP compared to CON ($p<0.05$). Faulkner et al. (2013) similarly showed that an internally heated insulated garment was able to maintain T_m 1˚C higher than with insulated pants alone over a 30 minute passive recovery period following WU; this T_m maintenance was associated with a ~9% higher peak power output during a 30s maximal sprint test. The current study found no difference in peak power output whereas Faulkner et al. (2013) found no difference in average power output. Although this makes it difficult to directly compare results, both studies found a significant improvement in power performance when T_m was maintained with passive heating. These findings are consistent with the literature as increased T_m has been shown to improve contraction velocity, rate of force development, and decrease co-contraction thereby increasing efficiency (Oksa, Rintamaki, Makinen, Hassi, & Rusko, 1995; Sargeant, 1987). The greater magnitude of performance improvement in the study by Faulkner et al. may be due to a more elite sample population (competitive cyclists and triathletes), warmer environmental testing conditions

(~16˚C), and/or a higher external heat load by the garment itself (heating element capable of reaching ~40-42˚C); these factors likely facilitated the effective heat transfer of the heated garment to the muscle. Indeed, T_m following 30 minutes of inactivity prior to sprint cycling performance was ~37.5˚C, ~0.5˚C higher than in the current study. The 45s WAnT test in the current study was used to test anaerobic sprint performance while considering slightly longer events that include an aerobic energy contribution. The coefficient of variation of the 30s WAnT test is slightly greater especially when performed by elite athletes compared to recreational athletes; these factors may have also played a role in the discrepancies in the magnitude of performance improvement between the two studies. Even so, the improvement in 45sPP output seen suggests that HP applied following WU to maintain T_m may enhance longer anaerobic performances that include a secondary reliance on aerobic power.

The current study found no significant differences in VJ performance, mean anaerobic capacity, and anaerobic fatigue associated with T_m maintenance (see section 4.3 for further discussion). However, all WAnT measures showed higher mean values during HP compared to CON. Although VJ performance declined during both HP and CON from end-WU (Table 2, Figure 10), HP resulted in a 5% maintenance and CON resulted in a 3% maintenance in VJ performance following 30 minutes of inactivity compared to baseline. In 2008, Sporer et al. found that the application of external heat following active WU at -10˚C similarly maintained T_m ~2˚C higher than without heating; subsequent VJ performance was maintained 5% higher (10% maintained in HP and 5% maintained in CON) compared to baseline values. It is possible that HP does not have as much of a positive effect on multi-joint coordinated movements (i.e. VJ) in cool environments as it does in cold ones. Passively heating the muscle may still provide valuable temperature-related benefits to muscle performance that were not easily assessed by VJ performance in cool conditions. Examples are increased nerve conduction rate and muscle contraction velocity which are difficult to isolate and evaluate and therefore to directly associate with VJ performance on a jump mat. Moreover, improved perceptions of TC and TS due to maintained muscle and skin temperature prior to competition in cool environments may play an important role in subsequent performance. Although there was no significant difference between HP and CON, TC and TS remained higher during the 30 minutes of inactivity following WU with HP compared to CON.

The participants who volunteered in this study all met a minimum VO_{2peak} inclusion criteria of $50mL \cdot kg^{-1} \cdot min^{-1}$; moreover, several of the participants had a history of high-performance sport participation. Although these inclusion criteria fall short of delegating this group as “elite”, participants were chosen based on these criteria to best represent the largest group from which individual responses were expected to be similar to those of summer sport athletes. A consistent improvement in mean performance score of as little as 1% could prove a key determinant in outcome between elite athletes. Based on a 3% improvement threshold for applied sport, there is a possible (26%) chance that HP will have a substantially positive effect and a possible (72%) chance that HP will have a trivial effect on VJ performance maintenance after 30 minutes of inactivity compared to post-WU jump height compared to CON.

Based on a 1.5% clinical effect analysis for applied sport, there is a 92% chance that HP will have a trivial or substantially positive effect on peak power performance, a 100% chance that HP will have a trivial or substantially positive effect on mean anaerobic capacity, and a 71% chance that HP will have a trivial or substantially positive effect on fatigue index compared to CON.

It is possible that VJ was not a sensitive enough measure in this study to show individual differences in these conditions. In colder temperatures, VJ may be a more appropriate and sensitive measure. A similar study was carried out which measured T_m and VJ performance following baseline, WU, and inactivity with and without passive heating following WU in a -10˚C environment with snowboard athletes (Sporer et al., 2008). Results showed that maintaining T_m with passive heating following WU corresponded with 10% maintenance in VJ performance gains after 30 minutes of inactivity post-WU. Applied HP in the current study also maintained VJ performance following 30 minutes of inactivity compared to baseline but to a lesser extent (5%); this was 2% higher than maintenance of VJ performance in CON, whereas Sporer et al. showed a 5% higher maintenance with HP compared to CON. Although the T_m maintenance in these studies was similar with HP (~2˚C), it is possible that a difference in the heated garments themselves including the magnitude and patterns of heating which enabled heat distribution to the lower legs in each study was accountable for the discrepancies in performance maintenance. Sporer et al. used a coiled overpant whereas the present study used electrically heat panels over the major muscle groups (quadriceps and hamstring). VJ performance relies heavily on ankle dorsiflexion and calf muscle agonist contraction and antagonist relaxation; cooling has been shown to increase co-contraction and detriment performance (Oksa, 2000). Insufficient warming and maintaining warmth of the muscles involved in the VJ movement may have negative effects on the ability to generate power through compromised muscle contraction properties including rate of force development, contraction velocity, nerve conduction velocity and depolarization time (Oksa, 2000; Rutkove, 2001). In the present study, temperature of the lower legs including the calf muscles and ankle joints were not monitored and specifically maintained; therefore cooling of the lower leg is another possible explanation for the lower muscle performance maintenance. Finaly, although the base pants were stretchy, possible restrictions on movement during a maximal jump test and the extra weight of wearing pants compared to wearing shorts could have impacted the VJ results between conditions.

No significant differences in TC were reported between HP and CON during the 30 minute inactivity phase following WU, although participants generally felt more “comfortable” (versus slightly uncomfortable) and remained “slightly warm” or “neutral” compared to “slightly cool” in HP compared to CON. With statistical differences in T_m and peak power output but not TC and TS between conditions, it is again important to note that TC and TS are not necessarily good indicators of muscle temperature and performance. However, perceptions of comfort and warmth are generally related to skin and ambient temperatures; being in a comfortable and warm range can play an important role in athletes’ mental preparedness prior to competition, and performance itself (Gagge, Stolwijk, & Saltin, 1969; Schlader, Simmons, Stannard, & Mündel, 2011). Even though the experimental environment was designed to represent cool summer sport conditions, the direct application of TC and TS scores in a controlled chamber to the competitive environment is limited. Local TS and TC of the right thigh were not considered; therefore, T_m and T_{sk} measured at the right thigh should not be directly connected to perceptions of whole-body TS and TC. Although perceptions of thermal comfort and sensation associated with optimal performance will vary with body composition, fitness, age, gender, and circulatory response (Gagge et al., 1967), the findings here still provide important insights into TC and TS at ~10˚C with and without passive heating as an intervention. With greater environmental stress, longer delays prior to competition, and/or different sport demands, this trend may play more of a factor in subsequent performance.

Table 2

T_m, VJ, and WAnt Changes Resulting From and Following WU (Mean values, n=8)

	Tm HP (˚C)	VJ HP (%)	WAnT HP (W)	Tm CON (˚C)	VJ CON (%)	WAnT CON (W)
Difference pre-post WU	3.6†	16†		3.9Φ	18 Φ	
10min inactivity post-WU	0.2	-7‡		-1.0§	-9§	
20min inactivity post-WU	-0.2	-12‡		-1.6§	-13§	
30min inactivity post-WU	-0.6‡	-11‡	923*	-2.9§	-15§	911

Φ indicates a significant time difference compared to end-baseline for CON only ($p<0.05$).

† indicates a significant time difference compared to end-baseline for HP only ($p<0.05$).

§ indicates a significant time difference compared to end-WU for CON only ($p<0.05$).

‡ indicates a significant time difference compared to end-WU for HP only ($p<0.05$).

* indicates a significant difference between HP and CON ($p<0.05$).

4.3 Sources of Error/Reasons for Inability to Maintain T_m

Inability to maintain T_m for the duration of the 30 minute inactivity phase post-WU could have been due to possible physiological differences in skin and muscle blood flow or thigh girth (effective insulation of muscle). A brief correlation analysis was run to examine the relationship between heat loss and both thigh girth and thigh skinfold; no correlations were seen (see Appendix I). Other possible explanations for lack of T_m maintenance could be differences in muscle probe placement and depth, uniformity of heating of the heated garment itself, and placement of heat over the measurement area (muscle probe insertion site). Controls were established in an attempt to allow accurate and consistent use of the equipment throughout the study. The muscle probe was inserted mid-femur on the lateral aspect of the vastus lateralis; a set distance was noted on the probe prior to insertion for proper depth placement and the depth was re-checked upon removal. Care was taken to ensure that the heating panel of the garment was centred over the muscle and muscle insertion site throughout testing components. The heated panels were also tested to ensure uniformity of heat; however, gaps between the heated panels between different muscle groups were necessary to allow for variations in leg girth. It was not possible to replicate the heat coverage between subjects, but within-subject coverage was the same across experimental sessions. Overall body fat could have also affected participants' ability to maintain elevated T_m and T_c after WU in the cool (10°C) environment, with leaner participants experiencing greater heat dissipation in the vastus lateralis as whole body cooling progressed. In session 1, participants had their height, weight, 8 skinfold sites, and thigh and calf girth measured to create an anthropometric profile. Participants came from different sporting backgrounds and although were overall lean-normal, inter-individual variations were present. Although no correlations between T_m maintenance and thigh girth or thigh skinfold were seen, Sporer et al. (2008) showed a moderate correlation between thigh skinfold and drop in T_m, with leaner National snowboard team athletes showing a faster drop in T_m than recreational athletes. See Table 1 for physical characteristics of participants.

The 45s WAnT was used to measure anaerobic power, capacity, and fatigue; however, only a statistical difference in 45s average power was seen. Variability between participants was high for these measures, and individuals did not always show a clear improvement in HP compared to CON. Although familiarization of the WAnT was run during session 1, it is possible that a learning effect occurred for the test itself. Fortyfive- and sixty-second duration tests are more difficult to maintain maximal effort from start to finish, which may have decreased the reproducibility of the results. Some of the participants found the T_m probe more uncomfortable during one experimental session over the other, which may have also played a role in WAnT performance.

Although rationale for use of VJ as a short-duration, high-intensity test indicative of field performance was given, it is possible that VJ was not sensitive enough in this study to show muscle performance changes associated with decline in or maintenance of T_m. The power may have been too low (n=8), or the movement too specific, despite familiarization trials, to differentiate between participants and conditions.

A key consideration in the outcome of this study was the fairly mild environmental temperature used as the control condition. The aim of the study was to measure the effect of WU and passive heating on T_m and performance in cool conditions as related to summer sport athletes, but it was difficult to incorporate performance measures that were sensitive enough to changes in muscle performance with the environmental and exercise stresses used. It is very likely that manipulating the environment to further extremes of the spectrum that athletes compete in would have demonstrated more noticeable differences and associations between both T_m and muscle performance. As previously discussed, passive heating following active WU at -10°C resulted in maintained VJ performance (Sporer et al., 2008). Similarly, Faulkner et al. (2013) maintained T_m ~0.5°C higher than the current study at 30minutes post-WU using passive heating; their study found an improvement in mean peak power with heating compared to insulated track pants alone.

4.4 Conclusions

In conclusions, these data show that a 15 minute moderate-intensity WU elevated T_m by an average of 3.8°C and induced temperature-related changes that benefitted subsequent performance. Following WU, passive heating can be used to maintain T_m for 20-30 minutes and may enhance muscle performance in certain power activities in cool environments (~10°C). This has important practical implications for athletes faced with unavoidable delays prior to competition; passive heating and micro-warm ups during these delays are easily implemented strategies that can result in substantial performance gains. Trends in higher TC and TS with passive heating compared to CON may also enhance mental preparedness in more extreme environments and/or with longer delays between WU and competition. Further research should be conducted in this area to better establish the relationship between non-invasively measured T_{sk} and T_m so that T_{sk} could be used as a practical tool to predict T_m prior to competition. Moreover, future studies considering passive heating will shed light on its effectiveness following WU in varying temperatures, how passive heating and micro-WUs can be combined for optimal pre-race state, the effect of passive heating following sport-specific WU across various sports, and how the use of passive heating can be facilitated for actual implementation and adherence by athletes in sport.

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Appendix A
Review of Literature

Introduction

The human body has a relatively small range with respect to tolerance of temperature, pressure, altitude, and air quality. Thermal homeostasis mechanisms exist to maintain and regulate the body's systems for comfort, performance, and survival. Unlike the cardiovascular or respiratory system, the thermoregulatory system does not function as an independent unit. Instead, the thermoregulatory control center located in the hypothalamus coordinates many of the body's systems and integrates their activities with the common goal of maintaining a stable core body temperature under most conditions. The hypothalamus receives inputs from local and peripheral receptors reflecting the thermal gradient of the human body from core to periphery, evaluates these inputs, and activates appropriate effector-mediated responses to maintain body temperature at its "set point" (37˚C). These responses result in heat loss or heat gain, such as sweating and shivering, depending on activity level and environmental conditions.

The stresses imposed while exercising in hot and cold environments not only affect health but also athletic performance. Winter sport athletes must cope with below-freezing temperatures and varying altitudes, while summer sport athletes often perform in extreme heat and even pollution, such as in 2004 and 2008 Summer Olympic Games in Athens and Beijing. However, athletes also encounter and perform in "atypical" environments regularly, training and competing in a variety of climates, altitudes, and weather patterns due to year-round training commitment and global competition schedules.

Pre-warming before exercising improves performance and is likely to decrease the risk of musculoskeletal injury. However, the benefits resulting from an active warm up (WU) are lost if there is a prolonged recovery period prior to performance. When there are unavoidable delays between warm up and exercise and/or the weather is cold, passive WU techniques may be an important strategy to supplement or maintain temperature increases produced by active WU. However, practical application of using passive heating as a bridging mechanism to maintain muscle temperature (T_m) and core temperature (T_c) has yet to be fully assessed.

This review will first describe a basic overview of thermoregulatory mechanisms as well as techniques and practical implications for measuring body temperature. Comparisons between physiological responses during exercise in varying conditions will be considered next, with a focus on performance in the cold. Finally, strategies for minimizing exercise and performance detriments in hot and cold climates will be discussed.

Thermal Homeostasis

Although the human body has a relatively defined T_c, it is remarkably capable of tolerating extremely hot and cold climates. Body temperature is regulated primarily in the hypothalamus which continually makes thermoregulatory adjustments to maintain T_c within a narrow range: 37°C ± 1°C (McArdle et al., 2010). The hypothalamus receives peripheral input from thermal receptors in the skin and direct input from the temperature of blood perfusing the hypothalamus itself. These inputs result in coordinated responses in the posterior hypothalamus for heat conservation or the anterior hypothalamus for heat loss. The theoretical "set-point" can be modulated temporarily due to dehydration, starvation, fever, and heat and cold acclimation (Brooks, Fahey, & Baldwin, 2005). Body temperature displays inter-individual variation as well as diurnal variability: the body's T_c is lower in the morning and higher in the late afternoon.

Uncompensable heat loss and heat gain lead to hypothermia ($T_c \leq 35^{\circ}C$) and hyperthermia ($T_c \geq 39.5^{\circ}C$), respectively (McArdle et al., 2010). Dehydration and negative energy balance occurring in extremes of heat, cold, or altitude can have serious consequences including impaired thermoregulation, ketosis, disturbed acid-base balance, depleted muscle glycogen, deterioration of fine motor skills, diminished exercise capacity and loss of fat-free body mass (McArdle et al., 2010). Age, gender, and body composition also influence thermoregulatory responses.

Heat production and heat loss.

The body has basic responses to exercise that contribute to heat production or loss. Radiation, conduction, and convection all contribute to heat transfer between skin and the environment. Circulatory convection allows heat to be dissipated via the circulatory system and is facilitated by the inherent countercurrent patterns of veins and arteries. Heat is lost to the environment via convection and conduction with respect to skin blood flow and the temperature gradient from core to periphery. The body's most important mechanism for heat loss is absorption of heat by the environment through sweat evaporation. Evaporation is critical at high environmental temperatures and during exercise. At high humidity, heat loss can be greatly compromised when sweat cannot vaporize, and simply accumulates and/or runs off the body. Sodium chloride, urea, lactic acid, and potassium chloride are lost in sweat in addition to water, which affects ion concentrations and contributes to impaired neuromuscular function in these conditions (McArdle et al., 2010). Evaporation also occurs as a result of water loss through ventilation and diffusion through the skin. This is particularly significant in cold, dry air, especially during exercise.

Conversely, shivering is the main mechanism for heat production via involuntary muscle contractions during negative heat balance. Thyroxin secretion from the thyroid and catecholamine (particularly norepeniphrine) secretion from the adrenals contribute to non-shivering thermogenesis through metabolic heat production (Brooks et al., 2005). The stimulation of brown adipose tissue and the release of leptin (a hormone) can also generate heat in response to cold exposure. Increased T_m elevates oxygen consumption of isolated mitochondria by a Q_{10}[1] effect and by decreasing the ratio between adenosine diphosphate (ADP) production and mitochondrial oxygen consumption (Bishop, 2003a).

The body's heat retention and dissipation mechanisms are also affected by non-thermal factors such as baroreceptors and mechanoreceptors, which have been shown to modulate the rate of local sweating and skin blood flow responses after the onset and following exercise (Kenny et al., 2009; Mekjavic & Eiken, 2006). Specifically, Kenny et al. postulated that non-thermal factors predominate the modulation of thermal control of post-exercise whole body heat loss in intermittent exercise bouts (3x30min with 15min rest between bouts), shown by differences in responses during exercise and post exercise despite increasing thermal load and heat storage. Mekjavic and Eiken (2006) also studied the effect of non-thermal contribution to thermoregulation, suggesting that T_c may not have a "set-point", but may fluctuate slightly with heat exchange between the environment and the skin instead of immediately initiating sweating or shivering responses when the "set-point" is disturbed. These slight fluctuations are buffered by behavioural adjustments, such as layering and removing clothing, but also by vasomotor responses contributing to either heat loss or heat retention. Mekjavic and Eiken further suggested that a reciprocal inhibition theory may support a T_c "zone" as opposed to a set-point; however, the position of the neuronal cross-over region for heat production and heat loss may have negative implications on this theory. Nevertheless, thermal and non-thermal factors should be considered when discussing body temperature regulation.

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[1] Q10 = (R2/R1)[10/(T2-T1)]; R1 and R2 are rate processes at temperatures T2 and T1 and T2 > T1. Q10 > 1.0 indicates a positive thermal dependence.

Temperature Measurement Modalities

Body temperature can be generally described as a heat gradient that is warmest at the core and coolest at the periphery. To best understand thermoregulatory mechanisms in the body, measurements across this heat gradient are important; a single ‘representative’ site of the body is not sufficient feedback for specific tissues and regions. Practical, accurate, and reliable means of measuring body temperature are difficult, particularly when an individual is exercising in a field setting. This section discusses different modalities of measurement for muscle, core, and skin temperature that can be used at rest or during exercise.

Muscle temperature. The temperatures of skeletal muscles are determined by muscle blood flow and metabolic rate. As noted, T_m is influenced by the environment, with higher temperatures in the heat and cooler temperatures in the cold. Even moderate changes in temperature can impede muscle performance; extreme temperatures can be dangerous, leading to impaired coordination, altered muscle patterns, fatigue, and muscle injury (Brooks et al., 2005). Elaboration on muscle response to temperature and exercise will be discussed below. A valid, reliable, and accurate measure of T_m offers significant insight into muscle response mechanisms. T_m is typically measured via an intra-muscular probe inserted into the calf, quadriceps, or hamstring. These large muscle groups have sufficient depth to allow probe insertion far enough below skin surface to avoid substantial interference from environmental influence. Kenny et al. (2003) examined the T_m transients before, during, and after exercise (bilateral, concentric knee extensions against a dynamic exercise resistance sufficient to elicit a specified heat load) at controlled ambient air temperature of 22˚C using a multisensory probe inserted at three depths in the vastus medialis. In contrast to previous studies, subjects showed similar muscle profiles during resting, exercise, and recovery T_m when a standardized probe position within the muscle of all subjects was used. Esophageal temperature was measured as an index of T_c. At rest, there was an overall temperature gradient from the core (T_{es}, 36.8˚C), to the deepest muscle probe measurement (36.14˚C), second-deepest (35.86˚C), and most superficial (35.01˚C). During exercise, T_{es} increased gradually with exercise time, reaching maximum at about 6-9min; post-exercise, T_{es} decreased rapidly before showing a typical sustained elevated value. The deep muscle measure followed the pattern of T_{es} the closest, and the most superficial muscle measure was the most affected by the changes in exercise intensity. The parallel response of deep T_m with T_{es} suggests a contribution of the transfer of residual heat from a previously active muscle in the sustained elevation in post-exercise T_{es}. Variation in T_m profile observed between rest, exercise, and recovery resulted from the change in metabolic heat production, as well as from changes in the convective heat transfer between blood, and muscle conductive heat transfer between muscle and skin surface. Moreover, post-exercise T_c response (and rate of temperature decay) is significantly influenced by heat transfer between muscle and core. Body profiles with more or less adipose tissue may interfere with this heat transfer. In a hot environment, this would most likely prove detrimental to performance, but in a cold environment this may actually enhance performance by allowing T_m to remain at a normal or elevated temperature.

Core temperature. Body T_c measurement is fundamental to the study of thermoregulation at rest and during exercise. However, the body's interior is not uniform in temperature and the thermoregulatory centre receives temperature inputs from many internal sites; there is no "core" anatomical location that can be physically measured to provide an index of average internal temperature (Byrne & Lim, 2007). The temperature of blood in the pulmonary artery is considered the best representation of the average internal temperature of the body because the mixed venous blood has returned from both the core and periphery and is almost identical to arterial blood (Byrne & Lim, 2007). This blood temperature very closely resembles that of the blood perfusing the hypothalamus, or the thermoregulatory control centre. Since the pulmonary artery is not accessible, T_c is often measured directly at the esophagus (T_{es}), rectum (T_{re}), mouth (T_{or}), or aural canal/tympanic membrane (T_{ac}), or indirectly using an ingestable telemetric temperature sensor in the gastrointestinal tract (T_{in}). T_{es} at the level of the left atrium provides the closest agreement with central blood and is considered the best available index of T_c for exercise studies (Byrne & Lim, 2007; Gagnon, Lemire, Jay, & Kenny, 2010). T_{re} is the most widely used index of T_c in exercise studies; however, T_{re} can be slow to respond to changes in exercise intensity and central blood temperature. T_{ac} and T_{or} are variable and unreliable due to affectation from environmental temperature and large variations resulting from respiration (Gagnon et al., 2010). T_{in} represents a valid index of T_c that is convenient and useful in ambulatory field-based applications (Byrne & Lim, 2007). However, disadvantages of T_{in} are a possibility of temperature gradients along the gastrointestinal tract, acute modifying effects of fluid and food ingestion, electromagnetic interference with the sensor, electronic malfunction, and the uncertainty of transit time (Byrne & Lim, 2007).

Skin temperature (T_{sk}) . T_{sk} is the most variable in the body since it is the most exposed and susceptible to changes in the environment. In addition to air temperature, T_{sk} is influenced by metabolic rate, clothing, hydration state, and humidity. These factors all play a role in heat transfer through convection, sweating, evaporation, and capacity for heat loss. T_{sk} is often measured using skin thermistors or thermocouples at various sites including the calf, thigh, chest, forearm, upper arm, tricep, head, and back (Gonzalez-Alonso et al., 1999; Kenny et al., 2003). These measurements are used to monitor T_{sk} changes through changing conditions and exercise intensities to better understand the temperature gradient from the core to the periphery in conjunction with core and muscle temperature measurements. Skin blood flow can be enhanced or repressed internally and by the environment. At the onset of exercise T_{sk} may decrease temporarily as blood flow to muscle increases (vasodilation) and therefore blood flow to skin decreases (vasoconstriction) (J. M. Johnson & Rowell, 1975; J. M. Johnson, 2010). As exercise continues and metabolic heat production becomes higher than T_c, T_c increases and the hypothalamus initiates heat loss responses. Blood vessels in the skin vasodilate to carry warm blood to the periphery and to increase surface area to enhance heat loss through circulatory convection.

Performance

Optimal temperature for performance. There is no single temperature that optimizes performance in all activities. Galloway and Maughan (1997) studied elite cyclists exercising until exhaustion in a temperature-controlled velodrome to establish a best-suited temperature for maximal human performance. Of the four controlled temperatures used (4˚C, 11˚C, 22˚C, 31˚C), average time to exhaustion was longest in the 11˚C condition (94min). Results from all four conditions suggested an inverted-U relationship with performance, where 11˚C is “optimal”, and colder or warmer temperatures would result in decreases in maximal-type performance. Parkin et al. (1999) also studied time to exhaustion during a set moderate-intensity workload using systematic temperature conditions: 3˚C, 20˚C, and 40˚C; the optimal temperature for long-term performance in this study was found to be 3˚C (Parkin et al., 1999). It is interesting to note in Galloway and Maughan’s results that the “cold” temperature at 4℃ had the greatest range in performance times, with the highest and lowest values of all the conditions (136min and 47min, respectively), suggesting an inter-individual variation in optimal temperature for submaximal exercise to exhaustion. Likely explanations are increased sweat evaporation in the cool condition for this long-term performance, increasing heat dissipation and attenuating metabolic heat load and exertional heat stress. Moreover, athletes may have been more comfortable in the cool condition due to reduced thermal strain in this cycling trial to volitional exhaustion, allowing a longer performance.

Because short-duration, high-intensity performance is improved with elevated body and muscle temperature, warmer environments are optimal to facilitate and maintain these increases for enhanced performance. During short duration activity, there is a positive relationship between performance and ˚C increases in $T_{m;}$ however, this relationship ends and performance decreases when T_c becomes too high and hyperthermia sets in (Racinais & Oksa, 2010). Falk et al. (1998) found that anaerobic 15-s performance resulted in a higher power output when performed at 35˚C compared to 22˚C. However, extremely hot and humid conditions are not ideal if they prevent body cooling as T_c increases to critical levels and contribute to thermal strain. Diurnal body temperature may be contributed to conflicted findings of increased short-term performance in warm environments. Racinais, Blonc and Hue (2005) found that a hot environment improved muscle contractility and muscle force in the morning when body temperature was at its lowest. Cold exposure, however, was likely to detriment performance both in the morning and the afternoon (Racinais, Blonc, Oksa, & Hue, 2009). Racinais et al. (2009) found that applied cooling or passive WU for 30 minutes prior to a cycling sprint performance in both the morning and the afternoon attenuated the diurnal variation in muscle power compared to a control trial, suggesting a higher influence of muscle than core temperature on muscle power.

Psychophysical perception of the environment has also been shown to play a role in performance. In a study considering thermal comfort (TC) and thermal sensation (TS) during exercise, subjects pedaled at varying intensities at 10˚C, 20˚C, and 30˚C (Gagge et al., 1967). After 30-40 minutes of exercise, subjects chose temperature sensations relating to skin and ambient air temperature and unrelated to metabolic rate, muscle, and rectal temperatures. Warm discomfort was principally related to skin sweating resulting from air temperature, metabolism, skin blood flow, T_{sk} and T_c. Gagge et al. found that TS seemed to be governed by skin sensory mechanics whereas TC was governed by thermoregulatory mechanisms (sweating and skin blood flow). The “zone” of optimal conditions was found to be highly individual; measures of comfort and TS varied most in the 10˚ conditions despite more sweating in the warmer conditions. Environmental acclimation, body composition, fitness, age, gender, and even circulatory response can all affect how an individual perceives TC, and how he or she performs in different environments.

The type, duration, and intensity of activity should all be taken into consideration when attempting to define an “optimal” temperature for performance. For example, a hot environment that is beneficial to sprinting and jumping in terms of mechanics and muscle performance would likely compromise performance if the activity had to be repeated and sustained, as in a soccer or lacrosse match, due to cumulative heat storage (Kenny et al., 2009) . Except for in controlled studies, it is unusual for the environment to accommodate the athlete; therefore, it is more applicable to study the effect the environment has on athletic performance, and at strategies to optimize performance when conditions are not ideal.

Thermoregulation and performance in hot versus cold environments. Much of the past literature concerning thermoregulation and performance has focused predominantly on exercise in the heat, particularly during prolonged exercise (Abbiss & Laursen, 2005; Kent-Braun, 1999; Nybo et al., 2001). Because field testing in a cold environment presents difficult practical implications, most research looking at exercise in cool or cold environments does so following cold-water immersion, exercising in or following exposure to a temperature-controlled climatic chamber, and even following whole body cryotherapy. Cold water immersion temperatures are often ~10-14˚C for shorter immersion times or ~20-30˚C for longer immersion times (Dixon et al., 2010; McArdle, Toner, Magel, Spinal, & Pandolf, 1992). Exercise and performance studies in cooled chambers generally look at 3˚C to 20˚C (Galloway & Maughan, 1997; Parkin et al., 1999). Whole body cryotherapy has been used for very short durations (1-3minute exposures) at -110˚C to treat pain and inflammation and to enhance recovery (Costello, Algar, & Donnelly, 2012). Much of the literature on performance in cool conditions focuses on long-term, moderate-intensity performance (Dixon et al., 2010; McArdle, Toner, Magel, Spinal, & Pandolf, 1992). Fewer studies have considered short-term, high-intensity exercise in both instantaneous and cumulative situations in the cold (Bishop & Maxwell, 2009; Dixon et al., 2010).

When studying cold and cool conditions in relation to muscle performance, the temperatures used are generally chosen to induce subnormal T_m (<~34˚C). Sargeant (1987) studied T_m effect on leg extension force and short-term power output based on a 20s maximal sprint on a cycle ergometer following three water immersion (WI) conditions (44°C, 18°C and

12°C) and one baseline condition (air temperature, 22˚C). T_m was measured at 4cm, 3cm, 2cm, and 1cm depths mid-thigh immediately prior to maximal exercise. In the warm (44˚C WI) condition, T_m was relatively constant throughout the muscle; however, in the cold conditions (18°C and 12°C WI) there was a marked temperature gradient across the muscle. Compared to baseline, the 44˚C WI resulted in 2.7˚C increase in T_m and 11% improvement in power output, the 18˚C WI resulted in a 4.7˚C drop in T_m and a 12% decrease in power output, and the 12˚C WI resulted in a 7.6˚C drop in T_m and a 21% decrease in power output. Results demonstrated a velocity-dependent effect of T_m on maximal power based on pedaling rates, and increased maximal peak power was also associated with an increased rate of fatigue. Of the different pedal rates tested (54, 95, and 140 revolutions per minute [rpm]) the lowest only improved maximal peak power by ~2% per ˚C T_m increase, but the highest pedaling rate by ~10% per ˚C. This is an important consideration for cyclists during training and competition; it is also a relevant and important consideration for short-term, high-intensity cycling tests aimed to measure muscle performance.

During prolonged exercise, both physiological and psychological factors play a role on exercise intensity and performance. Although multiple mechanisms of fatigue play a role in limiting long-term performance, thermal strain is the primary effector of reduction in central drive (Nybo et al., 2001). Compared with 10˚C, athletes who cycled a 100km trial with race-simulated “attack” high-intensity bouts at 34˚C had lower power output resulting in slower performance times, rise in T_{re}, higher final T_{re}, higher mean T_{sk}, and higher values of TS (Abbiss et al., 2010). Muscle activation and power output were reduced during exercise in the heat prior to significant differences in T_{re} between 34˚C and 10˚C conditions; therefore, Abiss et al. deduced that self-selected exercise intensity is centrally regulated to lower the thermal load (anticipatory effect).

Neuromuscular function is highly implicated in terms of exercise in the heat or in the cold. Hyperthermia brought on by environmental and/or heat stress affects brain perfusion and metabolic rate, causing impairment of brain heat loss and reduction in cerebral oxygenation (Brooks et al., 2005). However, neural drive alone and the theory of central fatigue do not solely contribute to decreasing performance in exercise-induced hyperthermia. Racinais and Oksa (2010) suggested a contribution of peripheral neuromuscular modifications affecting supraspinal adaptation which resulted in decreased muscle activation. In their review of the literature on short duration performance, Racinais and Oksa found a variation in performance improvement ranging from 2% to 5% per 1˚C change in T_m, an improvement that is even more apparent during faster versus slower movements similar to findings by Sargeant (1987). Hot environments act as a mode of passive WU, and may positively influence short-term, high-intensity performance; however, this may only be the case in the morning when diurnal temperature is lowest, and in cooler environments that are less likely to contribute to heat load. The positive relationships between neuromuscular performance and both T_c and T_m stops and performance is impaired when central temperature becomes hyperthermic (39˚C) due to decrement in neural drive to the muscle (Thomas, Cheung, Elder, & Sleivert, 2006). With increased T_m, nerve conduction velocity and muscle contraction velocity both increase, and depolarization time decreases; during cold temperatures, the opposite effects are seen (Rutkove, Kothari, & Shefner, 1997). Neuromuscular performance is also impaired by low T_c, mainly due to alterations of co-activation and coordination of the muscles, eliciting a “braking effect” where antagonist muscle activity increases during stretch-shortening cycle (Oksa, 2000). Peripheral cooling elicits a reduction in conduction velocity (Todnem, Knudsen, Riise, Nyland, & Aarli, 1989), and decreased T_m corresponds with a decrement in the rate of muscle contraction and relaxation, leading to less powerful contractions (Racinais & Oksa, 2010). The modifications associated with physiological failure may provide a protective mechanism to reduce injury or hyperthermia.

Thermoregulation following exercise. Understanding the body’s thermal responses to exercise cessation provides valuable insight into the implementation of recovery and cool-down strategies, and is particularly important for individuals performing intermittent and subsequent bouts of dynamic exercise. Prolonged exercise and heat stress has been shown to result in a continued sustained elevation of body temperature that counters the ‘set-point’ theory (Thoden et al., 1994). Thoden et al. found that post-exercise, metabolic heat production generally increased internal temperature due to body heat storage, initiating cooling responses. However, T_{es} remained elevated for a prolonged period despite oxygen consumption, sweating, skin blood flow, and T_{sk} levels declining rapidly following exercise cessation and shortly returning to baseline (Journeay, Carter, & Kenny, 2006). These mechanisms would expectedly stay elevated with T_{es} to enhance heat dissipation. Conversely, T_m response, particularly deep-tissue temperature, resembles the sustained prolonged elevation of T_{es} post-exercise, indicating that T_{es}

decay is significantly influenced by convective heat transfer between muscle and core (Kenny et al., 2003).

To date, the literature suggests a prominent role of non-thermal influences associated with hemodynamic regulation and hydration on thermoregulation during post-exercise recovery (Journeay et al., 2006; Kenny et al., 2009). Hypohydration and dehydration increase cardiovascular strain, reducing plasma volume and modulating HR during exercise; post-exercise hypohydration can alter muscle metabolism, reduce baroreceptor responsiveness, cause difficulty in sustaining blood pressure, elevate circulating catecholamines, increase hyperthermia, and impede psychological adaptations to heat acclimation (Journeay et al., 2006; Young, Sawka, Levine, Cadarette, & Pandolf, 1985).

Differences in recovery response in upright standing, seated, and supine recovery indicate a contribution of non-thermal factors and alterations in central blood volume and cardiac filling to heat convection, distribution, and dissipation (Journeay et al., 2006). Journeay et al. found that inactive recovery resulted in a decreased central blood volume and accumulation of blood in the venous system of the lower extremities in the absence of a muscle pump (active recovery). Persistent muscle vasodilation also contributed to lower central blood volume and subsequent reduced cardiac filling in the standing position compared to sitting. The magnitude of reduction in mean arterial pressure, which affects post-exercise hypotension, was greater during standing recovery compared with supine recovery. An inactive, upright seated posture also resulted in lower extremity blood pooling (Journeay et al., 2006).

Athletes are already predisposed to hypohydration and dehydration due to sweating and water loss from ventilation and skin diffusion, putting them at risk of impaired recovery following exercise cessation. Adequate rehydration and optimal recovery can have valuable implications on subsequent performance. These strategies should be considered following active WU in the competition environment. Although these studies were performed in primarily thermoneutral conditions, it is important to consider the effect of thermostressful environments on thermoregulatory responses. Optimal recovery in a cold environment does not necessarily mean optimizing heat dissipation, as maintenance of core and T_m increases following exercise may enhance subsequent performance. Athletes can also benefit from active recovery to maintain blood flow through the muscles and improve venous return while avoiding blood pooling in the lower extremities. Furthermore, athletes in cool or cold environments who wish to maintain WU

T_m prior to performance may benefit from short activation exercises to prolong elevated T_m without exhausting energy stores.

Exercise and performance in the cold. The definition of a cold environment varies with different activities and sports. As previously discussed, cooler temperatures (~10˚C) can have a beneficial effect on long-term, moderate-intensity performance (Galloway & Maughan, 1997) but are likely to detriment short-term, high-intensity performance (Dixon et al., 2010; Peiffer, Abbiss, Watson, Nosaka, & Laursen, 2009). T_c response to environmental temperature is affected by an individual's anthropometry and body composition, and heat loss is dependent on a surface area to mass ratio (Smith & Hanna, 1975).

At rest, during cold exposure, the body experiences peripheral vasoconstriction, increased metabolic heat production through shivering, and increased carbohydrate as a fuel source (Nimmo, 2004). Heat loss in cold air can be affected by ambient temperature, relative humidity and wind chill which affect evaporation and radiation heat transfer. Performance detriments will be seen in the cold if exercise is not sufficient to offset heat loss; this effect is further elucidated in wet and windy conditions, where the insulative properties of clothing and adipose tissue are reduced (McArdle et al., 2010). Rissanen, Oksa, Rintamaki and Tokura (1996) examined the insulative effects of clothing on muscle activity. Nine female subjects were exposed to 5˚C wearing shorts, trousers with long legs, or trousers with one long leg and one short leg while sitting and performing light exercise for 60 minutes. Muscle activity was measured using surface electromyography (EMG) on the three main leg muscle groups. It was concluded that exposing bare legs to a cool environment enhanced the motor activity in relation to covered legs; T_c decreased more when exercise began in the shorts condition compared to the trousers condition, possibly resulting from the greater convective cooling from uncovered legs compared to covered legs during exercise (Rissanen et al., 1996). Increased EMG amplitude in cool muscles has been suggested to indicate an increased recruitment of muscle fibres to compensate for diminished power output compared to warm muscles and had been shown to decrease muscular performance, notably pronounced at higher contraction velocities (Oksa et al., 1995).

Known effects of cold T_m including lower cell metabolism, vasoconstriction, decreased nerve conduction velocity, decreased muscle contractility, and decreased extensibility of collagen fibres can all reduce athletic performance (Dixon et al., 2010). However, low-intensity exercise in the cold may increase oxygen consumption due to shivering, increasing the need of muscle glycogen stores to provide carbohydrate fuel. This higher glycogen utilization has been associated with a shift in muscle recruitment from type I to type II fibres and a concomitant increase in blood lactate production (Dixon et al., 2010).

In a review on exercise in the cold, Nimmo (2004) highlighted that decreases in T_m have been shown to affect performance in extremely cold conditions due to compromised muscle enzyme activity and neuromuscular recruitment despite an increased T_c resulting from moderate-intensity (70%VO_{2max}) sustained exercise. In lab conditions, temperatures of -10˚C and colder have elicited reduced oxygen consumption and a reduction in endurance capacity(Layden & Patterson, 2002; Patton & Vogel, 1984). Rate and preference of carbohydrate utilization remains unclear during moderate-intensity exercise in the cold, however a reduction in lypolysis has been seen below 0°C compared with warmer conditions (Nimmo, 2004).

During high-intensity exercise, subnormal T_m (<34°C) has resulted in decreased dynamic performance during cycling and jumping and a reduction in optimal velocity for dynamic power output (Dixon et al., 2010; Nimmo, 2004; Oksa, Rintamäki, & Rissanen, 1997). Muscle strength after cold water immersion at 12°C was shown to significantly decrease isokinetic average peak torque, average power, and total work in active male college students (Howard, Kraemer, Stanley, Armstrong, & Maresh, 1994). Explanations for decreased power output following muscle cooling include impaired rate of force development, increased muscle-tendon unit stiffness, and/or decreased stretch tolerance of muscle (Church et al., 2001; Drinkwater, 2008). Oksa et al. (1997) found that plyometric (agonist and antagonist) performance was reduced in terms of decreased flight time of jump, average force production and take-off velocity in a dose-dependent manner with cooling. In this case, performance was affected under exposure to ambient temperatures of 20°C – a moderate stress environment. Reduced oxygen delivery resulting from vasoconstriction and decreased blood flow or increased energy demand caused by decreased efficiency are both possible explanations for increased fuel utilization during high-intensity exercise in the cold.

Influences of cool and cold environments on core, muscle, and skin temperature will readily influence performance. Long-term activities may be beneficially influenced in cool conditions if thermal comfort is maintained and pre-cooling can decrease the time to critical temperature (hyperthermia); however, cool temperatures are likely to negatively affect short-term high-intensity performance. The literature generally agrees that cold temperatures will negatively affect short and long duration activities due to reduced oxygen delivery to muscles combined with increased oxygen demand, higher glycogen utilization, decreased nerve conduction velocity, decreased muscle contractility, and decreased extensibility of collagen fibres. The deleterious effects of cold will have varying effects on muscle performance; however, strategies to increase tissue temperature and blood flow may be employed to minimize these associated performance deficits.

Strategies to Maximize Performance: Warm-up: WU routines prior to exercise are a well-accepted and widely used practice. A review and meta-analysis of WU studies showed that WU improved subsequent performance 79% of the time (Fradkin et al., 2010). Fradkin et al. noted that methodological issues were present in the studies that showed detriments in performance; therefore, little evidence was found to suggest that warming up is detrimental to sport performance. This section will review temperature related and non-temperature related mechanisms resulting from WU, effects of WU on performance, and effects of WU and stretching on muscle injury prevention. Finally, guidelines for how to structure an effective WU will be discussed.

Active and passive WU. Pre-warming before exercise facilitates work through an increase in body temperature. It is a widely accepted means of improving performance and also appears to reduce the incidence and likelihood of sports-related musculoskeletal-related injuries (DeRenne, 2010; Holt & Lambourne, 2008; S Racinais et al., 2005). Warming up before exercise may contribute to the following performance mechanisms: decrease in the viscous resistance of muscles and joints, speeding of rate-limiting oxidative reactions, increased nerve conduction rate, and greater release of oxygen from haemoglobin and myoglobin with consequent increased oxygen delivery to muscles (Bishop, 2003a; Brooks et al., 2005). Increased anaerobic metabolism (glycolysis, glycogenolysis, and high-energy phosphate degradation) with increased T_m during active WU may benefit short and intermediate performance (Febbraio, Carey, Snow, Stathis, & Hargreaves, 1996). However, WU prior to training and competition can also contribute to increased thermoregulatory strain and decreased exercise capacity in warm and humid environments, particularly for endurance events (Gonzalez-Alonso et al., 1999).

Non-temperature-related effects associated with a dynamic WU that may contribute to performance include increased blood flow to muscles, elevated baseline oxygen consumption, increased twitch potentiation, and decreased muscle stiffness (Bishop, 2003a). WU may also benefit performance through psychological mechanisms including pre-performance routine, improved preparedness and augmented mental activation.

Effects of passive and active WU on performance. Passive heating provides a means of increasing muscle and T_c without depleting energy substrates; methods include heating pads, diathermy, hot showers, hot baths, and saunas. Passive warming sufficient to increase T_m above normal (~35°) may improve dynamic short-term(<10s) and is likely to improve intermediate (10s-5min) performance through an increase in T_m above normal (~35°C) allowing for higher dynamic force, higher contraction velocities, decreased joint and muscle resistance, and/or increased nerve conduction rate (Bishop, 2003a). Passive heating may be most useful for short-term and intermediate performance as a bridging mechanism to maintain elevated T_m following active WU. Long-term (>5min) performance is likely to be negatively affected by passive warming due to a decrease in heat storage capacity and/or impaired thermoregulatory mechanisms resulting in earlier attainment of high T_c (rectal) and/or more rapid accumulation of metabolites (Gregson, Drust, Batterham, & Cable, 2002; Nybo et al., 2001).

Active WU involves dynamic exercise preceding performance; it can be more practical in certain sport situations, and may provide additional benefits over passive heating alone. In a review of WU literature, Bishop (2003a) found that an active WU of sufficient length and intensity to increase T_m above ~35° was likely to improve short-term and intermediate performance for a range of tasks including VJ, running, swimming, and cycling due to increases in power output. For short-term performance, very high-intensity WU was likely to detriment performance due to build-up of metabolites and/or decreased availability of high-energy phosphates. A lack of improvement in intermediate performance following active WU was likely because the intensity was too low, the recovery period between WU and performance was too long, and/or WU intensity or duration was fatiguing. Results were mixed regarding improvement of long-term performance following active WU; WU may have been too low or high of intensity, contributed to increased heat load, been performed too long before competition, or depleted energy substrates (Bishop, 2003a). Dixon et al. (2010) found that an active WU in ambient temperatures significantly improved lower body power as measured by VJ. Cold water immersion reduced muscular power, but a dynamic WU following cold-water immersion effectively decreased the associated reductions in power. The assigned WU focused on promoting essential activity-related physiology; in the case of power production through VJ, the WU consisted of a 14-exercise continuous dynamic circuit designed to increase HR, blood flow, T_m, and range of motion. Active and passive WU (15min, running) promoted a reduction in prolonged submaximal endurance performance in ambient temperatures, mostly likely due to early development of high T_c and decreased heat capacity (Gregson et al., 2002). In 2009, Bishop and Maxwell studied the effects of active WU on performance during prolonged, intermittent sprint exercise as would occur in a team-sport activity in the heat. In theory, a T_c increase caused by active or passive WU should have cause a performance detriment over prolonged performance period due to an increase in thermal strain; however, no differences in repeated intermittent sprint performance in the heat following an active WU were found. Using a full-game (72 minutes) instead of just a half (36 minutes) would have likely better represented the performance detriment in ‘prolonged’ performance expected.

Structuring WU. Timing, intensity, duration, and recovery of WU are all important considerations for optimizing performance-related benefits. A WU that is approximately 15 minutes long and is performed at 60-70% VO_{2max} has been recommended to improve range of motion and enhance subsequent anaerobic performance (Stewart & Sleivert, 1998). Athletes also need to be aware of the duration of recovery following WU, as too short of a recovery may not allow for replenishment of high-energy stores, but too long of a recovery can result in loss of elevated VO_2 baseline and T_m (Bishop, 2003b; Zochowski et al., 2007). Zochowski et al. showed a significant improvement in 200m swimming time-trial performance with 10 minutes compared to 45 minutes post-WU recovery.

Based on Bishop’s review considering WU structure and associated performance changes, guidelines to optimize performance should consider WU intensity, duration, recovery duration, and specificity to the activity (Bishop, 2003b). WU preceding short-term performance should be ~10-20 minutes at 40-60%VO_2 with a 5-15 minute recovery post-WU so that T_m increases without overly depleting high-energy phosphates immediately prior to activity. WU preceding intermediate performance should be ~10 minutes at ~70%VO_2 with a 3-5min recovery period to increase T_m and VO_2 baseline while preventing fatigue; the short recovery allows maintenance of elevated T_m and VO_2. WU preceding long-term performance follows the same guidelines as for intermediate performance, but modifications may be made to decrease WU duration or intensity based on activity to maintain energy substrates and to reduce pre-competition T_c. Task-specific bursts of activity should be incorporated into WU to provide ergogenic benefits, but should be brief enough so as not to cause significant fatigue (Bishop, 2003b). These are basic guidelines; WU routine can be modified to suit individual needs, event-specific confines, changes in environmental conditions, and more.

Muscle injury prevention following WU and stretching. Skeletal injury can occur in the form of delayed-onset muscle soreness, muscle strains, muscle sprains, overuse injury, injury resulting from a direct external blow, and eccentric injury (muscle is stretched while activated) (Woods et al., 2007). Skeletal muscle injuries comprise >30% of all injuries seen in sport related clinics (Woods et al.). In their review, Woods et al. summarized that WU effects positively reduce muscle injuries; specifically, a sport-specific WU seems to be the most effective. WU also provides a protective mechanism to muscle by requiring a greater length of stretch and force to produce a tear in the warmed muscle. Improvements in neural transmission speed due to T_m increase may improve reaction time and allow athletes to avoid twists or falls resulting in injury.

Stretching results in elongation of soft tissues and muscles. Long-term stretching can result in increased range of motion through lengthening of the connective tissue. The technique most effective for this lengthening occurs when low force, long duration stretching is implemented to a tissue with elevated temperature (Woods et al., 2007). Muscle strain injuries may be prevented by increasing the stretch reflex mechanism and the viscoelasticity of the muscle.

Conversely, stretching may prove detrimental to power and force production if administered before certain activities. For example, athletes who included proprioceptive neuromuscular facilitation (PNF) stretching in their WU before performing a VJ test showed decreased performance (Church, Wiggins, Moode, & Crist, 2001).

According to Woods et al. (2007), the majority of the literature showed that stretching routines decreased the incidence of muscle/tendon-related injuries and overuse injuries with enhanced flexibility. Studies that employed WU and stretching before exercise also showed reductions in muscle injuries. Ability to lengthen muscle without damage may allow athletes to assume unusual positions mid-activity that would otherwise result in injury. General classification of injury in previous studies and reviews most likely accounted for findings of no effects of stretching on injury occurrence. Over time, lengthened muscle from stretching will allow a greater range of motion before point of failure is reached. Moreover, long-term stretching may eventually result in a permanent shift of the optimum length of the muscle allowing a greater, or wider, “non-injury zone”. Stretching should be a long-term part of a fitness routine to attain the benefits of long-term changes in connective tissue.

Strategies to Maximize Performance: Other

Additional strategies that have been considered to optimize performance in changing environments include pre-cooling in the heat, acclimation, and diet manipulation.

Pre-cooling. As body temperature increases with rising metabolic heat production during exercise, increasing heat strain can develop into hyperthermia, compromising the body’s physiological cooling mechanisms, and further intensifying exertional heat stress. Furthermore, energy-store depletion and fatigue can negatively affect exercise performance, particularly long-duration exercise. Whereas reduced muscle and core temperature can impair performance in short-term, high-intensity exercise, pre-cooling the body via water-immersion, ice vests, and/or cryotherapy can improve endurance performance through a reduction in ambient heat stress, with auxiliary cooling of the skin during exercise, and by initiating exercise at a lower resting body temperature (Gonzalez-Alonso et al., 1999). Pre-cooling has been shown to decreased rectal temperature, HR, and T_{sk}, resulting in reduced thermal and cardiovascular strain (Cotter, Sleivert, Roberts, & Febbraio, 2001). Cotter et al. used a double-cooling strategy, with and without thigh cooling, including ice vests and cold air before 35min of cycling in the heat. Results showed similar results with and without thigh cooling, but cooling the T_c before exercise through a cooling re-cooling strategy was effective in reducing thermal, cardiovascular, and psychophysical strain. Similar performance gains were found when pre-cooling was implemented during baseline rest and WU prior to a 1500m rowing time trial; results showed a decrease inTC, T_c and T_{sk} and a concomitant increase in power output during the time trial compared to CON (Johnson, 2005).

Acclimation. Training in replicated competition environmental conditions can promote important physiological adaptations to that environment. Repetitive and significant heat stress, especially when paired with exercise, causes physiological adaptations to occur which affect the way T_c reacts to heat stimulus. Lowered sweating threshold, increased sweat rate, increased plasma volume, decreased skin blood flow, and decreased loss of sodium chloride in sweat are all mechanisms that the body utilizes to acclimatize to a hot environment by increasing heat loss (McArdle et al., 2010). Moreover, heat acclimatization can enhance exercise efficiency and performance by reducing oxygen uptake, expanding plasma volume, and increasing ventricular compliance (Young et al., 1985). In the case of heat acclimation, these changes can be induced in a simulated environment. Acclimation seems to require elevated T_c and sweat rates of 400-600 ml at temperatures over 30°C for at least 5 days, and is humidity-specific (Garrett, Rehrer, & Patterson, 2011).

Acclimation may prove a valuable strategy to improve performance in the cold. However, more research is needed to investigate the sport-specificity of such acclimation practices, and practical implications may limit their success (Nimmo, 2004). Lorenzo, Halliwell, Sawka, and Minson (2010) studied the effect of heat acclimation on aerobic performance in a hot (30°C) and cool (13°C) environment. Twelve competitive-level cyclists performed time trials before and after a 10-day heat acclimation program (45min, ~50%VO_{2max}, 40°C, 30%RH). Time-trial performance was measured as total work completed in 60minutes cycling. Compared to baseline values, heat acclimation increased VO_{2max}, time-trial performance, power output at lactate threshold, plasma volume and maximal cardiac output in both hot and cool conditions. Further research is needed to examine whether heat acclimation would improve performance in even colder temperatures (Lorenzo, Halliwill, Sawka, & Minson, 2010). More research is also needed considering cold acclimation in exercising subjects. In one study considering local cooling (8°C water immersion) of the hand while cycling, expected impairment of neuromuscular function after 30 minutes of cold water immersion was not attenuated with repeated cold exposures (fifteen immersions over 3 weeks), and was not affected by the increase of blood flow from exercising participant (Geurts, Sleivert, & Cheung, 2006). Upon baseline testing, (Westerlund, Oksa, Smolander, & Mikkelsson, 2009) found that neuromuscular performance as measured by agonist and antagonist activity during a drop jump was significantly lower following 2 minutes of whole-body cryoptherapy exposure (-110°C) compared to pre-exposure. After 3 months of 3x/week 2-minute exposures, participants performed the drop jump again prior to and following a single exposure. Following the adaptation period, no difference was seen in agonist and antagonist activity following exposure compared to pre-exposure, indicating an adaptation in neuromuscular function through a reduced co-contraction.

Diet manipulation. Temperature, exercise intensity and endurance affect substrate utilization. First and foremost, energy intake should match energy expenditure. Substrate usage in the cold has previously been discussed; despite a general decrease in metabolism, cold conditions may increase glycogen usage due to involuntary shivering, decreased muscle efficiency, recruitment of more type II muscle fibres, and/or increased oxygen consumption (Dixon et al., 2010; Young et al., 1985). However, Young (1989) also showed that that energy-depleted subjects did not lose their inherent ability to regulate temperature in cold conditions at rest.

During prolonged exercise in ambient conditions, performance is enhanced when glycogen depletion is prevented or delayed due to strategies such as carbohydrate ‘loading’. Exercise in the heat seems to increase carbohydrate utilization by augmenting the secretion of epinephrine and by increasing muscle metabolism (Febraio, 2000). In cool conditions (4°C, 11°C), Galloway and Maughan (1997) postulated that prolonged exercise performance is limited by muscle glycogen depletion. However, Febraio (2000) noted that exercise- and heat-induced fatigue is centrally mediated, and is unrelated to substrate availability. Pitsiladis and Maughan (1999) examined the effects of exercise and diet manipulation on prolonged exercise performance capacity in the heat and the cold. Results showed that cycling time to exhaustion was influenced by both ambient temperature and diet. Cycling time to exhaustion increased in the cold (10°C) from 89min on a low carbohydrate (CHO) diet to 158min on a high CHO diet. In the heat (30°C), cycling time to exhaustion increased from 44min on low CHO to 53min on high CHO. These results are consistent with the proposition that substrate depletion is the primary contributing factor to fatigue in the cold, but not in the heat. Cycling capacity in 10°C was greater regardless of low or high CHO trial over cycling capacity in 30°C, suggesting that fatigue in the heat was most likely due to thermoregulatory stress, hypohydration, and/or changes in muscle metabolism (Pitsiladis & Maughan, 1999).

Limitations of the Literature

To date, the majority of research examining the effect of T_m on performance has used exclusively male participants. Women generally tolerate physiological and thermal stress of exercise as well as men of comparable fitness and acclimation levels; however, women produce less sweat for a similar heat-exercise load than men despite possessing more heat-activated sweat glands per unit skin area and initiating sweating at a higher skin and core temperature than men

(McArdle et al., 2010). These differences may have considerable effects on T_m gradient and its effect on performance, especially during short-term performance. Although there are difficulties associated with using female participants in thermoregulatory studies such as fluctuating T_c due to menstruation, studies designed to include women participants will help clarify our understanding of these differences.

The current literature on WU is not consistent with regards to timing, intensity, duration, and recovery guidelines. When considering training and competition in cool environmental conditions, it is important to establish parameters around these variables to optimize WU. It should be of sufficient duration and intensity to result in performance benefits for short and intermediate duration performance resulting from elevated T_m.

Psychological and physiological benefits resulting from WU occur simultaneously; it is difficult, if not impossible, to differentiate between them which has a greater effect on performance. In addition to previously discussed benefits resulting from increased temperature and blood flow, WU can improve psychological performance through improved preparedness and mental activation state, and pre-competition routine. Psychological benefits of WU have been shown in the literature, but individual responses vary; therefore, recommendations for WU based on the specific environment and sport will allow individual athletes to establish an optimal WU routine that will prepare them both physiologically and psychologically for competition.

Two recent studies have shed light on the use of HP as a strategy to maintain muscle performance during delays between WU and competition (Cook et al., 2013; Faulkner et al., 2013); however, this area of research is still limited. HP could benefit athletes across sports that perform in varying cool and cold conditions where the nature of the training or competition environment includes unavoidable delays and periods of inactivity. During these delays, athletes will experience core and muscle cooling, thereby losing important temperature and non-temperature related mechanisms that improve performance. Peripheral cooling of the skin in cool and cold environments further amplifies muscle and core heat loss as superficial blood flow continues to cool at the skin-environment interface.

Summary

Despite having a narrow range of tolerance in terms of T_c, athletes who must compete in hot and cold conditions show remarkable adaptability to the environment. Heat loss and heat production mechanisms respond to both exercise and the surrounding environment to optimize thermal balance and consequent performance. Short-term, intermediate, and long-term performance in hot and cold conditions is modulated by thermal and non-thermal factors contributing to heat exchange. Post-exercise heat storage and elevated T_c can affect subsequent bouts during repeated intermittent exercise performance. Exercising in the heat may benefit some short-duration activities but contributes to exertional heat stress and fatigue during long-term performance. Cool conditions may improve long-term performance by attenuating core heating; however, cool and cold conditions are detrimental to short-term, intermediate, and sometimes prolonged exercise due to lower cell metabolism, reduced vasoconstriction, decreased nerve conduction velocity and impaired muscle contractility. Anthropometric profiles can contribute to heat loss or gain, and may be an important factor in preventing heat loss and improving performance in the cold; however, compromising optimal muscle condition, fibre type, and lean muscle mass for insulative adipose tissue or greater thigh girth may counteract benefits gained from heat retention.

Strategies for minimizing detriments caused by hot and cold conditions, and for maximizing performance, include pre-cooling in the heat, passive and active WU, acclimatization or acclimation, and diet manipulation if appropriate. An active WU preceding exercise can be adapted to almost any sport situation and can contribute to performance through decreased viscous resistance, increased T_m and activation, increased nerve conduction rate, increased oxygen delivery to muscles, and enhanced mental preparedness. However, the temperature-related and non-temperature-related benefits resulting from active WU are lost if the recovery period of inactivity following WU is too long. Heat is lost to the environment more readily in cool and cold environments, further exacerbating detrimental effects on performance. Although passive WU alone has not shown to significantly affect T_m and related performance advantages, passive heating may be a valuable method of maintaining T_m increases resulting from active WU (Sporer et al., 2008). Recent literature has shed light on the use of HP as a strategy to maintain muscle performance during delays between WU and competition (Cook et al., 2013; Faulkner et al., 2013; Sporer et al., 2008). However, this area of research is still limited, and the parameters of the studies were inconsistent with respect to environmental conditions considered and performance variables measured. The current study provides valuable insight into T_m and associated muscle performance while employing active and passive WU strategies to improve high-intensity performance in cool (~10°C) conditions.

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Appendix B
Participant Information Sheet

Information Sheet for Participants

"Time course of changes in muscle temperature and performance following active warm up in cool environments"

Thank you for showing an interest in this project. Please read the informed consent carefully for a detailed idea of the timelines and requirements of the study before deciding whether or not to participate, and don't hesitate to ask if you have any questions. If you decide not to take part there will be no disadvantage to you of any kind and I thank you for considering participating.

The aim of this study is to measure the response of inner muscle temperature to an active cycling warm up, during inactivity (sitting) following warm up, and during power performance tests (maximal vertical jump and a Wingate anaerobic test) in a cool environment (10°C). Body temperature will be measured from core to periphery of the body by measuring core, muscle, and skin temperature. Core temperature is measured by rectal thermometer - a thin flexible plastic tube inserted 10cm past the rectum. Muscle temperature is measured 3.5cm deep in the lateral thigh (vastus lateralis) using a muscle temperature probe that is inserted via needle - the needle is removed right away and the probe is taped down and stays in during the duration of the testing session. Skin temperature will be measured using skin thermistors that are taped to the outside of the skin (4 right leg, 2 left leg).

3 testing days consist of:

Day 1 (~1hr) - descriptive measures/tests (maximal incremental test on the bike, skinfold measurements) and familiarization with the performance tests (vertical jump and Wingate).

Days 2&3 (~2h each) - experimental session measuring core, muscle, and skin temperature (1 control session and 1 intervention session in heated pants) with performance tests (vertical jump and 45-s anaerobic sprint test on a cycle ergometer).
All 3 test session will take place at the Canadian Sport Institute Pacific Performance Lab and Mobile Environmental Trailer. The address is 4371 Interurban Rd, Camosun Interurban Campus, in the Pacific Institute for Sport Excellence (PISE). Canadian Sport Institute Pacific's Performance Lab is in room 206 of the building (second floor).

If you decide to volunteer for the study:

- Please bring shorts and shoes appropriate for cycling, running shoes you can cycle and jump in, a water bottle, and a long-sleeved shirt, sweater, or light jacket similar to what you would expect to wear in ~10°C weather when you would be training or competing outside.
- Please try to be consistent with your diet and training throughout your participation in the study.

Pre-Test Protocol for VO2max test (Day 1):

- No food or caffeine 3 hrs prior to testing
    - A snack is fine, but please avoid having a heavy meal beforehand
- No vigorous exercise 4 hrs prior to session
- No smoking 4h prior to test

These protocols are also recommended for the experimental sessions (2&3) - please don't have a heavy meal right before coming in for testing, but you will get hungry if you don't eat so have a light meal or snack about an hour beforehand if possible and bring a snack with you. Try to keep it consistent before both experimental sessions.

My contact information is below in case you have any questions or if you need to get a hold of me.

Thanks,

Megan Kidston
mkidston@uvic.ca
[redacted]

Appendix C
Testing Schedule

Testing Schedule

“Time course of changes in muscle temperature and performance following active warm up in cool environments”

During the recruitment process, a meeting will take place between potential subjects and a member of the research team during which the project and its objectives will be explained. Potential participants will be provided with an information sheet about the study and a Physical Activity Readiness Questionnaire (PAR-Q) form. If the information session is not conducted in person or by telephone, an information sheet and PAR-Q will be sent to the participant via e-mail. Should the participant express interest in taking part in the study, a signed hard copy of the PAR-Q must be obtained prior to participation.

Participants will be required to visit the testing facility on 3 different occasions.
On day 1 (session 1, approximately 1.25 hours), participants will be required to visit the Canadian Sport Institute Pacific’s Performance Lab to undergo basic anthropometric descriptive measures, perform an incremental exercise test, and be familiarized with anaerobic Wingate and vertical jump testing and protocols.
On days 2 and 3 (sessions 2 and 3, approximately 2 hours each), participants will be required to visit Canadian Sport Institute Pacific’s Mobile Environmental Trailer (MET) to perform the following two experimental trials at 10°C:

- 15 minutes of standardized aerobic activity followed by 30 minutes of inactivity
- 15 minutes of standardized aerobic activity followed by 30 minutes of inactivity with passive heating to maintain muscle temperature

The order of each of these conditions will be randomized. The timeline of events during testing days are as follows:

Time	**Event**
Session 1 (75 minutes)	
15 minutes	Height, weight, and basic anthropometric descriptive measures taken.
10 minutes	Participants will be instrumented with a heart rate monitor, head- and mouth-piece and will prepare for incremental exercise test.
15 minutes	Incremental exercise test on cycle ergometer.
15 minutes	Rest and recovery from incremental exercise test.
20 minutes	Familiarization with Monark cycle ergometer and anaerobic Wingate test, and vertical jump protocol.

Timeline of events (con't)

Time	**Event**
Sessions 2 and 3 (2 hours each, 4 hours total)	
45 minutes	Participants will be instrumented for heart rate, muscle, skin and core temperature measures. They will be instructed to wear typical cycling clothing for cool conditions.
15 minutes	Participants will enter the chamber and baseline measures will be measured continuously and recorded every 5 minutes. Vertical jump will be recorded at the end of baseline.
15 minutes	Aerobic cycle exercise for 15 minutes at a standardized intensity of 70% or maximum heart rate (HR) determined in maximal aerobic exercise test in session 1. Muscle temperature, HR, skin temperature and core temperature measures will be recorded. Vertical jump will be recorded following warm up.
30 minutes	Participants will stop exercising and remain inactive. HR and core, skin and muscle temperature will be measured continuously and recorded every 5 minutes. Thermal comfort, thermal sensation, and vertical jump height will be measured and recorded every 10 minutes. At the end of the 30 minutes following warm up, a 45s anaerobic Wingate test will be performed on the Monark cycle ergometer.
	Participants may walk out of the chamber after final measures have been recorded.
15 minutes	Removal of heart rate monitor, skin thermistors, muscle probe, and rectal probe. The research team will be responsible for cleaning and sterilization of all instrumentation once they have been removed. In the case of the rectal probe, sterilization will be done by the research team following the initial cleaning and placement of probe in the participant-labeled soap and water container by the participant.

Appendix D
Informed Consent Form

INFORMED CONSENT FORM

University of Victoria | School of Exercise Science, Physical & Health Education

Participant Consent Form

"TIME COURSE OF CHANGES IN MUSCLE TEMPERATURE AND PERFORMANCE FOLLOWING ACTIVE WARM UP IN COOL ENVIRONMENTS"

You are invited to participate in a research study entitled **"TIME COURSE OF CHANGES IN MUSCLE TEMPERATURE AND PERFORMANCE FOLLOWING ACTIVE WARM UP IN COOL ENVIRONMENTS"** that is being conducted by Megan Kidston. In summary, the study will look at the response of inner muscle temperature to an active cycling warm up, during inactivity (sitting) in a cool environment (10°C), and during power performance tests (maximal vertical jump and a Wingate anaerobic test).

Megan Kidston is a graduate student in the department of Exercise Science, Physical and Health Education (EPHE) at the University of Victoria. You may contact her if you have further questions by e-mail: mkidston@uvic.ca or phone: [redacted].

As a graduate student, I am required to conduct research as part of the requirements for a M.Sc. degree. The research is being conducted under the supervision of Dr. Ben Sporer and Dr. Lynneth Stuart-Hill. Please direct any questions for my supervisors to Dr. Sporer by e-mail: bsporer@resync.ca or phone: [redacted].

Purpose and Objectives

There are three purposes to this proposed project:

1) To evaluate the effects of inactivity on muscle temperature following a general aerobic warm up;
2) To relate changes in muscle temperature to exercise performance; and
3) To evaluate the effectiveness of passive heating in maintaining muscle temperature and performance.

Importance of this Research

Research of this type is important to Canadian athletes preparing to compete in possible cool temperatures such as the 2012 Olympic Games (July/August) in London. Other possible applications of this information include:

1) Identification of ways to lessen risk of injury due to cold, unprepared muscle;
2) Carry forward results from cycling into other sport and recreation activities to help athletes and participants perform better in cool conditions; and
3) Provide further understanding and information regarding the use of passive heating garments.

Participant Selection

You are being asked to participate in this study because you fit within the requirements of the target population (age 19-35 physically active recreational male or female athlete who has previously participated in regular training). This population represents the largest group from which individual responses are expected to be similar to those from summer sport athletes.

What is Involved

If you agree to voluntarily participate in this research, your participation will include travel to the Canadian Sport Institute Pacific at the Pacific Institute for Sport Excellence (PISE), located at 4371 Interurban Road, Victoria, BC.

Canadian Sport Institute Pacific Performance Lab

- *Day 1 (session 1, approximately 1.25 hours) will require participants to visit the Canadian Sport Institute Pacific's Performance Lab for initial screening, descriptive measures, familiarization with protocols and training including:*
    - Administration of the Canadian Society for Exercise Physiology's Physical Activity Readiness Questionnaire (PAR-Q) if not already completed;
    - Measuring height, weight and body composition through skinfold protocol;
    - Perform a maximal incremental exercise test;
    - A familiarization session to learn the vertical jump technique;
    - A familiarization session with the Monark cycle ergometer and the maximal anaerobic Wingate test; and
    - Familiarization with warm up bike and seat and handlebar height adjustment.

- *Before both testing sessions (approx. 45 minutes each):* Instrumentation (placement) of heart rate, muscle, skin and core temperature measures prior to both testing sessions.

Canadian Sport Institute Pacific's Mobile Environmental Trailer (MET)

- *Two testing sessions (approx. 1 hour each) where you will carry out one of the following two conditions at 10°C:*
  - 15 minutes of standardized aerobic activity followed by 30 minutes of inactivity; or
  - 15 minutes of standardized aerobic activity followed by 30 minutes of inactivity with passive heating to maintain muscle temperature.
      - Passive heating will be administered through heated leggings, constructed with commercially available fabrics using construction techniques and voltages similar to those used in heated seats for automotive applications and heated garments for outdoor activities. They have been tested extensively on their own and worn, with no instances of over-heating of any kind. The power supply has an upper limit, meaning that there will always be an external control on the supplied voltage, as well as a self-adjustable power control panel.

The order of each of these conditions will be randomized.

You will be provided with as much water as desired during both experiment days.

The timeline of events during experimental testing days 1 and 2 (sessions 2 and 3) will include:

Time	Event
Session 1 (75 minutes)	
15 minutes	Height, weight, and basic anthropometric descriptive measures taken.
10 minutes	Participants will be instrumented with a heart rate monitor, head- and mouth-piece and will prepare for incremental exercise test.
15 minutes	Incremental exercise test on cycle ergometer.
15 minutes	Rest and recovery from incremental exercise test.
20 minutes	Familiarization with Monark cycle ergometer and anaerobic Wingate test, and vertical jump protocol.

Time	Event
Sessions 2 and 3 (2 hours each, 4 hours total)	
45 minutes	Participants will be instrumented for heart rate, muscle, skin and core temperature measures (see below). They will be instructed to wear typical cycling clothing for cool conditions.
15 minutes	Participants will enter the chamber and baseline measures will be measured continuously and recorded every 5 minutes. Vertical jump will be recorded at the end of baseline.
15 minutes	Aerobic cycle exercise for 15 minutes at a standardized intensity of 70% HRmax based on incremental exercise test. Muscle temperature, HR, skin temperature, core temperature will be measured continuously. Vertical jump will be recorded following warm up.

30 minutes	Participants will stop exercising and remain inactive. HR and core, skin and muscle temperature will be measured continuously and recorded every 5 minutes. Thermal comfort, thermal sensation, and vertical jump height will be measured and recorded every 10 minutes. At the end of the 30 minutes following warm up, a 45s anaerobic Wingate test will be performed on the Monark cycle ergometer. Participants may walk out of the chamber after final measures have been recorded.
15 minutes	Removal of heart rate monitor, skin thermistors, muscle probe, and rectal probe. The research team will be responsible for cleaning and sterilization of all instrumentation once they have been removed. In the case of the rectal probe, sterilization will be done by the research team following the initial cleaning and placement of probe in the participant-labeled soap and water container by the participant.

Monitoring Core, Muscle and Skin Temperature

- You will have your internal temperature measured by wearing a rectal temperature sensor. The rectal sensor consists of a very thin and flexible plastic tube that is inserted 10 cm beyond the anus.
- Every 10 minutes during the session, your thigh muscle temperature will be recorded using sterile probes. The muscle temperature probe (a thin filament) will be inserted using a needle at the beginning of each session and removed at the end of each session. The needle will be removed immediately after insertion with only the filament remaining inserted for the duration of the session.
- Skin temperature will be measured using wires taped to the surface of the skin at 12 different locations (6 on each leg; 2 on each major muscle group).

Monitoring Heart Rate

You will wear a polar heart rate transmitter strap around your chest to monitor your heart rate throughout the testing session.

Measuring maximal oxygen capacity (VO_{2max})

You will be instrumented with a heart rate monitor, headpiece and a Rudolf valve attached to a mouthpiece that will be connected by a hose to a metabolic cart during testing to collect and analyze expired air.

Maximal aerobic power (VO_{2max}) will be directly determined using a cycle ergometer protocol involving incremental increases in power output. You will begin the test with a 10min warm up at self-selected intensity, trying out different workloads. The test begins at 0 Watts (W) and power output is increased by 1 W every 2 seconds in a 30W/min ramp protocol until exhaustion. The test will take approximately 10-15 minutes depending on the fitness level of each individual. Verbal encouragement will be provided during the later stages of this test. Your maximal heart rate will be recorded using a transmitter/receiver telemetry unit (Polar heart rate monitor). Expired gases will be collected and analyzed to determine oxygen consumption (VO_2), minute ventilation (VE), production of carbon dioxide (VCO_2), and respiratory exchange ratio (RER).

Measuring Vertical Jump Height

Vertical jump height will be measured following baseline measures, immediately following warm up, and at 10 minute intervals following warm up. You will perform a standardized countermovement vertical jump on a jump mat which will measure your air time and jump height. You will repeat the jump 3 times with 15 seconds of rest between each jump.

Anaerobic Wingate Test

A 45s maximal anaerobic test of short-term power will be performed at the end of the experimental trial 30minutes after warm up and immediately following the final vertical jump measures. There will be a 1-min lead-in to the testing at 60rpm before a weight basket containing your calculated workload based on body weight is dropped at the start of the test; at this point you pedal as hard and as fast as you can with the increased resistance on the flywheel for 45seconds. At the end of the test the weight is lifted so you can pedal easily and recover.

Inconvenience

Participation in this study may cause some inconvenience to you, including:

Muscle temperature

You may experience some tenderness associated with the muscle temperature measurements, however the discomfort should not persist for more than 24hrs.

Time commitment

Participation in this study requires a 5.25 hour time commitment over 3 days of testing: An initial screening, testing and familiarization session (1.25 hours), and two experimental trials (2 hours each). There is flexibility within these schedules in case anything us unclear and/or you would like additional explanations and familiarization with anything. You are free to terminate your participation in this study at any time without explanation.

Risks

There are some potential risks to you by participating in this research, including:

Maximal and sub maximal exercise: You may experience soreness, fatigue, and possibly nausea from the maximal aerobic and anaerobic tests. Your interest in this study indicates that you meet the requirements for participant characteristics and therefore you are a recreational athlete with a history of training. It should be communicated with any of the research team if you do not have experience with high-intensity (maximal) exercise and are uncomfortable with any of the testing protocols. You must complete a Physical Activity Readiness Questionnaire (PAR-Q) prior to inclusion in this study.

Insertion of the rectal probe may result in mild discomfort, but since you insert it yourself, this risk is minimal. If discomfort continues for more than 30 minutes after the experiment, tell the investigators and they will refer you to medical attention. Although there is a risk of perforation of the bowel, the investigators and their consultants are unaware of this ever having occurred.

Initially, the probe is given to you in a sterile, unopened package. Your probe will be disinfected using standard techniques following each testing session and you will reuse your own probe for the course of this study. Therefore, although there is a theoretical risk of transmission of infectious disease (such as HIV or hepatitis), this risk is negligible and will only occur if you accidentally use someone else's probe, that person has an infectious disease, and their probe has not been properly disinfected. However, this risk is avoided through proper disinfection of your probe after each use and placement of the probe in a clearly labeled package.

Needle insertion to measure muscle temperature might result in mild discomfort similar to that experienced during blood sample collection, as the size of the needle is similar. You will be asked to relax during the measurements. In the instance that you become dizzy and/or faintish during the procedure, equipment available to deal with this circumstance include a mat for lying down, cold towels, and fruit juice/snacks. Bruising and a feeling of stiffness at the puncture site may also occur following the testing session(s). If discomfort continues for more than 30 minutes after the experiment, please advise the principal investigator and you will be referred to medical attention. There is a risk of infection with the temperature measurement, including hepatitis and HIV. However, this risk is extremely low and similar to that during blood collection in a laboratory, as sterile procedures are used in our laboratory and a sterile muscle temperature probe is used for each measurement.

The heated leggings have been constructed with commercially available fabrics using construction techniques and voltages similar to those used in heated seats for automotive applications and heated garments for outdoor activities. They have been tested extensively on their own and being worn, with no instances of over-heating of any kind. The batteries are UL approved; in the configuration contemplated here there is no risk of injury to the participants.

To prevent or to deal with these risks the following steps will be taken:
A member of the research team will be accessible to you at all times, with the exception of bathroom breaks and core temperature probe insertion (for privacy reasons), to communicate verbally or physically (e.g. raise hand, get up and walk out of the MET) if you have any discomfort, pain, and/or distress, and/or if you would like to temporarily or permanently terminate the session at any time. Only the technician administering skinfold measurements will be present during anthropometric assessment, also for privacy/modesty reasons. You will never be left alone in the Mobile Environmental Trailer. Your safety and comfort are of utmost importance; all members of the research team are well trained to monitor participants for signs of discomfort during the session, to recognize signs that you are having difficulty performing a task, and to facilitate cessation of the session if the he/she deems it necessary and/or you wish to terminate the session for any reason.

There will always be two people facilitating the testing; one to act as a spotter for the participant and monitor the participant's safety during the testing, and the other to run the metabolic cart and/or record information being read off the computer/data logger/etc. In the event that a participant experiences dizziness, nausea, or fainting during the exercising protocol, they will stop immediately and be allowed to lie down on mats to rest until the symptoms disappear. Supplemental oxygen will be made available if the need arises. In the extremely unlikely event that the symptoms persist, EMS would be contacted. Should the circumstances arise, we have a defibrulator in the laboratory. A telephone will be dedicated to emergency calls during the trials. There will be at least two investigators or technicians present at all times. A First Aid and minimum CPR "A" certified individual will either be present during testing.

Maximal and Sub maximal Exercise

Participants will be screened prior to testing using the PAR-Q. The research team and Canadian Sport Institute Pacific staff are well trained in screening and monitoring participants prior to and during testing, and recognizing any signs that a participant is having difficulty performing the task. As a participant in this study, you are required to have an athletic training background and should communicate with the researchers if you are unable to perform or uncomfortable performing high-intensity exercise.

Termination criteria for VO_{2max}:

- Inability to maintain workload;
- VO2 does not increase even with an increase in workload; or
- Participant signals the end of the test.

Thermal Stress

Your core temperature will be monitored continuously during the experimental session and the session will be terminated immediately if core temperature drops below 35.0ºC. This is the historical cut-off temperature for studies involving human cooling. Furthermore, the clinical definition for the upper limit of hypothermia is deep core temperature of 35.0ºC; therefore you will be stopped prior to becoming hypothermic. The participant will be escorted from the environmental chamber and be given heating garments and warm fluids until core temperature returns to 36.5ºC.

Rectal Probe

Insertion of the rectal probe may result in mild discomfort, but since you insert it yourself, this risk is minimal. If discomfort continues for more than 30 minutes after removal of the probe, let any member of the research team know, and you will be referred to medical attention. Although there is a risk of perforation of the bowel, the investigators and their consultants are unaware of this ever having occurred. You will be trained in appropriate techniques for self-insertion of the rectal probe. Probes will be properly disinfected by the lab technician and assistants and will be clearly labeled to avoid inadvertently sharing probes between participants.

Muscle temperature

The lab technician is trained in the insertion of the needle probe and sterile techniques. The probes will be sterilized by autoclaving (high pressure and high heat steam sterilization) in the Canadian Sport Institute Pacific Performance Lab between each use. Investigators and support staff are trained in the use of sterile techniques when handling, preparing, removing, and cleaning probes, as well as preparing participants for needle insertion and sterilizing and covering the site following probe removal.

Termination Criteria

Experimental sessions will be terminated if:

- Rectal temperature goes lower than 35.0°C;
- Dizziness or nausea prevents further experimentation;
- Participant decides, for any reason, to end the experiment; and/or
- The investigators determine that the participant is unable or unfit to continue.

It is recommended to contact your family physician to see if there are any other reasons why you shouldn’t participate in this study (i.e. – decreased immune system). A telephone will be dedicated to emergency calls during the trials. There will be at least two investigators or technicians present at all times. A First Aid and minimum CPR “A” certified individual will either be present during testing or on-call from the Performance Lab.

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

Benefits

Your participation in this research is expanding the pool of knowledge in the area of body temperature regulation. The knowledge gained from this research will be beneficial to summer sports in optimizing timing of warm up and strategies to maintain muscle temperature prior to competition. The findings may also be applied to individuals working in physically demanding jobs in cool outdoor 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 not be used.

A member of the research team will be accessible at all times, with the exception of bathroom breaks and core temperature probe insertion (for privacy reasons), to communicate verbally or physically (e.g. raise hand, get up and walk out of the MET) if you experience any discomfort, pain, and/or distress, and/or if you would like to temporarily or permanently terminate the session at any time; any assistance needed or wanted will be given to remove all instruments (skin thermistors, muscle probe) in the Performance Lab.

Anonymity and Confidentiality

Concealing your name and identity in this project is not fully possible since the investigators will know of your participation. All data obtained will be used solely for the purpose of analyzing the group effects of warm up in cool environments and using passive heating as a strategy to prevent decreases in muscle temperature following warm up.

Results of this project may be published, but any data included will not be linked to a specific participant. Your data will be assigned a personal identification number to ensure anonymity in both the analysis and documentation of results. The data collected and the coded identifications will be securely stored in separate locked cabinets in such a way that only the principal investigators will be able to gain access to both. The results of this study may be used by Canadian coaches and athletes in preparation for competition in cool conditions.

Dissemination of Results

It is anticipated that the results of this study will be shared with others in the following ways:

- Thesis/Dissertation/Class Presentation;
- Presentations at scholarly meetings;
- Directly to participants and/or groups involved; and/or
- Published article.

Disposal of Data

At the end of the project any personal information will be destroyed immediately except any raw data on which the results of this project depend which will be retained in secure storage for five years, after which they will be destroyed.

Contacts

Questions, concerns, logistical or scheduling questions can be directed to Megan Kidston or Rob Gathercole. Lab technician Wendy Pethick may be reached at the Canadian Sport Institute

Performance Lab if you have questions or concerns regarding lab protocols (muscle and core temperature). Dr. Sporer may also be contacted regarding any aspect of the study design or protocols.

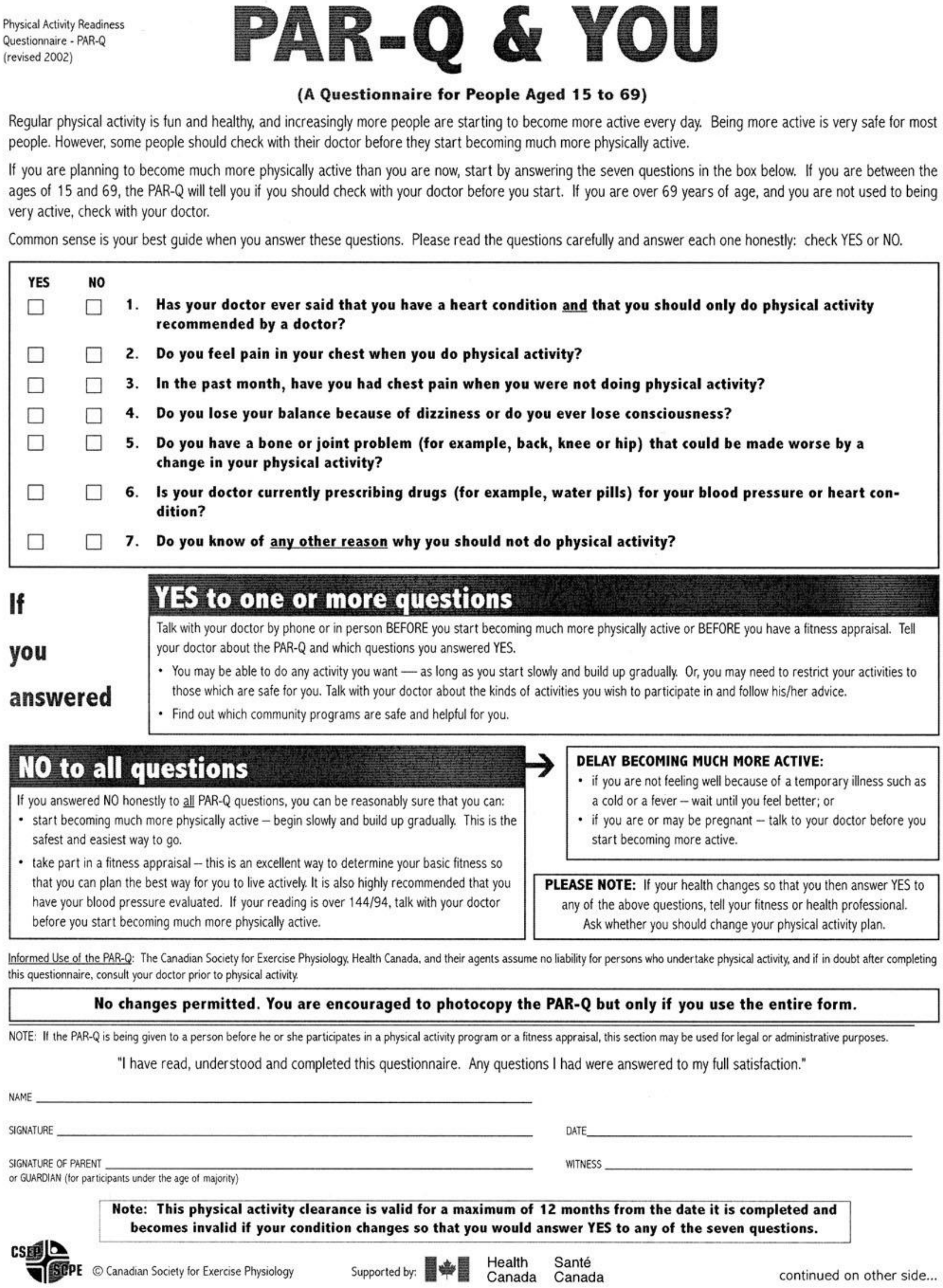
	E-mail	*Phone*
Megan Kidston, Principal Investigator	mkidston@uvic.ca	[redacted]
Rob Gathercole, Research and Recruitment Assistant	GathercoleR@camosun.bc.ca	[redacted]
Wendy Pethick, Lab Technician	wpethick@csipacific.ca	Canadian Sport Institute Pacific Performance Lab [redacted]
Dr. Ben Sporer, Supervisor	bsporer@csipacific.ca;	[redacted]

In addition, you may verify the ethical approval of this study, or raise any concerns you might have, by contacting the Human Research Ethics Office at the University of Victoria.
E-mail: ethics@uvic.ca Phone: (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*
Name of Witness	*Signature*	*Date*

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

Appendix E
Physical Activity Readiness Questionnaire



Physical Activity Readiness
Questionnaire - PAR-Q
(revised 2002)

PAR-Q & YOU

(A Questionnaire for People Aged 15 to 69)

Regular physical activity is fun and healthy, and increasingly more people are starting to become more active every day. Being more active is very safe for most people. However, some people should check with their doctor before they start becoming much more physically active.

If you are planning to become much more physically active than you are now, start by answering the seven questions in the box below. If you are between the ages of 15 and 69, the PAR-Q will tell you if you should check with your doctor before you start. If you are over 69 years of age, and you are not used to being very active, check with your doctor.

Common sense is your best guide when you answer these questions. Please read the questions carefully and answer each one honestly: check YES or NO.

YES	NO		
☐	☐	**1.**	**Has your doctor ever said that you have a heart condition and that you should only do physical activity recommended by a doctor?**
☐	☐	**2.**	**Do you feel pain in your chest when you do physical activity?**
☐	☐	**3.**	**In the past month, have you had chest pain when you were not doing physical activity?**
☐	☐	**4.**	**Do you lose your balance because of dizziness or do you ever lose consciousness?**
☐	☐	**5.**	**Do you have a bone or joint problem (for example, back, knee or hip) that could be made worse by a change in your physical activity?**
☐	☐	**6.**	**Is your doctor currently prescribing drugs (for example, water pills) for your blood pressure or heart condition?**
☐	☐	**7.**	**Do you know of any other reason why you should not do physical activity?**

If you answered

YES to one or more questions

Talk with your doctor by phone or in person BEFORE you start becoming much more physically active or BEFORE you have a fitness appraisal. Tell your doctor about the PAR-Q and which questions you answered YES.

- You may be able to do any activity you want — as long as you start slowly and build up gradually. Or, you may need to restrict your activities to those which are safe for you. Talk with your doctor about the kinds of activities you wish to participate in and follow his/her advice.
- Find out which community programs are safe and helpful for you.

NO to all questions

If you answered NO honestly to all PAR-Q questions, you can be reasonably sure that you can:

- start becoming much more physically active – begin slowly and build up gradually. This is the safest and easiest way to go.
- take part in a fitness appraisal – this is an excellent way to determine your basic fitness so that you can plan the best way for you to live actively. It is also highly recommended that you have your blood pressure evaluated. If your reading is over 144/94, talk with your doctor before you start becoming much more physically active.

→ **DELAY BECOMING MUCH MORE ACTIVE:**

- if you are not feeling well because of a temporary illness such as a cold or a fever – wait until you feel better; or
- if you are or may be pregnant – talk to your doctor before you start becoming more active.

PLEASE NOTE: If your health changes so that you then answer YES to any of the above questions, tell your fitness or health professional. Ask whether you should change your physical activity plan.

Informed Use of the PAR-Q: The Canadian Society for Exercise Physiology, Health Canada, and their agents assume no liability for persons who undertake physical activity, and if in doubt after completing this questionnaire, consult your doctor prior to physical activity.

No changes permitted. You are encouraged to photocopy the PAR-Q but only if you use the entire form.

NOTE: If the PAR-Q is being given to a person before he or she participates in a physical activity program or a fitness appraisal, this section may be used for legal or administrative purposes.

"I have read, understood and completed this questionnaire. Any questions I had were answered to my full satisfaction."

NAME ______________________________

SIGNATURE ______________________________ DATE ______________________

SIGNATURE OF PARENT ______________________________ WITNESS ______________________
or GUARDIAN (for participants under the age of majority)

Note: This physical activity clearance is valid for a maximum of 12 months from the date it is completed and becomes invalid if your condition changes so that you would answer YES to any of the seven questions.

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Appendix F
Psychophysical Scales

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)

Cue: “How hot or cold are you?”

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)

Cue: “How comfortable are you?”

Appendix G
Raw Data

Table G1

Individual, mean, and standard deviation (SD) scores of participants' physical characteristics (n=8).

Participant	Age (yrs)	Height (m)	Weight (kg)	Thigh girth (mm)	BMI (kg·m^2)	Sum of 8 (mm)	Calc. fat (%)	Relative V0$_{2peak}$ (mL·kg^{-1}·min^{-1})
1	22	1.795	78.9	58.2	24.5	55.3	8.8	56.4
2	33	1.877	92.52	58.4	26.3	114.2	17.6	49.0
3	28	1.875	87.06	56.7	24.8	88.7	13.9	53.5
4	33	1.805	86.44	60.5	26.5	75.3	11.7	66.3
5	22	1.865	76.5	54.7	22.0	92.6	14.6	54.0
6	33	1.743	72.24	54.2	23.8	78	12.3	57.3
7	27	1.943	79.58	49.9	21.1	60.4	9.4	67.0
8	31	1.841	67.14	49.1	19.8	57.7	9.1	60.9
Mean	29	1.843	80.05	55.2	23.6	77.8	12.2	58.0
SD	5	0.061	8.34	4.1	2.4	20.3	3.1	6.3

Table G2

Individual, mean and standard deviation(SD) scores of muscle temperature (°C) in the control condition during 15-minute baseline, 15-minute warm up and 30-minute post-warm up (n=8).

	Time (min)											
	Baseline			Warm up			Post-warm up					
Participant	5	10	15	20	25	30	35	40	45	50	55	60
1	35.2	35.1	34.9	37.5	38.2	38.6	37.9	37.6	37.2	36.8	36.3	35.8
2	34.3	34.3	33.8	35.4	36.5	37.1	36.5	35.9	35.7	35.4	34.9	34.7
3	33.5	33.5	33.1	35.4	36.4	36.5	36.0	35.5	34.9	34.3	34.1	33.8
4	33.4	33.1	32.7	35.1	36.5	37.1	36.7	36.3	35.8	35.3	34.8	34.2
5	33.0	32.7	32.3	34.8	36.7	36.6	36.5	36.5	36.4	37.3	33.4	33.0
6	34.6	34.3	34.2	36.9	38.3	39.0	37.9	37.6	37.4	36.8	36.0	35.5
7	31.8	31.4	31.1	33.1	34.6	35.6	35.0	34.6	34.1	33.7	33.4	33.1
8	35.3	35.1	35.7	37.6	38.4	38.7	37.8	37.3	37.0	36.5	36.3	35.9
Mean	33.9	33.7	33.5	35.7	36.9	37.4	36.8	36.4	36.1	35.8	34.9	34.5
SD	1.2	1.3	1.5	1.5	1.3	1.2	1.0	1.1	1.2	1.3	1.2	1.2

Table G3

Individual, mean and standard deviation (SD) scores of muscle temperature (°C) in the heated pants condition during 15-minute baseline, 15-minute warm up and 30-minute post-warm up (n=8).

	Time (min)											
	Baseline			Warm up		Post-warm up						
Participant	5	10	15	20	25	30	35	40	45	50	55	60
1	34.3	34.0	33.7	35.6	36.7	37.4	37.8	38.1	38.0	37.7	37.4	37.6
2	33.4	33.4	33.1	34.1	35.5	36.9	37.4	37.5	37.2	37.2	36.8	36.5
3	34.0	33.9	33.8	35.6	36.8	37.6	37.7	37.7	37.8	37.5	37.3	37.0
4	33.3	33.2	33.2	36.5	37.7	37.8	37.7	37.6	37.2	37.1	37.1	36.9
5	33.6	33.7	33.5	35.3	36.5	37.1	37.4	37.4	37.1	36.9	36.6	36.4
6	36.0	36.1	36.0	37.4	38.0	38.2	38.0	37.9	37.7	37.6	37.5	37.4
7	33.0	33.1	32.9	34.5	35.7	36.6	37.3	37.3	36.8	36.9	36.2	35.9
8	35.3	35.3	35.2	37.4	38.3	38.7	38.3	38.1	38.0	37.9	37.8	37.6
Mean	34.1	34.1	33.9	35.8	36.9	37.5	37.7	37.7	37.5	37.4	37.1	36.9
SD	1.0	1.1	1.1	1.2	1.0	0.7	0.3	0.3	0.5	0.4	0.5	0.6

Table G4

Individual, mean and standard deviation (SD) scores of countermovement vertical jump height (cm) in the control condition immediately following 15-minute baseline, 15-minute warm up and at 10-, 20- and 30-min post-warm up (n=8).

	Time (min)				
	BL	WU	P-WU		
Participant	15	30	40	50	60
1	48.5	55.9	53.1	50.0	47.8
2	42.9	53.1	50.3	49.3	47.2
3	39.6	47.8	41.9	39.6	41.4
4	54.9	63.2	58.9	57.9	56.4
5	54.4	63.5	56.4	54.6	52.3
6	42.4	52.6	49.3	46.2	45.5
7	54.4	65.3	60.7	57.9	58.2
8	53.3	57.2	54.4	52.6	52.6
Mean	48.80	57.31	53.12	51.02	50.17
SD	6.31	6.22	6.00	6.18	5.69

Table G5

Individual, mean and standard deviation (SD) scores of countermovement vertical jump height (cm) in the heated pants condition immediately following 15-minute baseline, 15-minute warm up and at 10-, 20- and 30-min post-warm up (n=8).

	Time (min)				
	BL	WU	P-WU		
Participant	15	30	40	50	60
1	50.3	58.2	52.6	52.1	52.1
2	47.5	56.1	52.8	51.6	51.3
3	39.6	48.3	44.5	41.9	41.4
4	58.2	65.8	63.8	60.2	61.2
5	51.8	61.7	53.6	50.8	53.3
6	40.6	48.8	46.0	43.9	43.4
7	57.2	63.2	63.0	57.7	61.5
8	52.1	57.7	55.6	54.1	53.1
Mean	49.66	57.47	53.98	51.53	52.17
SD	6.82	6.36	6.95	6.21	7.21

Table G6

Individual, mean and standard deviation (SD) scores of Wingate relative 5s peak power (5sPP), relative average 45s power (45sPP)and Fatigue Index in heated pants (HP) and control (CON) conditions at 30-min post-warm up (n=8).

	CON			HP		
Participant	5sPP (W/kg)	45sPP (W/kg)	Fatigue Index (%)	5sPP (W/kg)	45sPP (W/kg)	Fatigue Index (%)
1	1118.75	688.47	63.64	1155.57	699.53	65.10
2	779.00	576.58	49.50	787.94	588.40	48.37
3	809.31	645.39	37.11	917.96	671.41	40.25
4	767.94	618.68	40.35	805.69	618.27	43.75
5	821.35	663.22	43.45	822.68	689.92	39.64
6	1065.80	782.42	45.24	998.75	800.79	40.29
7	1092.62	728.45	58.44	1068.42	718.5	60.63
8	836.05	593.45	59.23	830.48	597.69	59.71
Mean	911.35	662.08	49.62	923.44	673.06	49.72
SD	152.12	69.45	9.76	137.13	70.93	10.51

Appendix H
Raw Data of Excluded Participants

Table H1

Individual, mean, and standard deviation (SD) scores of excluded participants' physical characteristics (n=7).*

Participant	Age (yrs)	Height (m)	Weight (kg)	Thigh girth (mm)	BMI (kg·m^2)	Sum of 8 (mm)	Calc. fat (%)	Relative V0$_{2peak}$ (mL·kg^{-1}·min^{-1})
1	20	1.884	88.60	56.7	25.0	83.6	13.0	53.61
2	22	1.716	80.18	60.6	27.2	72.9	11.9	63.11
3	28	1.719	83.96	59.5	28.4	150.1	24.8	53.72
4	34	1.758	73.94	54.6	23.9	115.8	17.8	59.37
5	32	1.870	81.36	54.8	23.3	73.9	11.6	57.89
6	20	1.686	61.04	52.1	21.5	46.9	7.5	65.86
7	26	1.79	81.48	58.1	25.4	76.5	12.3	55.35
Mean	26.00	1.77	78.65	56.63	25.0	88.5	14.1	58.42
SD	5.66	0.08	8.92	3.00	2.4	33.9	5.6	4.71

*Two participants completed session 1 (familiarization and descriptive measurements) but did not complete experimental sessions 2 & 3

Table H2

Individual, mean and standard deviation(SD) scores of excluded participants' muscle temperature (°C) in the control condition during 15-minute baseline, 15-minute warm up and 30-minute post-warm up (n=5).

	Time (min)											
	Baseline			Baseline			Baseline					
Participant	5	10	15	20	25	30	35	40	45	50	55	60
1	33.9	33.5	32.9	34.0	36.7	37.2	37.0	36.1	35.3	34.7	34.0	33.5
2	32.3	31.9	31.6	34.5	35.9	36.6	35.9	35.0	34.4	33.5	33.1	32.5
3	35.8	35.5	35.3	38.0	38.9	39.2	38.1	37.4	36.9	36.4	36.2	35.9
4	34.3	34.1	33.9	35.4	36.9	37.4	36.6	36.2	35.6	34.9	34.5	34.2
5	34.3	34.2	33.9	36.4	37.5	37.8	37.2	36.6	36.2	35.9	33.7	33.4
Mean	34.1	33.8	33.5	35.7	37.2	37.6	37.0	36.3	35.7	35.1	34.3	33.9
SD	1.2	1.3	1.4	1.6	1.1	1.0	0.8	0.9	0.9	1.1	1.2	1.3

Table H3

Individual, mean and standard deviation (SD) scores of excluded participants' muscle temperature (°C) in the heated pants condition during 15-minute baseline, 15-minute warm up and 30-minute post-warm up (n=8).

	Time (min)											
	Baseline			Warm up			Post-warm up					
Participant	5	10	15	20	25	30	35	40	45	50	55	60
1	34.0	34.1	33.8	37.0	38.1	38.7	38.5	38.3	38.1	38.1	37.7	37.2
2	32.0	31.6	31.6	35.2	36.8	37.5	37.3	37.2	36.3	35.8	35.5	35.0
3	33.9	33.8	33.6	35.3	37.1	37.8	37.4	37.3	36.8	36.6	36.2	35.7
4	33.4	33.4	33.4	35.7	37.0	37.5	37.3	37.0	36.7	36.6	36.4	36.2
5	34.2	34.2	33.7	36.6	37.7	38.3	37.4	37.3	36.8	36.4	36.2	36.2
Mean	33.5	33.4	33.2	36.0	37.3	38.0	37.6	37.4	36.9	36.7	36.4	36.1
SD	0.9	1.1	0.9	0.8	0.5	0.5	0.5	0.5	0.7	0.8	0.8	0.8

Table H4

Individual, mean and standard deviation (SD) scores of excluded participants' countermovement vertical jump height (cm) in the control condition immediately following 15-minute baseline, 15-minute warm up and at 10-, 20- and 30-min post-warm up (n=5).

	Time (min)				
	BL	WU	P-WU		
Participant	15	30	40	50	60
1	43.2	49.5	47.5	44.7	42.7
2	54.9	58.9	57.4	55.9	53.6
3	51.1	57.2	51.6	50.5	49.0
4	50.8	55.1	51.8	51.3	48.8
5	48.3	54.9	52.3	47.8	46.2
Mean	49.6	55.1	52.1	50.0	48.1
SD	4.3	3.5	3.5	4.2	4.0

Table H5

Individual, mean and standard deviation (SD) scores of excluded participants' countermovement vertical jump height (cm) in the heated pants condition immediately following 15-minute baseline, 15-minute warm up and at 10-, 20- and 30-min post-warm up (n=5).

	Time (min)				
	BL	WU	P-WU		
Participant	15	30	40	50	60
1	43.7	50.5	45.7	46.5	44.5
2	55.4	60.7	61.5	58.9	55.4
3	50.8	58.4	55.9	54.6	52.3
4	51.8	54.1	53.1	50.8	50.8
5	50.0	54.9	52.6	50.3	47.8
Mean	50.3	55.7	53.7	52.2	50.1
SD	4.2	3.9	5.7	4.7	4.2

Table H6

Individual, mean and standard deviation (SD) scores of excluded participants' Wingate relative 5s peak power (5sPP), relative average 45s power (45sPP)and Fatigue Index in heated pants (HP) and control (CON) conditions at 30-min post-warm up (n=5).

	CON			HP		
Participant	5sPP (W/kg)	45sPP (W/kg)	Fatigue Index (%)	5sPP (W/kg)	45sPP (W/kg)	Fatigue Index (%)
1	887.95	608.91	47.89	912.06	601.51	50.08
2	943.46	720.51	49.07	981.34	723.64	51.95
3	1041.82	698.91	54.02	1111.55	742.45	71.20
4	985.19	669.55	50.53	931.77	671.33	54.31
5	886.8	716.4	41.91	857.05	691.79	39.73
Mean	949.04	682.86	48.68	958.75	686.14	53.45
SD	66.24	45.95	4.43	96.32	54.75	11.38

Appendix I
Correlations: Heat Loss vs. Thigh Girth

Table I1

Correlations Between Measures (n=8)

Measure	Heat Loss (CON)	Heat Loss (HP)
Thigh Girth	.441	.126
Thigh Skinfold	.318	.145