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The Effects of Wearing a Cooling Vest During the Warm-Up on Long Distance Interval Training

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THE EFFECTS OF WEARING A COOLING VEST DURING THE WARM-UP ON LONG DISTANCE INTERVAL TRAINING

by

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Department of Exercise Sciences

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GRADUATE COMMITTEE APPROVAL

of a thesis submitted by

Andrew R. Tegeder

This thesis has been read by each member of the following graduate committee and by majority vote has been found to be satisfactory.

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Date	Ron Hager
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BRIGHAM YOUNG UNIVERSITY

As chair of the candidate's graduate committee, I have read the thesis of Andrew R. Tegeder in its final form and have found that (1) its format, citations, and bibliographical style are consistent and acceptable and fulfill university and department style requirements; (2) its illustrative materials including figures, tables, and charts are in place; and (3) the final manuscript is satisfactory to the graduate committee and is ready for submission to the university library.

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ABSTRACT

THE EFFECTS OF WEARING A COOLING VEST DURING THE WARM-UP ON LONG DISTANCE INTERVAL TRAINING

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Purpose: Reducing body temperature before exercise is called precooling. Past research suggests that reducing body core temperature (T_c) slightly can result in improved running performance. This study evaluated the effects that warming up, while wearing a cooling vest prior to an interval workout, had on T_c, and interval time in long-distance runners. **Methods**: Nineteen healthy male collegiate cross-country runners were recruited for this study. Each subject warmed up and exercised under two different conditions: (a) an experimental condition in which subjects wore a Nike PreCool® ice vest during warm-up and (b) a control condition. Subjects performed a warm-up followed by running eight 1000 m intervals separated by 90 s of rest. Heart rate (HR) and T_c were measured prior to warm-up, just prior to start of the first interval, and after each interval. **Results**: T_c measured directly prior to the first interval was significantly lower in the vest condition than the non-vest condition (difference = 0.37°C; $P < 0.05$). This difference persisted through the end of the sixth interval. T_c rose at a faster rate in the non-vest condition, though this difference was not significant (*P* = 0.07). Differences in HR and interval times were found to be nonsignificant between conditions for all intervals. **Conclusion**: Wearing an ice vest prior to and during warm-up effectively lowers T_c during long-distance interval training.

ACKNOWLEDGMENTS

I would like to thank Dr. Hunter for his help through this long process. Thanks also to Dr. Mack, Dr. Hager, and Sandy Alger for their assistance and suggestions. Special thanks to Julie and Noah for helping me relax at the end of the day.

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The Effects of Wearing a Cooling Vest During the Warm-up on Long-Distance Interval Training.

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Purpose: Reducing body temperature before exercise is called precooling. Past research suggests that reducing body core temperature (T_c) slightly can result in improved running performance. This study evaluated the effects that warming up, while wearing a cooling vest prior to an interval workout, had on T_c, and interval time in long-distance runners. **Methods**: Nineteen healthy male collegiate cross-country runners were recruited for this study. Each subject warmed up and exercised under two different conditions: (a) an experimental condition in which subjects wore a Nike PreCool® ice vest during warm-up and (b) a control condition. Subjects performed a warm-up followed by running eight 1000 m intervals separated by 90 s of rest. Heart rate (HR) and T_c were measured prior to warm-up, just prior to start of the first interval, and after each interval. **Results**: T_c measured directly prior to the first interval was significantly lower in the vest condition than the non-vest condition (difference = 0.37°C; $P < 0.05$). This difference persisted through the end of the sixth interval. T_c rose at a faster rate in the non-vest condition, though this difference was not significant ($P = 0.07$). Differences in HR and interval times were found to be nonsignificant between conditions for all intervals. **Conclusion**: Wearing an ice vest prior to and during warm-up effectively lowers T_c during long-distance interval training.

INTRODUCTION

One of the limits to endurance exercise is internal body core temperature (T_c). When T_c reaches a critical limiting level of ~39°C to 40°C the individual experiences fatigue (9,15). In theory, if endurance athletes had the ability to prolong the time to reach this critical T_c then they may be able to train harder, produce a higher level of fitness, and improve run times during competitions. One method to achieve a reduced T_c is to precool the body.

Reducing T_c prior to exercise improves running performance (1,4,5). Various methods to precool subjects have been used such as immersion in cold water, exposure to cold air, wearing a liquid-perfused garment or wearing a cooling vest. Several companies have designed vests that are meant to reduce T_c in athletes before competition. These cooling vests hold frozen ice packs in close contact with the body. Because of their relatively light weight, athletes are able to wear vests during the warm-up directly prior to an event. One recent study showed that T_c (rectal temperature), skin temperature, and esophageal temperature all decreased during warm-up with a cooling vest (1). More importantly, time to complete a 5km simulated race was reduced following a warm-up with a cooling vest, than without (1). This study showed a reduction in heart rate (HR) when athletes exercised under precooled conditions. This leads to speculation that athletes may be able to perform more work if they precool before competition or training.

Previous studies evaluating cooling vests have focused on the effects the vest might have on performance during a simulated race or long-duration, submaximal exercise. This study will evaluate the use of a cooling vest as a training aid for long-distance runners. Long-distance runners routinely perform interval workouts during training. Other precooling studies have only looked at the effect precooling has on continuous exercise. This experiment demonstrates the effects of wearing a cooling vest during warm-up on T_c, HR, and interval completion time during interval training in NCAA division I distance runners.

METHODS

Subjects. Nineteen healthy subjects were recruited from a Western states university men's cross-country team. Subjects were similar in age (21.2 yrs ± 0.6 yrs), height (1.81 m ± 0.8 m), mass (68.1 kg ± 0.02 kg), and body surface area (1.87 m^2 ± 0.03 m^2). All subjects provided written informed consent and all procedures were approved by the institutional review board at Brigham Young University.

Testing Protocol and Procedures. Each subject warmed up and exercised under two different conditions: (a) an experimental condition in which subjects wore a cooling vest (Nike, Beaverton, OR) during warm-up and (b) a control condition in which subjects wore a regular T-shirt during warm-up. The testing days were separated by 6 days, and groups were randomly assigned (randomized crossover design) which day they wore the cooling vest during warm-up. Each subject served as his own control.

Subjects reported for testing after a two-hour fast. However, subjects were allowed to drink as much water as they desired. Subjects were instructed not to consume caffeine 12 hours before testing. Three hours before reporting for testing, each subject swallowed a telemetry pill. Each subject's T_c was taken prior to putting on the cooling vest. Subjects put on the cooling vest 30 minutes prior to their warm-up. After resting 30 minutes with the cooling vest on, subjects began warming up while still wearing the cooling vest. The warm-up protocol before the training sessions was the same on each day and consisted of about 15 minutes of jogging, followed by stretching and 100m strides at the workout pace. Before the warm-up, subjects placed a heart-rate monitor around their chest. Subjects were allowed to drink as much water as they wanted during warm-up and in between the interval workouts.

After the warm-up, subjects removed the cooling vest and ran eight 1000m intervals separated by 90 seconds. Each subject performed the intervals with a group of runners with similar running abilities. The coach gave each group a minimum time requirement in which they had to complete each interval during the training session. HR and T_c were measured prior to warm-up, just prior to start of the first interval, and after each interval. Time to complete each interval was also recorded.

Testing Equipment. T_c was measured using the CorTemp T_c monitoring system (HQ Inc., Palmetto, FL). The CorTemp system consists of a small precalibrated ingestible sensor (telemetry pill) which measures and transmits T_c. Each subject swallowed a sensor (about the size of a large vitamin) three hours before T_c was measured. T_c was measured with a monitor after the pill entered the subject's GI tract. HR was measured by a Polar HR monitor (Polar Electro, Woodbury, NY) and reported in beats per minute (bpm). Environmental conditions at the workout site (dry bulb temperature, wet bulb globe temperature (WBGT), and relative humidity) were measured using a heat stress indicator (Microtherm Heat Stress W136T, Casella, Amhurst, NH) while wind speed was taken from measurements at a university weather station located within one mile of the testing site.

Statistical Analysis. Data were analyzed using a repeated-measures ANOVA to determine the significance of the means by condition (vest v. non-vest) using the SAS System for Univariate and Multivariate Statistics (version 9.2). Level of significance was set at 0.05 and all data are represented as means ± SE. Significant differences of HR, T_c, and interval times between conditions at any given measurement period was determined by computing a minimum significant difference (MSD) value using Tukey's honest significant difference method.

RESULTS

Temperatures and humidity on testing days. Testing was performed on 2 days separated by 6 days. Average dry bulb temperature for the first day of testing was 24.6°C ± 0.17°C, relative humidity was 39.9% ± 2.7%, WBGT was 19.9°C ± 0.15ºC, and wind speed was 1.15 m/s ± 0.01 m/s. Average dry bulb temperature on the second day of testing was 31.1°C ± 0.07°C ($P < 0.05$, different from day 1), relative humidity was 38.9% ± 0.3%, WBGT was 24.7°C ± 0.06ºC ($P < 0.05$, different from day 1), and wind speed was 1.09 m/s ± 0.01 m/s. Small differences in dry bulb temperature and WBGT on the testing days may have limited our ability to compare these two sets of data. However, the plateau in T_c during each workout reached similar levels on both days (first testing day = 38.66°C ± .07°C; second day = 38.82°C ± .06°C). Based on the work of Lind (13), we felt that both WBGT values fell below the upper limit of the expected prescriptive zone for our experimental conditions (WBGT and exercise intensity). As such, comparing the T_c response for vest and non-vest conditions from these two days was deemed acceptable. In addition, repeated measures ANOVA did not reveal a time-by-treatment interaction for T_c, HR, or interval times. This indicates that each of these variables responded similarly for each condition on the two testing days.

T_c responses: baseline, warm-up and during 1000 m intervals. Baseline T_c measured prior to warm-up or precooling period were similar between conditions (vest = 37.1°C ± 0.08ºC, non vest = 37.24°C ± 0.14ºC). T_c measured directly prior to the first interval was significantly lower in the vest condition than the non-vest condition (vest = 37.05°C ± 0.22ºC, non vest = 37.42°C ± 0.2ºC) ($P < 0.05$). Figure 1 shows the average temperatures for each condition. T_c in the vest condition was significantly less than the non-vest condition directly before the first interval (difference = 0.37°C ± 0.2°C) ($P < 0.05$). This significant difference between T_c persisted through the end of the 6th interval. After the 7th and 8th intervals differences between conditions were not significant.

T_c for both conditions leveled out at similar values (vest = 38.78°C ± 0.02°C; non-vest = 38.84°C ± 0.02°C). The vest grouped reached its peak T_c after the 7th interval and the non-vest group reached its peak T_c by the 5th interval. The vest condition (0.051°C/min ± 0.01°C/min) had a slightly lower rate of T_c increase ($P = 0.07$) than the non-vest condition (0.066°C/min ± 0.01°C/min).

HR and interval time responses during 1000m intervals. The HR response to exercise was similar with or without precooling (Fig. 2). The interval times were also similar for the vest and non-vest condition (Fig. 3).

DISCUSSION

The most important observation of this study is that precooling with an ice vest reduced T_c and delayed the time to reach the peak T_c of 38.8ºC. As such, the subjects were allowed to train at a lower T_c for approximately 30 minutes of an interval workout. Despite the reduction in T_c, there was no marked impact on the average interval time or HR.

The reduction in T_c we observed was similar to those found in previous precooling studies employing a cooling vest (1,10). The magnitude of the decrease in T_c following precooling is dependent on the technique used. For example, whole-body cooling using either water immersion or cold air exposure has resulted in a substantially larger decrease in T_c than precooling with an ice vest (12,14,15). The unique aspect to precooling with an ice vest is that it is more practical to athletes since it can be used while performing their typical warm-up activities. Relatively few studies have employed cooling vests as a means of precooling. One study using a cooling vest found that precooled subjects had reduced 5km run times (1,6). Our study demonstrated a similar reduction in T_c during the warm-up period prior to an interval workout but no change in our index of performance, interval split time.

Many studies show improved exercise performance after precooling (4,9,10,11,12,16). Whether a cooling vest precools the body sufficiently to allow an improvement in exercise performance is unclear. In 2003 White, Davis, and Wilson (17) showed that both whole-body precooling and lower-body precooling reduced T_c. More importantly, lower-body precooling "minimized metabolic increases and negative perceptual effects associated with whole-body precooling" (17). Cotter, Sleivert, Roberts, and Febbraio (6) compared cycling performance between three groups: a control group, an ice vest group, and an ice vest plus thigh cooling group. They found that both precooled groups performed better in the heat than the control group during continuous exercise in the heat, but there was no difference between the two precooled groups (6). Their results suggest that an ice vest alone provides a benefit to performance without the need to specifically cool other parts of the body or those muscles directly involved with the exercise. The results of our study confirm the ability of upper-body cooling with an ice vest will significantly reduce T_c during exercise in a warm environment. However, no performance benefit was observed during this high intensity, intermittent exercise workout.

Not every precooling study has seen an improvement in exercise performance (8). Bergh and Ekblom (2) were the first to evaluate precooling's affects on performance. Using cold-water immersion, these researchers achieved a very low pre-exercise T_c of 35.8°C in one group and 34.9°C in another. The results showed a decreased performance in arm and leg exercise to exhaustion among precooled subjects. Bolster et al. (3) used cold-water immersion to determine if precooling enhances triathlon performance. The researchers found that precooling attenuated the rise of T_c, but the effect was transient (3). Their results showed no benefit to HR, RPE, thermal discomfort, oxygen uptake, or sweat rate. They concluded that precooling might not be beneficial to triathletes under the environmental conditions they imposed (3).

The unique aspect of this study is the use of high intensity long-distance interval running as the exercise mode. One previous study by Drust et al. (7) focused on thee effects of precooling on T_c, HR, and other physiological responses to soccer-specific intermittent exercise (7). The exercise protocol consisted of subjects running on a treadmill at varying speeds for specific periods of time. The protocol consisted of static pauses, walking, jogging, sub-maximal high intensity running, and sprinting. Subjects in this study ran on a treadmill, simulating the type of exercise intensities they would experience in a regular soccer match. The researchers did not see significant differences for oxygen consumption, HR, or rectal temperature. They concluded that precooling would therefore not be beneficial to soccer specific intermittent exercise. It is possible that the improvement in exercise performance with a reduction in Tc is not manifest in a high intensity, intermittent exercise setting.

Results of this study show that during the interval workout, T_c reached a plateau level of 38.8°C ± 0.3°C in both groups. The rate of increase in T_c tended to be lower ($P = 0.07$) in the vest group (0.056°C/min ± 0.01°C/min) than the non-vest group (0.064°C/min ± 0.01ºC/min). The rate of heat storage is dependent on the balance between heat production, related to metabolic rate or training pace, and heat dissipation, related to radiant and convective heat loss and evaporative heat loss. The similar rates of heat storage during the interval workouts reflect the similar rates of metabolic heat production and similar balance of heat dissipating mechanisms. The cooling vest allowed for the athletes to reduce the initial T_c during the warm-up period and thereby store more heat during the interval workout. The plateau in T_c, the point at which the rate of heat production and heat dissipation were equal and therefore the rate of heat storage was equal to zero, occurred earlier in the non-vest group. A higher capacity to store heat should mean less thermal strain during exercise in conditions where heat dissipating mechanisms are unable to match metabolic heat production.

The nature of this field study imposes specific limitations. This study was conducted in the field where the environmental factors are not controlled. Fortunately, the WBGT index for the two days was within the prescriptive zone of this exercise intensity and should not significantly impact the analysis of T_c. Also, the rest period between each interval was short making it difficult to measure thermal discomfort and rating of perceived exertion (RPE). Fluid consumption was not controlled in this study. Fluid ingestion could have impacted our data in two ways. First, insufficient fluid intake could lead to dehydration and excessive hyperthermia in some subjects. Second, the ingestion of cold fluid might impact the T_c measurement directly if the sensor had not moved far enough into the small intestines prior to the start of the workouts. Six subjects showed at least one unusual post-interval T_c decrease. It is not clear whether these "unusual" drops in T_c reflect fluid ingestion or some other artifact associated with rapid movement of the sensor through the GI tract. In support of this latter possibility, we noted one subject had passed the sensor through the entire GI tract by the start of the interval workout.

In summary, precooling with an ice vest effectively lowered T_c in trained athletes completing a long-distance interval workout. The lower T_c was apparent through six out of eight 1000m intervals. Performance in the form of interval times and HR was not affected by the precooling technique. However, the nature of this study made controlling for other variables that affect performance impossible. Future research should explore potential benefits of long-term training with an ice vest in hot and humid climates.

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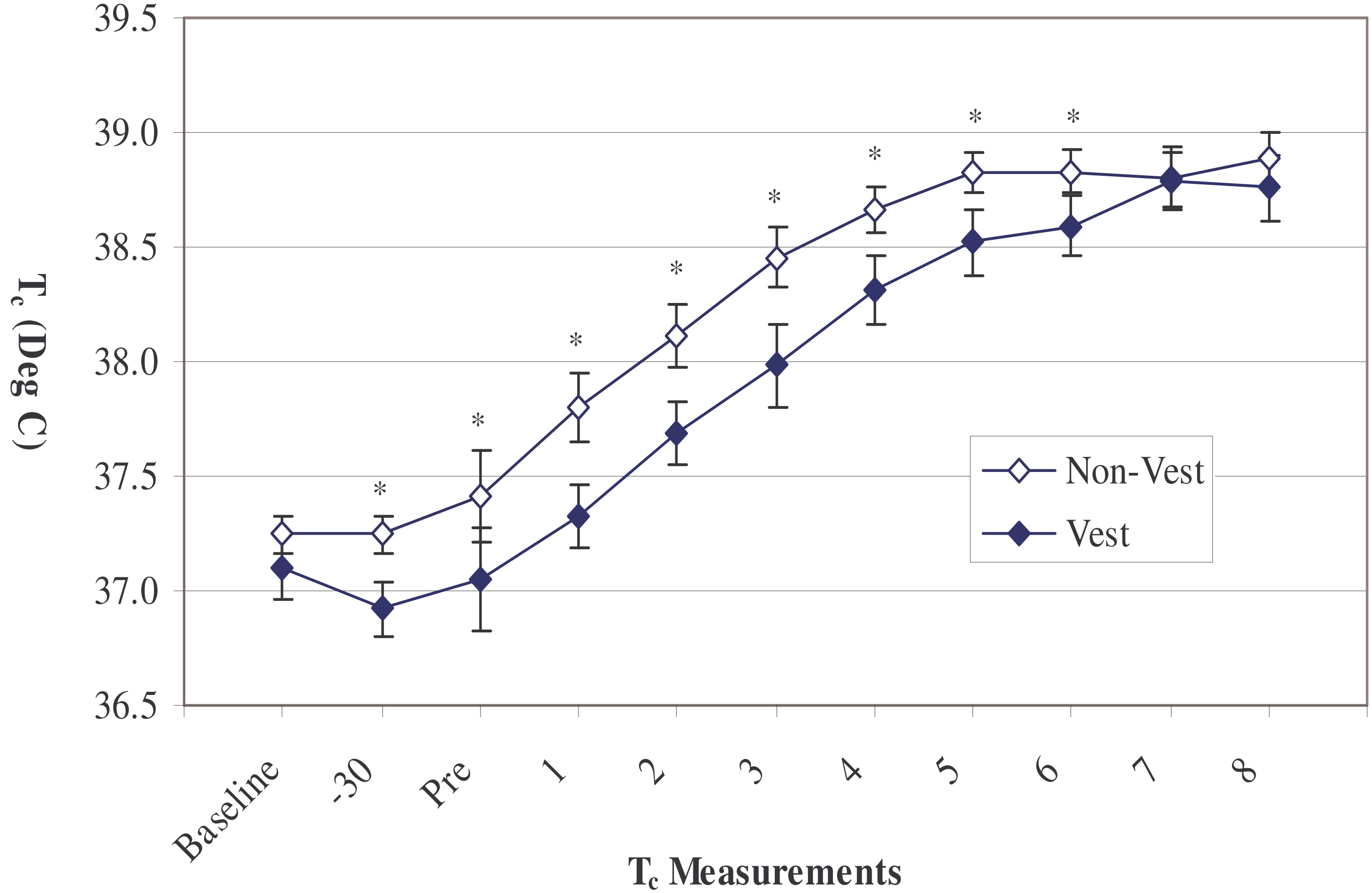
Figure Legends

Figure 1. Average body core temperatures (°C) measured at baseline, prior to warm-up period, just before the 1st interval, and immediately following each 1000m interval. Values are mean ± SE. * denotes significantly different from Vest condition ($p < 0.05$)

Figure 2. Average heart rates (bpm) measured directly after each 1000m interval. Values are mean ± SE

Figure 3. Average time (s) to complete each 1000m interval. Values are mean ± SE



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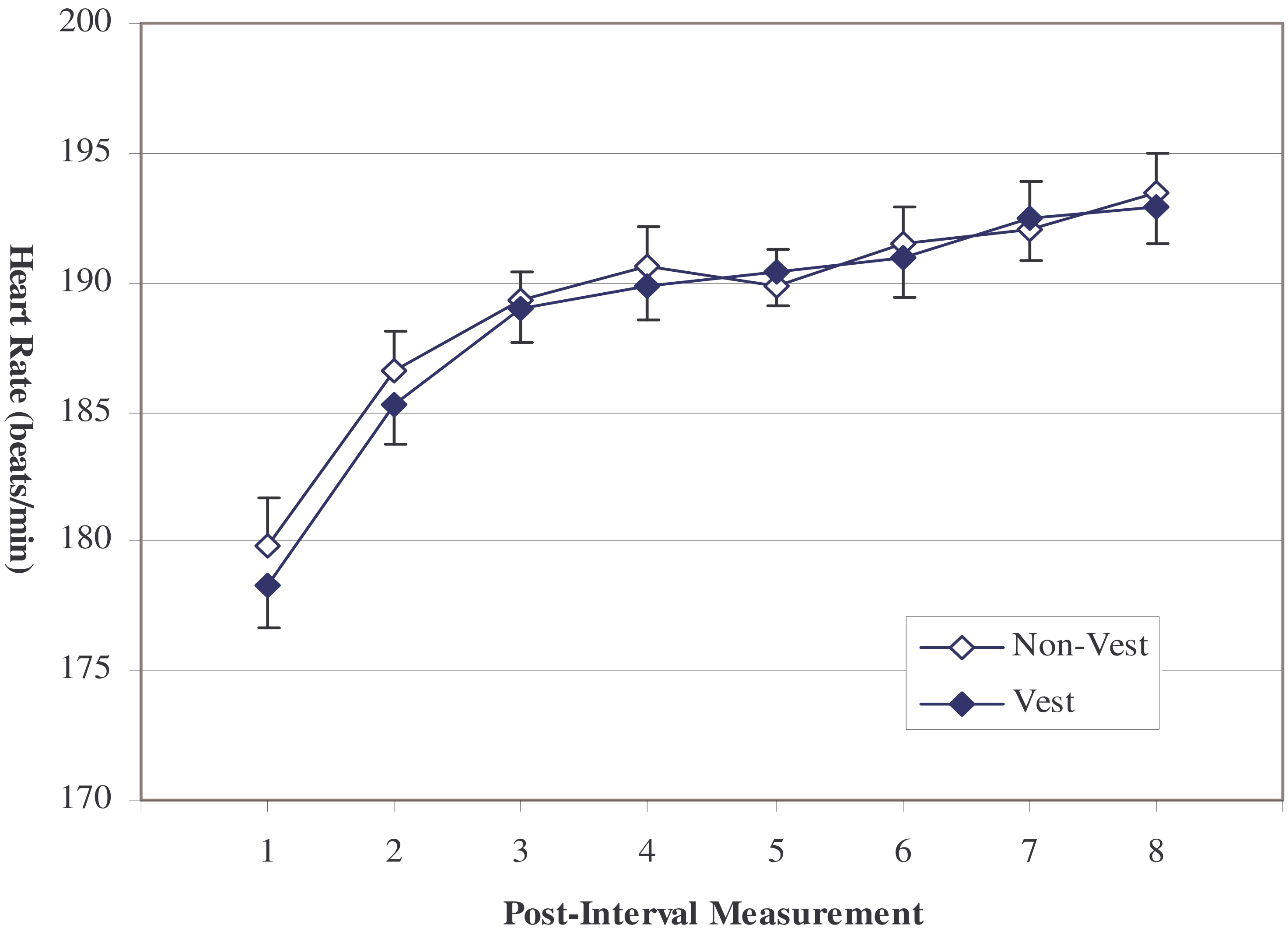

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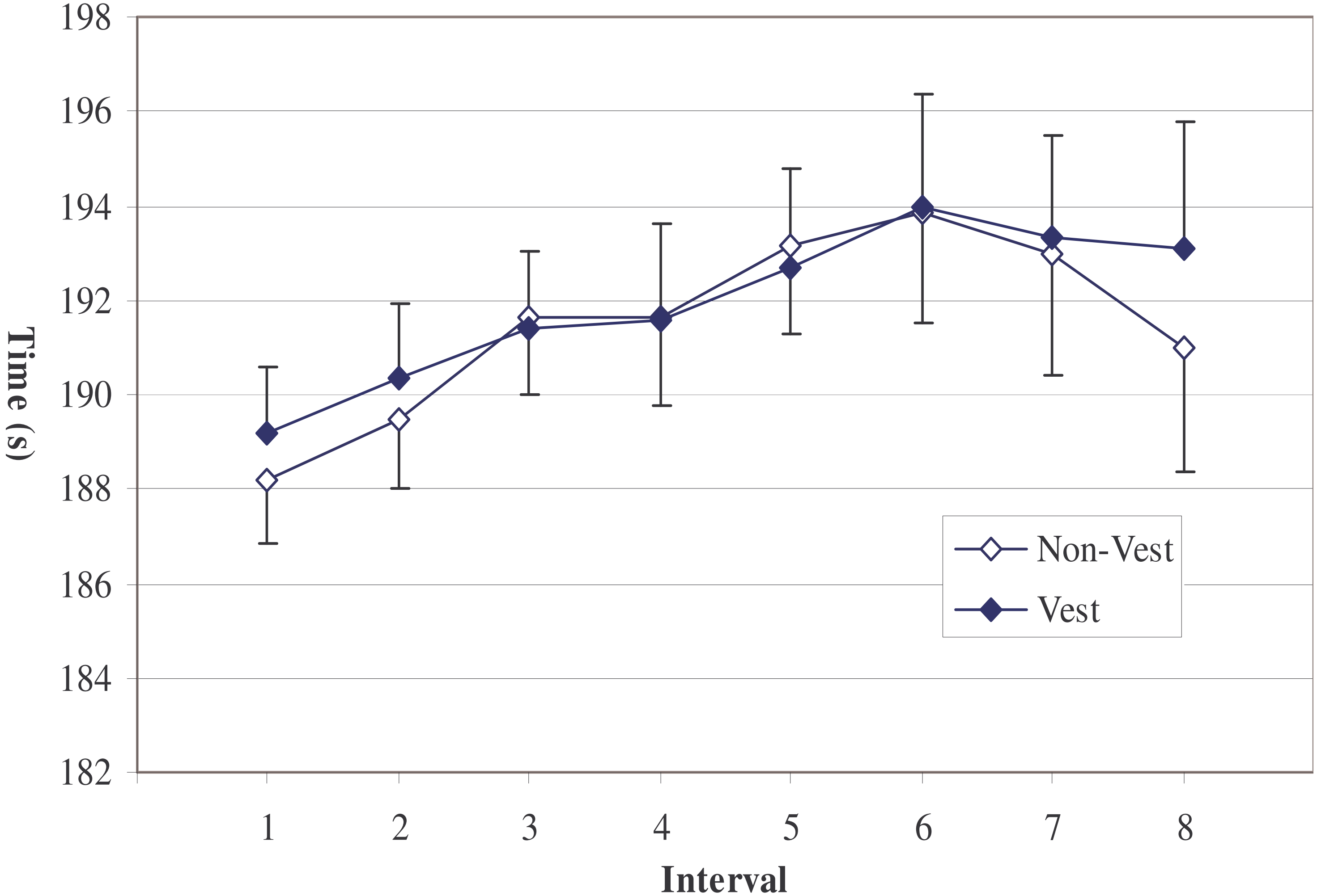

Figure 3. Average time (s) to complete each 1000m interval. Values are mean ± SE

Appendix A

Prospectus

Chapter 1

Introduction

One of the limits to endurance exercise is internal body core temperature (T_c). When T_c reaches a critical limiting level of ~39°C to 40°C the individual experiences fatigue (11,19). In theory, if an endurance athlete had the ability prolong the time to reach this critical T_c then they may be able to train harder and produce a higher level of fitness and improved run times during competitions. One method to achieve a reduced T_c is to precool the body.

Reducing T_c prior to exercise improves running performance (1,5,7). Various methods to precool subjects have been used such as immersion in cold water, exposure to cold air, wearing a liquid-perfused garment or wearing a cooling vest. Several companies have designed vests that are meant to reduce T_c in athletes before competition. These cooling vests hold frozen ice packs in close contact with the body. Because of their relatively light weight, athletes are able to wear vests during warm-up and directly prior to an event. One recent study showed that T_c (rectal temperature), skin temperature, and esophageal temperature all decreased during warm-up with a cooling vest (1). More importantly, time to complete a 5-km simulated race is reduced following a warm-up with a cooling vest than without (1). This study showed a reduction in heart rate (HR) when athletes exercised under precooled conditions. This leads to speculation that athletes may be able to perform more work if they precool before competition or training.

Previous studies evaluating cooling vest have focused on the effects the vest might have on performance during a simulated race or long-duration, submaximal exercise. The use of a cooling vest as a training aid for long-distance runners has not been evaluated. Long-distance runners routinely perform interval workouts during training. Other precooling studies have only looked at the effect precooling has on continuous exercise. This experiment demonstrates the effects of wearing a cooling vest during warm-up on T_c, HR, and interval completion time during interval training in NCAA division I distance runners.

Statement of the Problem

The purpose of this study is to evaluate the effects that warming up, while wearing a cooling vest prior to an interval workout, will have on core body temperature, heart rate, and interval time in long-distance runners.

Hypothesis

Warming up with a cooling vest will decrease heart rate, body temperature, interval times, and thermal discomfort in long-distance runners.

Null Hypothesis

Warming up with a cooling vest will have no effect on heart rate, body temperature, interval times, and thermal discomfort in long-distance runners.

Assumptions

1. Athletes will be well trained both physically and cognitively.
2. Athletes will perform workouts with equal maximal effort on both control and treatment days.
3. Athletes will adhere to dietary requirements prior to exercise.
4. Athletes will answer survey questions truthfully.

Delimitations

1. Athletes will be training at a high intensity during the week between trials.
2. Some data from this study will be self-reported.
3. This study only uses a population of college-aged, highly trained cross-country runners.

Significance

If an endurance runner can improve their performance during training sessions, they can improve their performance in competition. This study will determine if a warm-up with a cooling vest will help reduce heart rate, body core temperature, and increase running performance during a high intensity interval workout. Small improvements in training can lead to victories during competition.

Chapter 2

Review of Literature

Precooling Research

Research involving the effects of cooling the body is not a new area of study. Cooling the body prior to exercise is known as precooling. As early as the 1930s scientists were studying the effects of precooling (2). Rather than studying the effects of precooling on exercise performance, however, these researchers focused on precooling's ability to reduce thermal strain as well as its effects on the circulatory system and oxygen consumption (15).

Much of the early precooling research sought to determine if precooling before exercise would postpone fatigue and enhance exercise performance. There is evidence from past studies that endurance exercise may be limited by the attainment of a critical internal temperature (22). Past research has demonstrated that the onset of fatigue occurs at a core temperature of between ~39°C to 40°C (1,5,11,14,15,19,). While some highly motivated individuals, such as marathoners, may reach core temperatures of ≥ 41°C before fatiguing most research shows fatigue setting in between 39°C to 40°C (19). This temperature associated with the onset of fatigue is known as the critical limiting temperature (15). In order for subjects to continue exercising once this temperature has been reached, they must reduce their exercise intensity or terminate the exercise (15).

Research has shown that precooling can lower core temperature before exercise. This gives athletes a lower starting point with body core temperature. If an athlete has a lower core temperature to start with, it would take longer for them to reach the limiting critical temperature, giving them an edge for training as well as competition.

Physiological Principles of Precooling

As discussed, the goal of precooling is to maintain a reduced core temperature or hinder core temperature reaching critical levels. During exercise, temperatures in the body rise. Active skeletal muscle produces heat as a result of exercise (10). Only a small amount of this heat is lost from the overlying skin on the muscle (10). Most of the heat produced during exercise is passed to the body core through convection as a result of venous blood returning to the heart and then out to the skin to dissipate (10). This can bring a rapid increase in core temperature (15).

When exercise is prolonged or takes place in hot environment body temperatures reach the critical limiting temperature, which has been determined to be between 39°C to 40°C in humans (1,14). Prolonged exercise causes a rise in body temperature that is proportional to the metabolic rate (15). Exercise that involves large muscle activities can have a high rate of heat production (13). The goal of precooling is to reduce body temperature prior to exercise. This increases the margin for metabolic heat production and increases the time required to reach a critical limiting core temperature (15,17).

There are several methods researchers use to reduce body core temperature prior to exercise. The methods of precooling used in past studies include immersion in cold water, exposure to cold air, wearing a water-perfused suit with cold water continuously running through it, wearing a cooling vest, or even a combination of methods (7,8,15).

The majority of recent studies on precooling and exercise have used water immersion or cold air exposure to reduce core temperature.

Precooling affects the cardiovascular system by lowering steady-state exercise heart rate. One researcher suggested that by "reducing the rate of rise in body temperature, the need for skin blood flow is reduced, thereby increasing the volume of blood available for the central circulation" (15). More blood available would lead to an increase in stroke volume, reducing the heart rate needed to sustain a given cardiac output. Many studies show that heart rate during exercise after precooling is lower (15).

Results of Precooling Research

Three researchers from the Justus-Liebig University in Giessen, Germany, have done numerous precooling studies in the 1980s. These researchers were among the first to determine the positive effects that a slightly lowered body temperature could have on exercise performance. In each of their separate studies on precooling and exercise, Schmidt, Brück and Olschewski (7,19,20) concluded that slightly lowering body temperature can contribute to improving exercise performance. These researchers used immersion in cold water as well as cold air exposure to precool subjects and found both methods improved exercise performance (7,19,20).

Researchers since then have seen similar results with regards to exercise performance after precooling. Booth et al. (5) and Marino (15) of Charles Sturt University in Bathurst, Australia have completed several precooling studies with similar results. They confirmed that cold-water immersion is an effective means of lowering body core temperature (5). They found that precooling reduced thermoregulatory strain, as evidenced by lowered heart rate and core temperatures. Subjects additionally reported they felt cooler during exercise (5).

Lee and Haymes (13) found similar results to these other studies after precooling subjects with cold air in an environmental chamber. Based on their results, they concluded precooling increased the duration of high-intensity running in an environmental chamber (13). Especially in the early stages of exercise, subjects displayed relatively lower heart rates, temperatures (rectal, skin, body), and VO_2 (13). According to Lee & Hayes (13), precooling led to less strain on the metabolic and cardiovascular systems.

Though the majority of precooling studies show favorable outcomes to exercise performance after precooling, one study in 1979 suggests that lowered body temperatures negatively affect performance (4). This was one of the first studies to evaluate the effects of precooling on exercise performance, says Marino (15). Bergh and Ekblom (4) achieved reductions in body temperature by having subjects swim in very cold water (13°C to 15°C) for 15-25 minutes. Bergh and Ekblom (4) reported that precooling does not improve exercise work time but rather reduces it.

Other researchers, however, have offered explanations explaining why a reduction in work time could have been seen in this study. Marino (15) points out that the low esophageal temperatures show that subjects were close to hypothermia, rather than being in a state of cold stress. It is possible that the extremely cold water caused low enough temperatures to negatively affect central nervous system function (15). Also, the method of precooling had subjects swim in the cold water. This exercise may have used available substrates, leaving fewer substrates available to use for work during the exercise trials (15).

Measuring Core Body Temperature

There are several means by which researchers measure core body temperatures. Exact body core temperature refers to the temperature of blood at the hypothalamus. The most common temperature devices used are rectal thermometers, esophageal thermometers, and tympanic thermometers (12). There is still debate about the appropriateness of each site for approximating body core temperature. Tympanic temperature measurements can be influenced by the local ear canal and ambient air temperatures (12). Past research has found tympanic membrane measurements to be clinically unreliable (16). Esophageal probes can provide accurate measurements of body core temperatures in laboratory settings. The temperature in the pulmonary artery is considered to represent the “true” body core temperature (9) and research suggests that esophageal temperature measurements correlate with pulmonary artery readings. However, esophageal probes are not always suitable for measuring temperatures in subjects who are exercising (16). Past precooling researchers have all relied on rectal probes for accurate body core temperature estimations. However, rectal temperatures can also be influenced by changes in exercise intensity. Research suggests that when exercise is performed predominantly with legs, the large blood flow to the local muscle increases rectal temperature readings (12)

Researchers also measure body core temperatures by using telemetric pills. As early as 1968 a “radio pill” existed that would monitor core temperature after being ingested (16). In the years following, researchers developed other pills that proved to be more reliable than the early versions. One drawback to early telemetry systems was that the pills all transmitted data on the same frequency (16). This meant two pills in close proximity would interfere with each other when transmitting temperature measurements to a monitor (16). The most recent telemetry pills have their own individual frequencies in order to not interfere with each other.

One study performed in 1993 suggests telemetric pills are not as accurate as rectal probes (21). More recent studies, however, have found that telemetric pills give accurate body core temperature measurements even when core temperature is manipulated (18). A study conducted in 2004 suggests that telemetry systems are “as least as accurate as rectal probe monitors” (16). This same study states that subjects found the telemetry pill system preferable to the rectal probe monitors (16).

Precooling with Cooling Vests

Even though cooling vests are not entirely new, little research has been done with cooling vests as the means of precooling prior to exercise. Firefighters as well as the military have used cooling vests to fight against the high ambient temperatures they sometimes work in (3). Recently, more researchers have studied cooling vests and their possible benefits to athletes. With the increased interest in using cooling vests as an ergogenic aid for endurance competition, more research is likely to be done.

While many studies have shown that a small decrease in body core temperature can have a beneficial effect on exercise, their methods of precooling are not practical for endurance athletes (7,15). Researchers point out the time required to achieve a decrease in body temperature might also make precooling impractical for athletes to use as a competition aid (15). Athletes normally do not have access to environmental chambers for cold-air exposure or large baths for cold-water immersion, nor ample time to spend in either one.

A study performed by Cotter et al. (8) was one of the first to use a cooling vest to reduce body temperature. Subjects rested in cold air while wearing a cooling vest and then warmed up with the vest before an endurance cycling bout. The exercise bout took place in an environmental chamber with the ambient temperature set to 35°C. The researchers found this method of precooling reduced physiological strain and improved subjects' ability to do more work in a given period of time (8). This suggests that cooling vests, when used with cold air exposure, could positively affect exercise performance.

A more recent study looks at the effects that precooling with only an ice vest during warm-up might have on endurance running performance (1). Seventeen competitive distance runners were used in the study and ran two simulated 5-km races. Before one 5-km, the subjects performed a 38 min warm-up while wearing an ice vest. The other simulated 5-km race was performed after a warm-up period without a cooling vest. The results showed significant reductions in rectal, skin, esophageal, and total mean body temperature after subjects performed a warm-up with a cooling vest. The researchers found that the cooling vest reduced both cardiovascular and thermal strain during the warm-up period (1). The runners reported feeling cooler after 30 minutes of warm-up with the vest, up to the start of the 5-km run. Run times for the simulated race were significantly less after warming up with the cooling vest compared to the control (1). Unlike water immersion or cold air exposure, wearing a cooling vest prior to competition could be a practical means of reducing body temperature in endurance athletes, because they could warm up while wearing one.

There is a need for more research regarding the effectiveness of cooling vests on exercise performance and training. Because cooling vests are meant to be for athlete use before exercise, more research should be applied to specific training circumstances and specific sports.

Chapter 3

Methods

This chapter describes the procedures that will be used to test the hypothesis that warming up with a cooling vest will decrease working heart rate, body core temperature, and increase performance in long-distance runners. The specific details regarding subjects, instruments, testing procedures, and statistical analysis will be outlined.

Subjects

Subjects in this study will be male cross-country runners. Nineteen healthy subjects will be recruited from the Brigham Young University men's cross-country team. All subjects will be required to sign an informed consent.

Testing Equipment

T_c was measured using the CorTemp T_c monitoring system (HQ Inc., Palmetto, FL). The CorTemp system consists of a small precalibrated ingestible sensor (telemetry pill) which measures and transmits T_c. Each subject swallowed a sensor (about the size of a large vitamin) three hours before T_c was measured. T_c was measured with a small monitor after the pill entered the subject's GI tract. HR was measured by a Polar HR monitor (Polar Electro, Woodbury, NY) and reported in beats per minute (bpm). Environmental conditions at the workout site (dry bulb temperature, wet bulb globe temperature (WBGT), and relative humidity) were measured using a heat stress indicator (Microtherm Heat Stress W136T, Casella, Amhurst, NH) while wind speed was taken from measurements at a university a weather station located within one mile of the testing site.

Testing Protocol and Procedures

The subjects will report on a Monday after a two-hour fast. However, they will be allowed to drink as much water as they desire. Subjects will also be instructed to not consume caffeine 12 hours before testing. Three hours before subjects are to report, each subject will swallow a telemetry pill. Each subject's core temperature will be taken prior to putting on the cooling vest and warming up. Each subject will warm up and exercise under two different conditions: (a) an experimental condition in which subjects will wear a cooling vest during warm-up and (b) a control condition in which subjects will wear a regular T-shirt during warm-up. The testing days will be separated by 6 days, and groups will be randomly assigned which day they will wear the cooling vest during warm-up. Each subject will serve as his own control.

Subjects will put on the cooling vest 30 minutes prior to their warm-up. After resting 30 minutes with the cooling vests on, subjects will begin warming up while still wearing the cooling vests. The warm-up protocol before the training sessions will be the same on each day and will consist of exercises distance runners would typically perform before an interval workout. Before the warm-up, subjects will place a heart-rate monitor around their chests. Subjects will be instructed to drink as much water as they wish during warm-up and in between the interval workouts.

Subjects will perform their typical warm-up, which consists of about 15 minutes of jogging, followed by stretching and 4 x 100 m strides at the workout pace. After the warm-up, subjects will remove the cooling vest or T-shirt and run eight 1000 m intervals separated by 1:30 minutes of rest. Each subject will perform the intervals with a group of runners with similar running abilities. Each group will be given a set minimum time requirement in which they must complete each interval during the training session. Heart rate and body core temperature will be measured prior to warm-up, just prior to start of the first interval, and after each interval. Time to complete each interval will also be recorded for each interval.

Statistical Analysis

Statistical analysis will be completed using the SAS system for Univariate and Multivariate Statistics. All data will be repeated as means $\pm$ SD. Data will be analyzed using a repeated-measures ANOVA to determine the significance of the means by condition (vest v. non-vest). Level of significance will be set at 0.05. Differences of HR, body core temperatures, and interval times between conditions will be compared by computing a minimum significant difference (MSD) value using Tukey's honest significant difference method.

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Appendix B

Additional Results

Table B1. Tables of Appendix B Tables

Table	Title
B2	Summary of Subject 1
B3	Summary of Subject 2
B4	Summary of Subject 3
B5	Summary of Subject 4
B6	Summary of Subject 5
B7	Summary of Subject 6
B8	Summary of Subject 7
B9	Summary of Subject 8
B10	Summary of Subject 9
B11	Summary of Subject 10
B12	Summary of Subject 11
B13	Summary of Subject 12
B14	Summary of Subject 13
B15	Summary of Subject 14
B16	Summary of Subject 15
B17	Summary of Subject 16
B18	Summary of Subject 17
B19	Summary of Subject 18
B20	Summary of Subject 19

Table B2. Summary of Subject 1

Vest Condition

Interval	T_c (ºC)	HR (bpm)	Time (s)
Minus 60	-	-	-
Minus 30	-	-	-
Pre	-	-	-
1	-	-	-
2	-	-	-
3	-	-	-
4	-	-	-
5	-	-	-
6	-	-	-
7	-	-	-
8	-	-	-

Non-Vest Condition

Interval	T_c (ºC)	HR (bpm)	Time (s)
Pre	37.77	-	-
1	37.8	198	181
2	38.1	197	185
3	38.6	196	189
4	38.7	186	189
5	39.05	195	188
6	39.03	193	194
7	38.97	196	189
8	38.9	194	189

Table B3. Summary of Subject 2

Vest Condition

Interval	T_c (ºC)	HR (bpm)	Time (s)
Minus 60	36.6	-	-
Minus 30	36.74	-	-
Pre	36.95	-	-
1	36.91	176	184
2	36.94	184	188
3	37.54	187	189
4	37.99	189	186
5	38	191	187
6	38.08	-	188
7	38.45	190	191
8	38.08	197	182

Non-Vest Condition

Interval	T_c (ºC)	HR (bpm)	Time (s)
Minus 30	37.08	-	-
Pre	36.62	-	-
1	37.54	177	181
2	38.19	189	186
3	38.61	192	189
4	38.73	193	192
5	38.68	189	195
6	38.5	189	193
7	38.26	188	194
8	37.8	188	194

Table B4. Summary of Subject 3

Vest Condition

Interval	T_c (ºC)	HR (bpm)	Time (s)
Minus 60	36	-	-
Minus 30	36.5	-	-
Pre	37.39	-	-
1	37.66	172	184
2	38.37	180	188
3	38.73	186	189
4	38.86	181	186
5	39.13	190	187
6	39.26	190	188
7	39.32	192	183
8	39.54	193	180

Non-Vest Condition

Interval	T_c (ºC)	HR (bpm)	Time (s)
Minus 30	37.24	-	-
Pre	38.21	-	-
1	38.24	174	188
2	38.49	184	186
3	38.72	187	186
4	38.88	191	185
5	39.05	190	187
6	39.14	191	188
7	39.25	192	184
8	39.28	195	184

Table B5. Summary of Subject 4

Vest Condition

Interval	T_c (ºC)	HR (bpm)	Time (s)
Minus 60	36.83	-	-
Minus 30	36.66	-	-
Pre	36.5	-	-
1	36.51	181	186
2	36.93	191	188
3	37.47	195	189
4	37.71	199	189
5	38.12	199	189
6	38.43	198	198
7	38.63	199	200
8	38.64	200	204

Non-Vest Condition

Interval	T_c (ºC)	HR (bpm)	Time (s)
Minus 30	37.17	-	189
Pre	37.63	-	190
1	37.66	185	189
2	38.05	195	189
3	37.93	193	188
4	38.22	199	189
5	38.54	200	188
6	38.33	200	189
7	38.44	201	188
8	38.68	201	187

Table B6. Summary of Subject 5

Vest Condition

Interval	T_c (ºC)	HR (bpm)	Time (s)
Minus 60	37.95	-	-
Minus 30	37.85	-	-
Pre	38.47	-	-
1	38.44	172	189
2	38.65	175	187
3	39	180	187
4	39.27	185	192
5	39.48	181	190
6	39.61	180	190
7	39.77	181	191
8	39.9	181	195

Non-Vest Condition

Interval	T_c (ºC)	HR (bpm)	Time (s)
Minus 30	37.64	-	-
Pre	38.15	-	-
1	38.28	170	189
2	38.28	170	189
3	39.06	180	190
4	39.12	178	188
5	39.22	178	188
6	39.26	179	189
7	39.28	176	195
8	39.2	179	195

Table B7. Summary of Subject 6

Vest Condition

Interval	T_c (ºC)	HR (bpm)	Time (s)
Minus 60	36.76	-	-
Minus 30	36.21	-	-
Pre	36.64	-	-
1	36.85	186	185
2	37.32	190	188
3	38.45	188	189
4	38.14	195	186
5	-	195	187
6	37.97	195	190
7	-	202	190
8	37.8	196	192

Non-Vest Condition

Interval	T_c (ºC)	HR (bpm)	Time (s)
Minus 30	37.2	-	-
Pre	36.07	-	-
1	38.06	176	189
2	38.31	192	189
3	38.6	192	190
4	38.77	192	189
5	38.89	193	190
6	39.14	191	189
7	39.26	193	187
8	39.4	195	184

Table B8. Summary of Subject 7

Vest Condition

Interval	T_c (ºC)	HR (bpm)	Time (s)
Minus 60	37.13	-	-
Minus 30	36.86	-	-
Pre	36.77	-	-
1	36.77	181	200
2	36.94	189	204
3	37.1	188	204
4	37.25	190	207
5	37.52	188	207
6	37.54	188	216
7	37.77	190	213
8	37.96	190	208

Non-Vest Condition

Interval	T_c (ºC)	HR (bpm)	Time (s)
Minus 30	37.24	-	-
Pre	36.73	-	-
1	37.24	182	195
2	37.89	187	195
3	38.39	190	198
4	38.73	191	197
5	38.88	190	199
6	38.94	191	198
7	38.98	193	198
8	38.97	190	197

Table B9. Summary of Subject 8

Vest Condition

Interval	T_c (ºC)	HR (bpm)	Time (s)
Minus 60	37.72	-	-
Minus 30	36.85	-	-
Pre	37.38	-	-
1	37.27	172	203
2	37.51	176	205
3	38.1	191	204
4	38.31	181	206
5	38.18	183	205
6	38.26	184	201
7	38.84	185	202
8	39.14	185	208

Non-Vest Condition

Interval	T_c (ºC)	HR (bpm)	Time (s)
Minus 30	37.43	-	-
Pre	38.1	-	-
1	38.43	174	197
2	38.77	181	197
3	39.09	182	202
4	39.32	181	212
5	39.48	177	209
6	39.3	178	221
7	39.61	178	218
8	39.62	184	211

Table B10. Summary of Subject 9
Vest Condition

Interval	T_c (ºC)	HR (bpm)	Time (s)
Minus 60	37.37	-	-
Minus 30	37.16	-	-
Pre	37.19	-	-
1	37.44	186	190
2	37.88	177	187
3	38.3	188	189
4	38.64	188	192
5	38.8	189	194
6	38.93	194	192
7	38.98	187	192
8	39	192	192

Non-Vest Condition

Interval	T_c (ºC)	HR (bpm)	Time (s)
Minus 30	37.56	-	-
Pre	37.75	-	-
1	38.2	183	191
2	38.1	190	193
3	38.88	187	198
4	39	189	197
5	39.1	190	195
6	39.2	192	194
7	39.29	192	193
8	39.38	195	188

Table B11. Summary of Subject 10
Vest Condition

Interval	T_c (ºC)	HR (bpm)	Time (s)
Minus 60	37.5	-	-
Minus 30	37.12	-	-
Pre	35.59	-	-
1	36.4	192	189
2	37.14	192	193
3	37.73	196	193
4	38.14	200	197
5	38.49	200	200
6	38.76	204	203
7	38.95	205	202
8	39.1	205	216

Summary of Subject 10
Non-Vest Condition

Interval	T_c (ºC)	HR (bpm)	Time (s)
Minus 30	36.93	-	-
Pre	35.72	-	-
1	36.1	185	195
2	37.3	187	195
3	37.76	191	198
4	38.26	197	198
5	38.59	198	200
6	37.89	200	200
7	37.74	192	207
8	38.45	201	217

Table B12. Summary of Subject 11

Vest Condition

Interval	T_c (ºC)	HR (bpm)	Time (s)
Minus 60	37.34	-	-
Minus 30	36.76	-	-
Pre	36.89	-	-
1	37.02	171	178
2	37.48	177	177
3	38.04	180	176
4	38.44	183	175
5	38.49	184	175
6	38.61	184	174
7	38.55	184	174
8	38.73	186	171

Non-Vest Condition

Interval	T_c (ºC)	HR (bpm)	Time (s)
Minus 30	37.54	-	-
Pre	37.74	-	-
1	37.94	174	177
2	38.23	182	174
3	38.51	184	175
4	38.07	186	176
5	38.18	185	178
6	38.4	188	175
7	38.09	188	177
8	38.03	189	171

Table B13. Summary of Subject 12
Vest Condition

Interval	T_c (ºC)	HR (bpm)	Time (s)
Minus 60	37.33	-	-
Minus 30	37.41	-	-
Pre	37.94	-	-
1	38.03	183	186
2	38.4	188	188
3	38.74	194	188
4	38.92	194	185
5	39.02	196	187
6	39.11	197	186
7	39.2	200	184
8	39.13	199	182

Non-Vest Condition

Interval	T_c (ºC)	HR (bpm)	Time (s)
Minus 30	37.42	-	-
Pre	38.03	-	-
1	38.16	190	189
2	38.41	191	187
3	38.63	195	189
4	38.82	196	186
5	39	186	187
6	39.07	197	186
7	39.02	199	184
8	39.31	200	180

Table B14. Summary of Subject 13
Vest Condition

Interval	T_c (ºC)	HR (bpm)	Time (s)
Minus 60	37.41	-	-
Minus 30	36.69	-	-
Pre	37.85	-	-
1	38.05	168	185
2	38.29	176	185
3	38.55	179	184
4	38.79	183	183
5	38.88	183	183
6	39.21	184	183
7	39.42	186	181
8	39.6	187	176

Non-Vest Condition

Interval	T_c (ºC)	HR (bpm)	Time (s)
Minus 30	37.58	-	-
Pre	-	-	-
1	-	173	184
2	-	177	184
3	-	195	183
4	-	181	183
5	-	183	184
6	-	184	184
7	-	181	183
8	-	188	178

Table B15. Summary of Subject 14

Vest Condition

Interval	T_c (ºC)	HR (bpm)	Time (s)
Minus 60	35.53	-	-
Minus 30	36.83	-	-
Pre	-	-	-
1	-	182	187
2	-	192	188
3	-	192	192
4	36.61	193	190
5	37.36	195	192
6	37.71	194	194
7	38.07	195	198
8	38.4	195	198

Non-Vest Condition

Interval	T_c (ºC)	HR (bpm)	Time (s)
Minus 30	36.43	-	-
Pre	-	-	-
1	-	-	184
2	36.3	180	188
3	37.2	190	189
4	37.8	197	186
5	38.24	193	187
6	38.51	196	185
7	38.74	194	184
8	-	198	184

Table B16. Summary of Subject 15

Vest Condition

Interval	T_c (ºC)	HR (bpm)	Time (s)
Minus 60	37.36	-	-
Minus 30	37.1	-	-
Pre	37.44	-	-
1	37.86	180	187
2	37.91	188	188
3	37.7	191	189
4	38.69	192	188
5	38.75	190	190
6	38.83	191	189
7	38.6	192	190
8	38.44	195	186

Non-Vest Condition

Interval	T_c (ºC)	HR (bpm)	Time (s)
Minus 30	37.64	-	-
Pre	36.12	-	-
1	38.38	185	182
2	38.4	190	189
3	38.45	190	197
4	35.52	192	192
5	38.68	190	200
6	38.87	190	203
7	38.08	190	202
8	38.69	190	202

Table B17. Summary of Subject 16

Vest Condition

Interval	T_c (ºC)	HR (bpm)	Time (s)
Minus 60	37.37	-	-
Minus 30	37.55	-	-
Pre	37.52	-	-
1	36.92	183	189
2	37.22	190	189
3	37.6	192	189
4	37.93	195	188
5	38.15	196	190
6	38.33	198	191
7	38.45	198	194
8	38.57	200	193

Non-Vest Condition

Interval	T_c (ºC)	HR (bpm)	Time (s)
Minus 30	37.28	-	-
Pre	37.39	-	-
1	37.53	171	187
2	37.96	181	185
3	38.28	187	189
4	38.51	195	190
5	38.67	195	194
6	38.74	197	195
7	38.7	204	187
8	38.87	203	188

Table B18. Summary of Subject 17

Vest Condition

Interval	T_c (ºC)	HR (bpm)	Time (s)
Minus 60	37.13	-	-
Minus 30	35.8	-	-
Pre	36.7	-	-
1	37.55	-	191
2	38.01	194	188
3	38.35	191	192
4	38.55	186	192
5	38.67	183	195
6	38.64	184	196
7	38.77	188	193
8	38.7	186	193

Non-Vest Condition

Interval	T_c (ºC)	HR (bpm)	Time (s)
Minus 30	37.21	-	-
Pre	38.02	-	-
1	38.28	173	189
2	38.81	179	190
3	39.05	179	192
4	39.17	182	192
5	39.19	186	194
6	39.21	192	194
7	39.18	197	191
8	39.25	191	188

Table B19. Summary of Subject 18

Vest Condition

Interval	T_c (ºC)	HR (bpm)	Time (s)
Minus 60	36.94	-	-
Minus 30	37.02	-	-
Pre	34.59	-	-
1	37.07	178	195
2	37.7	184	195
3	38.35	187	197
4	38.77	192	196
5	38.35	192	195
6	38.77	192	198
7	-	191	198
8	-	194	193

Non-Vest Condition

Interval	T_c (ºC)	HR (bpm)	Time (s)
Minus 30	37.28	-	-
Pre	37.69	-	-
1	36.81	177	189
2	37.8	191	194
3	37.5	191	194
4	38.3	191	196
5	38.4	194	202
6	38.5	194	201
7	-	-	-
8	38.46	195	192

Table B20. Summary of Subject 19

Vest Condition

Interval	T_c (ºC)	HR (bpm)	Time (s)
Minus 60	37.59	-	-
Minus 30	37.48	-	-
Pre	37.98	-	-
1	37.77	168	197
2	38.06	192	200
3	38.34	196	205
4	38.55	192	210
5	38.74	193	215
6	38.81	190	215
7	38.89	200	204
8	38.97	195	197

Non-Vest Condition

Interval	T_c (ºC)	HR (bpm)	Time (s)
Minus 30	36.39	-	-
Pre	38.32	-	-
1	38	190	200
2	38.6	196	204
3	38.93	195	204
4	39.01	204	204
5	39.04	195	205
6	38.87	197	205
7	38.8	203	213
8	38.75	200	200

Appendix C

Additional Figures

Figure Legends

Figure C1. Average body core temperatures (°C) as measured over time.

* denotes significantly different from Vest condition ($p < 0.05$)

Figure C2. Rate (°C/min) to reach peak body core temperature for each condition

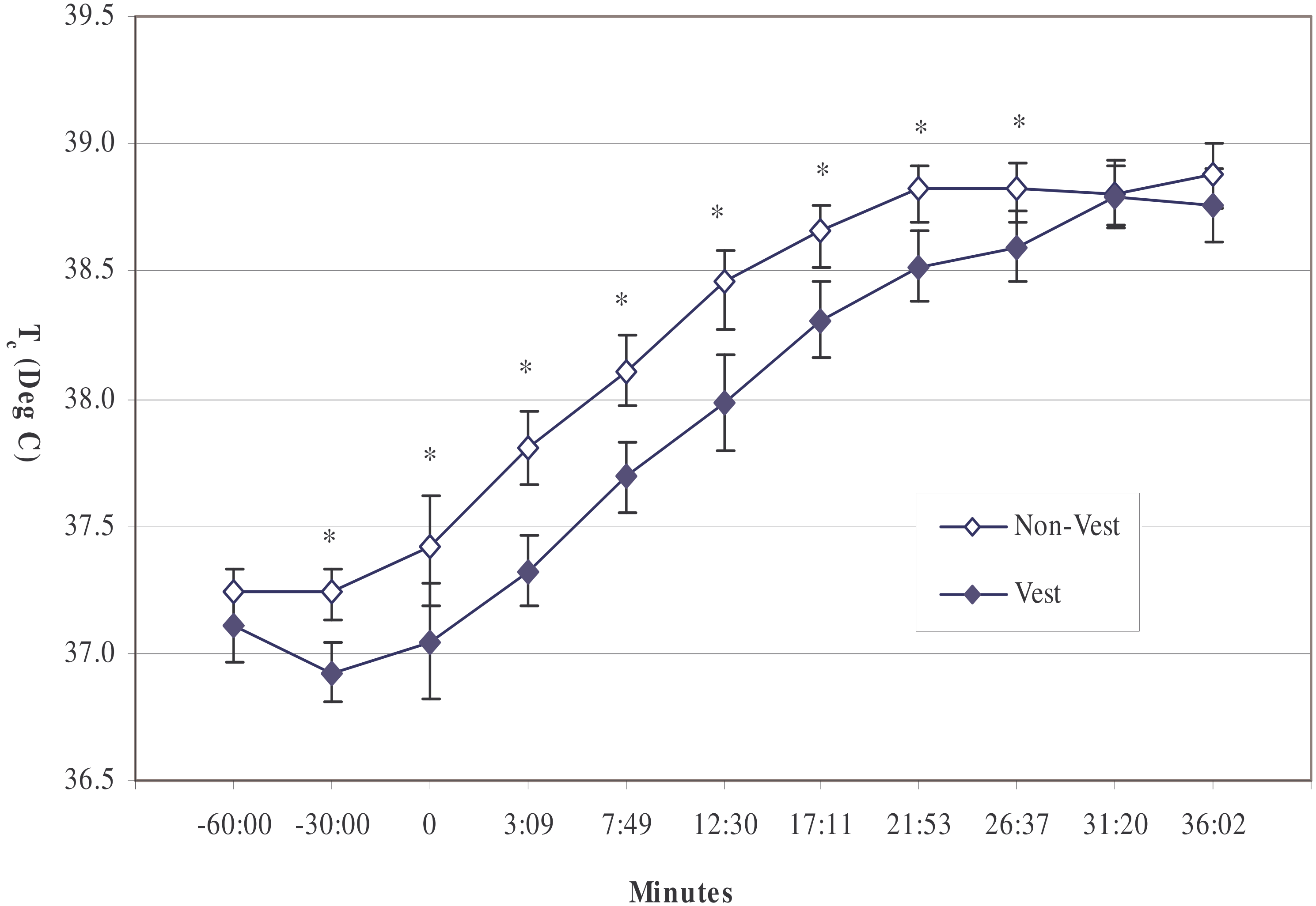

Figure C1. Average body core temperatures (°C) as measured over time. * denotes significantly different from Vest condition ($p < 0.05$)

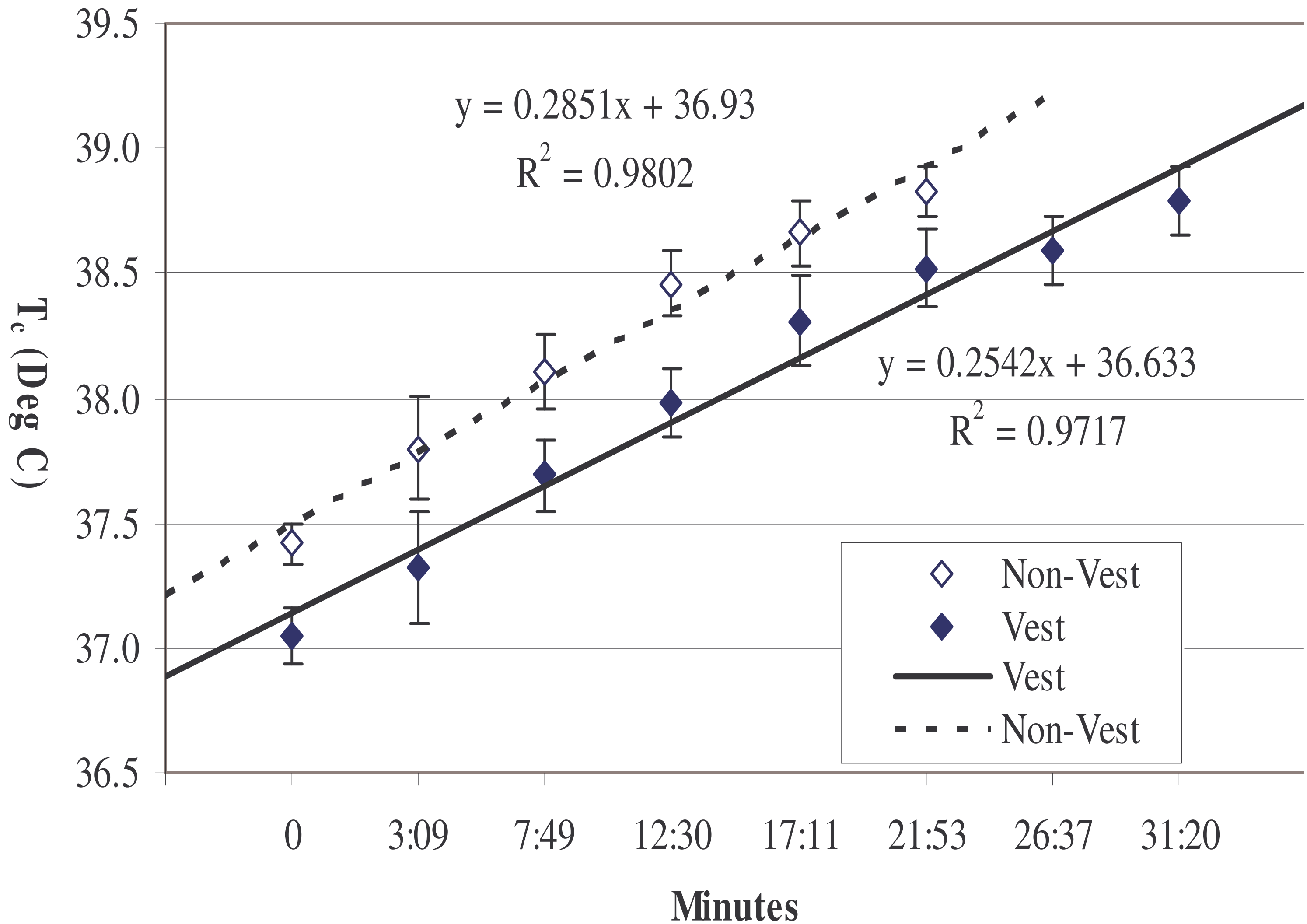

Figure C2. Rate (°C/min) to reach peak body core temperature (38.8ºC) for each condition