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CHANGES IN INTRAMUSCULAR TEMPERATURE DURING
POST-EXERCISE APPLICATION OF A COLD MODALITY

presented by

Julie Lorraine Homuth

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CHANGES IN INTRAMUSCULAR TEMPERATURE DURING POST-EXERCISE APPLICATION OF A COLD MODALITY

By

Julie Lorraine Homuth

A THESIS

Submitted to
Michigan State University
in partial fulfillment of the requirements
for the degree of

MASTERS OF SCIENCE

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ABSTRACT

CHANGES IN INTRAMUSCULAR TEMPERATURE DURING POST-EXERCISE APPLICATION OF A COLD MODALITY

By

Julie Lorraine Homuth

Cold application is a common treatment used to care for acute injuries. Most research is related to intramuscular tissue temperature changes with regards to cold application on tissues at rest. The purpose of this study was to determine the difference in post-exercise intramuscular tissue temperature during application of two common cold modalities, as well as after removal. A temperature probe was inserted 1 cm below the subcutaneous adipose layer of the left lower leg in 18 subjects. Each subject participated in all three conditions (control, crushed ice pack, ice massage) in a randomized order.

The treatment phase lasted for 20 minutes followed by a 30 minute re-warming phase. While both cold modalities decreased intramuscular tissue temperature compared to the control condition, the greatest decrease occurred with ice massage. Re-warming showed a continued cooling of 7 and 3 minutes for the crushed ice pack and ice massage conditions, respectively, followed by an increase in temperature that remained significantly lower than resting tissue temperature. There was also a slower increase in temperature during re-warming following application of a crushed ice pack compared to ice massage. Both conditions created a significant decrease in intramuscular tissue temperature compared to the control condition after 20 minutes of cold modality application.

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*Some images in this thesis are presented in color

CHAPTER 1

INTRODUCTION

Overview of Problem

Athletic trainers need to know the effects of cold application on intramuscular tissue temperature to determine the most appropriate intervention to treat an injury. While athletes primarily suffer injuries during physical activity when the body tissues are warm (Noonan, Best, Seaber, & Garrett, 1993), the majority of research assessing intramuscular tissue temperature changes during a cold application have been conducted on non-warm tissues (Merrick, Jutte, & Smith, 2003; Merrick, Knight, Ingersoll, & Potteiger, 1993; Myrer, Measom, Durrant, & Fellingham, 1997; Myrer, Measom, & Fellingham, 1998; Myrer, Myrer, Measom, Fellingham, & Evers, 2001; Zemke, Andersen, Guion, McMillan, & Joyner, 1998). Furthermore, it is important for the athletic trainer to know which cold modality, ice massage or crushed ice pack, decreases intramuscular tissue temperature at a faster rate, which could contribute to a faster healing process and allow an injured athlete to return to play quicker (Kellett, 1986; McMaster, Liddle, & Waugh, 1978; Merrick et al., 2003; Merrick et al., 1993; Merrick, Rankin, Andres, & Hinman, 1999; Myrer et al., 1998; Myrer et al., 2001; Otte, Merrick, Ingersoll, & Cordova, 2002; Zemke et al., 1998). The purpose of this study was to determine the difference in post-exercise intramuscular tissue temperature 1 cm below the subcutaneous adipose layer during the application of a crushed ice pack, an ice massage treatment, or a control period. A secondary purpose was to determine which cold modality keeps the muscle tissue colder for a longer period of time after removal of the crushed ice pack or ice massage.

Significance of Problem

When an individual becomes injured during activity, it is important to decrease tissue temperature in order to prevent secondary hypoxic injury of the surrounding cells (Mancuso & Knight, 1992; Merrick et al., 2003; Merrick et al., 1999). The type of cold modality used to complete this task should be able to penetrate deep enough to decrease temperature of the injured tissues. By examining the time it takes for post-exercise tissue temperature to decrease, it is possible to determine how each type of cold modality penetrates the tissues and determine which cold modality cools the tissue at a faster rate, creates a greater temperature change, or keeps the tissues colder for a longer period of time after removal of the cold modality. This knowledge will allow the athletic trainer to select the most appropriate cold modality for injury treatment, since it has been demonstrated that application of a cold modality can speed the healing process and allow quicker return to play (Best, 1997; Kellett, 1986; Knight, 1995; Merrick et al., 2003; Merrick et al., 1993; Merrick et al., 1999; Myrer et al., 1998; Myrer et al., 2001; Otte et al., 2002; Zemke et al., 1998).

Previous research has examined superficial skin temperature changes of warm tissue during application of a cold modality (Jutte, Merrick, Ingersoll, & Edwards, 2001), as well as changes in superficial skin and intramuscular tissue temperature during simultaneous application of a cold modality and activity (Bender et al., 2005). Currently, there has been little research conducted that has examined the change in intramuscular tissue temperature during post-exercise application of a cold modality (Long, Cordova, Brucker, Demchak, & Stone, 2005). Previous research has assessed various cold modalities and their effectiveness in changing tissue temperature while the subject was at rest (Merrick et al., 1993; Merrick et al., 2003; Myrer et al., 1998; Zemke et al., 1998). While this information is useful, it does not reflect the conditions under which most athletic injuries occur. Thus, it is important to determine how cold application effects warm muscle tissues. Therefore, the specific aim of this study was to address the effects of cold application on intramuscular tissue temperature post-exercise. This develops data for determining the best intervention to be used on warm tissues and possibly exercise induced injury.

Purpose

The purpose of this study was to determine the difference in post-exercise intramuscular tissue temperature 1 cm below the subcutaneous adipose layer during the application of a crushed ice pack, an ice massage treatment, or a control period. A secondary purpose was to determine which cold modality keeps the muscle tissue colder for a longer period of time after removal of the crushed ice pack or ice massage.

Hypotheses:

1) The application of an ice massage treatment will produce a more rapid decrease in intramuscular tissue temperature following exercise.
2) After the removal of the cold modality, the intramuscular tissue temperature will begin re-warming within one minute.
3) The overall change in intramuscular tissue temperature will be the same for the crushed ice pack and ice massage treatment.

Limitations and Delimitations

A few aspects of the subject's activities of daily living were controlled prior to data collection. Subjects were instructed not to perform any form of physical activity 12 hours prior to testing to make sure that body temperature was at a resting state. Consumption of alcoholic beverages 12 hours prior to testing was also not permitted.

Items that were not controlled for include: hydration status, physical fitness level, changes in fitness level during the testing process, amount of sleep the night before, and nutrition.

Definitions

Cold modality – a cold substance that causes an involuntary decrease of temperature in the body (Starkey, 1993).

Subcutaneous adipose layer – the layer of adipose tissue between the skin and the muscle, half a skinfold measurement (Zemke et al., 1998).

Skinfold – thickness of two layers of skin and subcutaneous adipose layers measured by a caliper (Heyward, 2002).

CHAPTER 2

REVIEW OF LITERATURE

Principle of Cold Treatments:

Secondary hypoxic injury is the death of cells surrounding the site of initial tissue damage resulting from a decrease in oxygen delivery (Knight, 1995). Primary changes incurred after injury include swelling within the cell leading to rupture, hemorrhaging, decreased blood flow, inability to use oxygen at the cellular level, dependence on the glycolytic energy system, and increased extravascular pressure around the injury site from an expanding hematoma (Merrick et al., 1999). A common modality used by athletic trainers for decreasing tissue temperature is cold application that aims at preventing secondary hypoxic injury following an acute injury. This type of treatment has been shown to reduce cellular metabolism and secondary hypoxic injury within the tissues (Bleakley, McDonough, & MacAuley, 2004; Karunakara, Lephart, & Pincivero, 1999; Knight, 1995; Mancuso & Knight, 1992; Merrick et al., 2003; Merrick et al., 1993; Merrick et al., 1999; Myrer et al., 1998; Otte et al., 2002; Zemke et al., 1998). Additionally, cold application has been shown to reduce blood flow through vasoconstriction, the inflammatory response, edema formation, and hemorrhaging (Airaksinen et al., 2003; Curl et al., 1997; McMaster et al., 1978; Yanagisawa, Kudo, Takahashi, & Yoshioka, 2004). It is theorized that this reduction in secondary hypoxic injury allows for the injured tissues to heal quicker, and an injured athlete return to activity in a timelier manner.

Blood flow to an area of the body has been shown to be reduced with short duration cold application ranging from 5-15 minutes (Curl et al., 1997; Ho et al., 1995; Karunakara et al., 1999; Knight & Londeree, 1980; Lee et al., 2005; Thorsson, Lilja, Ahlgren, Hemdal, & Westlin, 1985), but the optimal length of application has not been determined. Ho et al. (1995) showed a decrease in blood flow after just 5 minutes of cold application with the greatest decrease occurring at 25 minutes. A significant decrease in blood flow occurred within 5 minutes of cold application pre-set to 3 ^{o}C (Lee et al., 2005). Thorsson et al. (1985) determined a significant decrease in blood flow occurred during the first 15 minutes of instant cold-pack application. Simultaneous measurement of intramuscular tissue temperature and microcirculation was not performed which results in the inability to compare blood flow to temperature (Curl et al., 1997; Karunakara et al., 1999; Knight & Londeree, 1980; Thorsson et al., 1985; Yanagisawa et al., 2004). Ho et al. (1995) was able to measure intramuscular tissue temperature and blood flow simultaneously. Research revealed no correlation between the intramuscular tissue temperature and change in blood flow.

Knowledge of Cold Modalities:

Crushed Ice Pack

Merrick et al. (2003) compared intramuscular tissue temperature changes in college age students at 1 and 2 cm below the subcutaneous adipose layer during three 30 minute cold applications. An Iso-Thermex-16 instrument recorded temperature changes in response to a 1 kg crushed ice pack attached with an elastic wrap, Wet-Ice attached with elastic bands, or Flex-i-Cold attached with elastic wraps. Each subject underwent all three conditions in a randomized order. Results showed non-significant differences between the conditions at a depth of 1 cm below the subcutaneous adipose layer. The differences showed that the ice pack (7.9°C) and Wet-Ice (8.4°C) produced a greater decrease in tissue temperature than the frozen gel in the Flex-i-Cold (6.0°C). The researchers concluded that the use of a cold modality which changes state, from a solid to a liquid, produces a greater decrease in intramuscular tissue temperature when compared to other forms of cold modalities.

Merrick et al. (1999) examined the application of a crushed ice pack for five continuous hours on a crush injury of the triceps surae muscle of rats. This study showed that the combination of a crushed ice pack and compression decreased the amount of secondary hypoxic injury that occurred within the skeletal muscle over the 5 hour application.

Additionally, it has been shown that the application of a crushed ice pack can decrease temperature within joints as well as intramuscularly (Bocobo, Fast, Kingery, & Kaplan, 1991). In this regard, intra-articular temperature was recorded during application of a crushed ice pack with compression for 5, 15, or 30 minutes or cold water immersion for 15 minutes on the knees of five dogs. After termination of the cold application, temperature was recorded every minute until the temperature returned to pre-cold application baseline or plateaued. This study showed that both cold modalities decreased intra-articular temperature in the knees of dogs during application, as well as producing a continued decrease in temperature after removal. Cold water immersion produced the greatest decrease in intra-articular temperature and created a prolonged cooling period of the joint after removal from the cold water bath.

McMaster et al. (1978) examined the effects of four types of cold modalities (crushed ice pack, chemical pack, gas refrigerant, and gel pack) on muscle temperature in dogs at an unspecified depth. The researchers showed a greater change in intramuscular tissue temperature with use of a crushed ice pack (11.3°C) and gel pack (8.4°C) than with use of a chemical pack (3.5°C) or gas refrigerant (less than 2°C). From this data, it was concluded that a crushed ice pack was the most effective, economical, and available cold modality for decreasing intramuscular tissue temperature, but there was the possibility that the ice could melt and leak onto the injured person.

Merrick et al. (1993) examined which cold modality or combination of modalities was the most effective at decreasing intramuscular tissue temperature at different tissue depths. In this study, 11 college aged students participated in all four conditions (control, one kilogram ice pack, cold compression, or a combination of ice pack and compression) in a randomly assigned order. An isothermex implantable electrode (Model TX-23-21) was inserted to monitor intramuscular tissue temperature at depths of 1 and 2 cm below the subcutaneous adipose layer of the anterior thigh. Skin temperature was also monitored with surface electrodes (Model TX-31). Temperature changes were monitored during the 30 minute treatment phase and for 20 minutes after removal of the cold modality. Results demonstrated that the ice pack and combination of ice pack and compression significantly decreased tissue temperature at all tissue levels compared to the control and compression conditions. Furthermore, the combination of ice pack and compression showed a greater change in temperature when compared to the ice pack condition. During the re-warming phase for the ice pack and combination conditions, there was a continued decrease in temperature for 5 and 7 minutes at the depths of 1 and 2 cm, respectively.

Myrer et al. (1998) compared the cooling effects that occur during application of a crushed ice pack or immersion in a cold whirlpool. This study examined 32 healthy college aged students randomly assigned to one of these two conditions. Intramuscular tissue (1 cm below the subcutaneous adipose layer) and skin (0.5 cm below the skin) temperatures were recorded every 30 seconds with Physitemp MT-26/2 and MT-26/4 needle microprobes attached to a BAT-12 digital monitor. A baseline temperature was recorded 3 minutes after temperature probe insertion followed by continued readings during the 20 minute treatment phase and 30 minute re-warming phase. Researchers determined that the crushed ice pack condition created a greater change in temperature than the cold whirlpool condition during the 20 minute treatment phase. The cold whirlpool however, caused a continued decrease in temperature during the re-warming phase. Both conditions were found to be beneficial in decreasing tissue temperature; therefore, the cold modality chosen should depend on the goal of the treatment.

Ice Massage

Ice massage is a common modality used for the treatment of injuries in the athletic training field, and Waylonis (1967) examined the effects of 5 and 10 minutes of ice massage on intramuscular tissue temperature changes. An 8 oz ice cube was applied to a 4x6 inch area located on the posterior aspect of the thigh or the calf. Subjects were randomly assigned to one of the three ice massage conditions; posterior thigh 5 minutes, posterior thigh 10 minutes, or posterior calf 5 minutes. In order to have an equal number of subjects for each condition, two individuals volunteered to take part in more than one condition. Tissue temperature was measured at the level of the skin, 0.5 cm, 1 cm, 2 cm, 3 cm, and 4 cm for the experimental leg. Additional readings were recorded on the skin of the contralateral leg and in the rectum. This study showed that ice massage decreased temperature of the skin and underlying tissue but had no effect on the contralateral leg or rectal temperatures. While a treatment time of 5 minutes decreased intramuscular tissue temperature, it was shown that an additional drop in temperature was produced with a longer 10 minute treatment. The location of ice massage had no effect on the outcome of the treatment, intramuscular tissue temperature decreased with cold modality application.

When compared to other studies, ice massage was shown to not be as effective of a treatment as ice pack or cold spray, however, the design of the other studies did not thoroughly define the depth at which tissue temperature was measured. Ice massage seemed to produce no complications as a cold modality and was determined to be effective, inexpensive, and self-applicable. During re-warming of the tissues, there was a rapid increase in temperature during the first 10 minutes that leveled off for the remaining 40 minutes of the re-warming phase as it neared baseline temperature.

In an attempt to determine an effective application time for ice massage, Lowdon and Moore (1975) examined multiple application times, ranging from 5 to 15 minutes. Random assignment for order of application of the conditions (5, 10, and 15 minutes of ice massage) occurred for the 12 subjects. Intramuscular tissue temperature of the biceps brachii muscle was recorded every minute during testing at a depth of 2 cm below the skin. Results showed an immediate decrease in intramuscular tissue temperature in response to 5 minutes of ice massage that continued throughout the 10 and 15 minute treatment phases. The continued decrease of intramuscular tissue temperature occurred at a steady, non-significant rate. Previous research has shown an inverse relationship between skinfold and limb circumference with temperature change. It was also determined that ice massage created a rapid intramuscular tissue temperature decline during a 5 minute application, that application longer than 5 minutes produced no significant change, and superficial adipose thickness and limb girth should be considered when determining length of cold application.

Zemke et al. (1998) examined muscle temperature responses of 14 subjects who were randomly assigned to either a crushed ice pack or ice massage application. Intramuscular tissue temperature was recorded using a Physitemp MT-23/3 microprobe attached to a BAT-12 digital monitor during the testing process. Testing included 15 minutes of cold application and 30 minutes of re-warming after removal of the cold modality. Intramuscular tissue temperature was recorded during the 15 minute treatment phase and 30 minute re-warming phase. Results revealed the ice massage condition decreased temperature more rapidly than the crushed ice pack condition, but overall there was no difference between the conditions. The researchers concluded that if tissue temperature needs to be decreased as quickly as possible, it is recommended to use ice massage instead of a crushed ice pack. Although, if the greatest difference in pre to post intramuscular tissue temperature is the desired outcome, either ice massage or crushed ice pack would be sufficient. No difference in the duration of lowest tissue temperature (re-warming) was noted between the two experimental conditions. Zemke et al. (1998) listed a limitation and suggested performing further research on the affects of cold modality application on intramuscular tissue temperature changes post-exercise or post-injury to determine if warm tissue responds the same as cold tissue.

Additional Factors Related to Intramuscular Tissue Temperature

Body Composition

Thickness and density of subcutaneous adipose tissue can influence changes in intramuscular tissue temperature since adipose tissue functions as an insulator. To examine the influence of body composition, Johnson, Moore, Moore, and Oliver (1979) examined the differences in intramuscular tissue temperature change for 10 subjects during cold-water immersion. Intramuscular tissue temperature was recorded for a 5 hour testing session; once at the end of the 30 minute pre-treatment phase, during the 30 minute treatment phase, and during the 4 hour post-treatment (re-warming) phase. The variables analyzed were tissue temperature related to body composition and tissue temperature between the two legs. The researchers determined there was a significant decrease in intramuscular tissue temperature of both legs during the treatment phase and an increase during the beginning of the re-warming phase. There was also a significant relationship between temperature and body composition and between the temperatures of the two limbs. Body composition was shown to act as an insulator preventing heat transfer between the leg and the cold water bath, and was directly related to the amount of temperature reduction that occurred within the leg.

The effect of adipose thickness and intramuscular tissue temperature was investigated by Myrer et al. (2001) on 30 uninjured college students. Tissue temperature was measured using a Physitemp MT-26/2 or MT-26/4 microprobe attached to the Iso-Thermex model TX-31 thermocouple. Measurements were taken for a total of 50 minutes following a 3 minute baseline period. The treatment phase included application of a 1.8 kg crushed ice pack for 20 minutes on the triceps surae muscle group. The results showed that the greater the thickness of adipose tissue, the smaller the absolute temperature change. At 3 cm below the adipose layer, there continued to be a decrease in temperature after removal of the crushed ice pack. The researchers suggested that knowing the thickness of the subcutaneous adipose layer prior to cold application aids in determining the length of time it should be applied.

Myrer et al. (1997) examined 16 subjects who volunteered for a study examining tissue temperature changes at specific depths in the body. Temperatures were taken from 0.5 cm below the skin and 1 cm below the subcutaneous adipose layer. Subjects participated in both conditions: control (ice pack only) and contrast therapy (hydrocollator heat pack alternated with an ice pack). Measurements were taken during the 20 minute treatment phase and the 30 minute re-warming phase. A significant decrease in intramuscular tissue temperature occurred at 1 cm below the subcutaneous adipose layer at every 5 minute interval of the treatment phase. These researchers concluded that the thickness of the subcutaneous adipose tissue affects the rate of temperature changes whereby thicker adipose tissue makes the intramuscular tissue temperature decrease at a slower rate.

Jutte et al. (2001) examined skin temperature, intramuscular tissue temperature, and adipose thickness. Each of the 15 subjects participated in the same condition: a 3 minute baseline, a 30 minute crushed ice pack application, and a 120 minute re-warming phase. Temperature measurements were taken at the skin and 2 cm below the subcutaneous adipose layer of the quadriceps muscle group. Skinfold thickness was determined using a Lange Skinfold caliper. The value was divided by 2 to calculate the subcutaneous adipose thickness and then added to 2 cm to determine how deep the temperature probe was to be inserted. During the treatment phase, there was a slight decrease in intramuscular tissue temperature of about 8 °C and core body temperature of about 2 °C, while there was a decrease of about 27 °C for skin temperature. Removal of the crushed ice pack caused an immediate increase in skin temperature and a continued drop in intramuscular tissue temperature. This shows the importance of measuring intramuscular tissue temperature and not using skin temperature as a means to determine what is occurring within the muscle. Researchers also found a weak relationship between adipose thickness and changes in intramuscular tissue temperature. Differences were found in intramuscular tissue temperature changes among muscles examined (biceps brachii, quadriceps, and triceps surae muscle groups), each produced varying results from cold application.

Body composition is not the only factor that can influence intramuscular tissue temperature change; limb girth was examined by Petajan and Watts (1962). In this study, cold water immersion was used to decrease skin and intramuscular tissue temperature for 11 subjects. Researchers discovered the subject with the smallest calf girth measurement had the greatest decrease in intramuscular tissue temperature; however, this relationship did not remain consistent for all subjects. The subject with the greatest calf girth ranked 7^{th} out of 11 for decrease in intramuscular tissue temperature, but had the slowest rate of change during cold application. The average intramuscular tissue temperature change that occurred among subjects was 6 °C.

Effects of Exercise

Mancuso and Knight (1992) examined the effect of exercise on superficial tissue temperature over the anterior talofibular ligament in 12 young males. Subjects participated in all three conditions: control, 15 minutes of exercise, and 30 minutes of exercise. The order of participation was randomly assigned for each subject, and testing sessions were separated by 24-48 hours. Tissue temperatures were recorded prior to the assigned exercise condition, during the 30 minute application of a crushed ice pack, and for 90 minutes after removal of the cold modality. Superficial skin temperature was recorded with a Yellow Springs Instrument 402 attached to a 12-Channel Telithermister (#44TD). During the treatment phase, the crushed ice pack was shaken every 5 minutes to prevent the production of a thermal gradient along the surface of the skin. After exercise, the skin temperature increased 2.0 °C and 2.3 °C for the 15 and 30 minute bouts of exercise, respectively. Skin temperature for the exercise conditions returned to resting temperature at 110 minutes after completion of the exercise bout while skin temperature for the control condition did not return to resting temperature. The skin temperature remained slightly higher during the treatment phase for the exercise conditions than the control condition. Researchers showed that exercise has an effect on skin temperature, producing a higher temperature during treatment, but the rate of temperature change is equal among all conditions.

Recently, the effect of cold application on warm intramuscular tissue due to exercise was examined in 6 healthy, active subjects using three conditions: exercise and ice, exercise and no ice, and no exercise and ice (Long et al., 2005). Testing sessions were performed at about the same time of day for each subject and at least 48 hours apart. A skinfold measurement was taken of the anterior thigh, midway between the base of the patella and the anterior superior iliac spine. The same clinician performed all measurements in order to maintain validity of the numbers recorded. A flexible Teflon catheter was inserted into the quadriceps muscle at the depths of 1 and 2 cm below the subcutaneous adipose layer to allow for ease of insertion of the thermocouples. The thermocouples were removed from the leg during exercise to prevent the chance that they could break during activity. Intramuscular tissue temperature was recorded every 15 seconds for 5 minutes prior to the exercise bout which consisted of 30 minutes of riding a stationary bike at 70%-80% of estimated maximal heart rate. During the control condition, subjects laid supine on the treatment table for 30 minutes before application of the cold modality. This study showed that warm tissues, due to exercise, decreased 10 °C below pre-exercise tissue temperatures faster than the non-exercised tissue during cold application. Intramuscular tissue temperature at 1 cm below subcutaneous adipose tissue decreased quicker than the tissue temperature at 2 cm. However, the temperature at both depths reached the goal temperature within 7 minutes of each other, with the temperature at 1 cm reaching the goal prior to the temperature at 2 cm. From the design of the study, it could not be determined how much of the cooling was the result of the cold modality or the normal thermoregulatory changes that occur post-exercise. This study did support the concept that a longer treatment time is needed to decrease intramuscular tissue temperature at a deeper level, 2 cm versus 1 cm.

Changes in intramuscular tissue temperature have not been examined during exercise until Bender et al. (2005) assessed temperature changes in the triceps surae muscle group while walking on a treadmill. A great point was included that most athletes get ice to-go after practice; therefore, 16 college aged subjects were tested in that exact situation. Each participant took part in both the control (lying prone for 30 minutes) and the experimental conditions (walking at 4.5 km/h for 30 minutes). The researchers determined there was no decrease in intramuscular tissue temperature while walking but there was a decrease in intramuscular tissue temperature while resting and a decrease in skin temperature during both conditions.

Multiple research studies have examined the use of cold modalities and the effects on temperature change of both skin and intramuscular tissue. Studies examining changes in superficial skin temperature bring awareness to a decrease in skin temperature with application of ice but nothing more can be determined about what is occurring to the underlying tissues. By inserting a temperature probe into the subcutaneous tissue, whether it is adipose or muscle tissue, a better understanding of the inner-workings of how cold application affects deep tissue can be determined (Merrick et al., 1993; Myrer et al., 1997; Myrer et al., 1998). Acute injuries generally occur during activity and affect the deep muscle tissue, not skin tissue (Mancuso & Knight, 1992); therefore, it is important to determine what occurs within the muscle itself. According to Jutte et al. (2001), there is not a relationship between changes in skin temperature and changes in intramuscular tissue temperature. Skin temperature tends to increase at a faster rate and return to resting temperature much quicker than intramuscular tissue temperature.

Therefore, the current study attempted to determine what occurred to intramuscular tissue temperature at 1 cm below the subcutaneous adipose tissue during and after post-exercise application of a cold modality.

CHAPTER 3

METHODS

The specific aim of this study was to determine the difference in post-exercise intramuscular tissue temperature 1 cm below the subcutaneous adipose layer during the application of a crushed ice pack, an ice massage treatment, or a control period. A secondary aim was to determine which cold modality keeps the muscle tissue colder for a longer period of time after removal of the crushed ice pack or ice massage. The following hypotheses were tested:

1) The application of an ice massage treatment will produce a more rapid decrease in intramuscular tissue temperature following exercise.
2) After the removal of the cold modality, the intramuscular tissue temperature will begin re-warming within one minute.
3) The overall change in intramuscular tissue temperature will be the same for the crushed ice pack and ice massage treatment.

Research Design

A repeated measures design was used for this study. The dependent variable measured was intramuscular tissue temperature 1 cm below the subcutaneous adipose layer at the posterior aspect of the left lower leg. The independent variables were treatment (control, crushed ice pack, or ice massage) and time (30 second intervals).

Participants

Twenty-four college aged individuals (12 male, 12 female) between the ages of 20-28 years volunteered for this study. Five subjects withdrew from this study for multiple reasons and 1 subject completed all testing sessions but was dropped from the study due to being an outlier. This subject was considered an outlier because intramuscular tissue temperature did not follow the normal changes that occurred for other subjects during the different phases of testing. Participants with a cold allergy (ex. Raynaud's phenomenon), history of hypothermia, or peripheral vascular disease were excluded from the study. Participants were also excluded if they suffered a lower extremity injury within the past six months or had lower extremity surgery in the past 12 months. Recent injury or surgery may have altered the subjects gait causing abnormal firing of the muscle in the lower leg which in turn could alter the temperature of the involved muscles.

Instrumentation

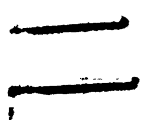
Temperature Probe

Intramuscular tissue temperature was measured 1 cm below the subcutaneous adipose layer using a Physiotemp MT-26/4 or MT-26/6 temperature probe (Figure 1) attached to a THERMES-16 software unit. Each temperature probe was soaked in STAT III TB, a germicidal detergent, for at least 10 minutes after use, and was sterilized using a Harvey SterileMax Autoclave prior to use. The tip of the temperature probe is where the temperature recording occurs, so it was placed in the center of the triceps surae muscle group.

Software

The THERMES-16 software unit was set to record temperature every 30 seconds during the length of the experiment. The unit has the capability of recording 16 different temperatures simultaneously which allowed for collection of data on multiple subjects during one testing session. An additional plug was inserted into one of the ports not in use for data collection and not connected to a temperature probe. This allowed for the channels in use to be turned on and off for each phase of data collection. Temperature was recorded to the nearest 0.01 °C; however, the unit was only calibrated to the nearest 0.1 °C so the results were rounded to the nearest 10^{th}.

Figure 1: MT-26/4 and MT-26/6 Temperature Probes made by Physitemp Instruments, Inc., Clifton, NJ



Pre-Testing Procedures

<u>*Consent*</u>

Prior to the start of data collection, approval was granted from the University Committee on Research Involving Human Subjects (UCRIHS) at Michigan State University. All subjects completed a health history questionnaire and signed an informed consent (Appendix B). Data collection took place in the Athletic Training Research Laboratory at Michigan State University. Subjects were instructed to wear shorts, t-shirt, socks, and running shoes to each testing session.

<u>*Anthropometric Measurements*</u>

Prior to the start of data collection, the participant's age was recorded and height and weight were measured. The participant then placed his or her left foot on a chair so the hip, knee, and ankle were at 90 degrees. The circumference of the left calf was measured to find the location of greatest girth and marked with a felt tip pen. The participant then stood with both feet flat on the ground, all body weight was shifted to the right leg, and the left knee was bent. A skinfold measurement was taken with a Lange Skinfold Caliper at the posterior aspect of the calf at the location of the greatest girth. A minimum of three skinfold measurements were taken, with additional measurements taken if they were greater than 2 mm apart (Heyward, 2002; Pollock & Jackson, 1984). The measured skinfold thickness was recorded and divided by 2 to determine the single layer thickness of the subcutaneous adipose layer. To insure repeatability of finding the same location of greatest girth of the left lower leg, a measurement was taken from the base of the medial malleolus to this location, recorded, and used for subsequent tests. The same researcher completed all measurements during subsequent testing sessions which has been shown to increase validity of the numbers collected (Pollock & Jackson, 1984).

Determination of Exercise Intensity

Maximal heart rate was estimated using the equation 220 – age (Heyward, 2002) and multiplied by 70% to determine the desired heart rate for data collection. A Polar heart rate monitor was placed around the subject's chest and the preliminary treadmill test was performed to determine the intensity of running required to maintain 70% of estimated maximal heart rate (Appendix B). The treadmill started at a speed of 3 mph with a 0% incline and increased 0.5 mph every minute until 6 mph was reached. The speed of 6 mph was then maintained and the grade was increased by 3% every minute until the calculated 70% of estimated maximal heart rate was reached and maintained. The running speed and incline was recorded and used during data collection.

Testing Day Procedures

<u>*Subject Preparation*</u>

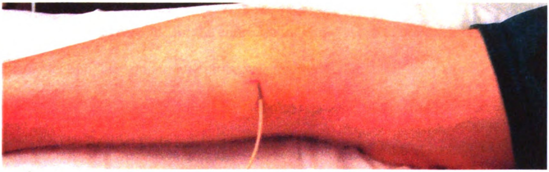
On the days of data collection, all subjects went through the same series of events. Upon arrival, clothes were changed into what would be worn during the running phase of the test. The left shoe was removed and the sock was moved to expose the medial malleolus. Subjects lay prone on a table with the left lower leg accessible and the foot hanging just over the end of the table to prevent the ankle from being forced into plantarflexion. Pillows were placed under the abdomen and at the head for comfort of the subject. The hip was rotated in either direction to place the leg in a neutral position with the toes of the foot pointing towards the floor. The base of the medial malleolus was located with the researcher's finger and a tape measure was placed flush with the finger and held in place. The recorded distance to the location of greatest girth of the lower leg was measured and marked with a felt tip pen. A laminated index card was placed at the posterior aspect of the lower leg level with the mark signifying greatest girth. The subcutaneous adipose tissue thickness calculated for the subject was added to 1 cm to determine the location of temperature probe insertion. A sliding caliper was placed at this distance, the measurement was taken from the index card, and a mark was made with a permanent marker at this location.

<u>*Insertion of Temperature Probe*</u>

The temperature probe insertion site was shaved and cleaned with a 10% betadine swabstick in expanding circles out from the point of insertion. After the betadine dried, a 70% isopropyl alcohol prep pad was used in the same fashion. The researcher then put on sterile gloves and was handed a 1 cc sterile syringe with a 25 gauge by 5/8 inch needle. One cc of 1% lidocaine without epinephrine was drawn into the syringe after the top was cleaned with a 70% isopropyl alcohol prep pad. The lidocaine was then injected subcutaneously at the location of probe insertion and did not reach the underlying muscle. The needle was also used to create an entry site for the temperature probe at the medial aspect of the lower leg. A sterile gauze pad was placed over the site of injection while the lidocaine anesthetized the area. This is similar to methods performed by Myrer et al. (1998).

The temperature probe was then removed from a sterlized Fisherbrand Instant Sealing Sterilization Pouch (5.25 x 10 inches) and inserted into the triceps surae complex at the measured depth (Figure 2). Once the probe was inserted, it was connected to the THERMES-16 interface unit and data collection began when the channel in use was activated.

Figure 2: Insertion of Temperature Probe in Lower Leg



Exercise Protocol

Temperature measurements were taken every 30 seconds for 5 minutes to create a baseline reading. The channel was then turned off to allow for the temperature probe to be removed from the leg and placed back into the sterilization pouch. A bandage was placed over the insertion site, the subjects put his or her shoes back on, and the Polar heart rate monitor was applied. Heart rate was monitored during running to make sure the subjects were at 70% of estimated maximal heart rate. The running portion of the testing session included 2 minutes of walking on a treadmill at a speed of 3 mph followed by running at the predetermined speed and incline for 8 minutes. When time elapsed, the subject stepped off the treadmill, removed the heart rate monitor and shoes, for added comfort, and immediately returned to the prone position on the treatment table.

Once back on the table, the bandage was removed and the area was cleaned in the same fashion as previously, with a 10% betadine swabstick and a 70% isopropyl alcohol prep pad. The temperature probe was then reinserted and a 2 minute baseline was recorded. The 2 minutes allowed for the temperature probe to equilibrate to the new intramuscular tissue surroundings. Following the post-exercise baseline reading, temperature was recorded for 20 minutes of the designated condition and 30 minutes of re-warming after removal of the cold modality. Temperature measurements were recorded every 30 seconds for the entire testing time. After 52 minutes of post-exercise data collection, the temperature probe was removed from the subject's lower leg and the insertion site was cleaned with a 70% isopropyl alcohol prep pad and bandaged. Each subject underwent all three conditions (control, crushed ice pack, ice massage) in a randomly assigned order. Data collection took place during three separate testing sessions separated by at least 48 hours to allow for healing of any tissue damage or hematoma formation.

Conditions

Control

The control condition had no cold modality applied to the triceps surae muscle group. Testing procedure was the same as either cold modality condition with tissue temperature recorded for a 2 minute baseline, a mock 20 minute cold application, as well as for the 30 minute re-warming phase.

Crushed Ice Pack

The crushed ice pack consisted of 1 kg crushed ice centered over the tip of the temperature probe without placing pressure on the external portion of the temperature probe. The crushed ice pack was filled and weighed, excess air was squeezed out, and a knot tied near the opening of the bag to achieve equal size and weight of the packs between subjects. This crushed ice pack size represents a typical ice pack used in the athletic training room, as well as being of similar size to the ice pack used by Zemke et al. (1998).

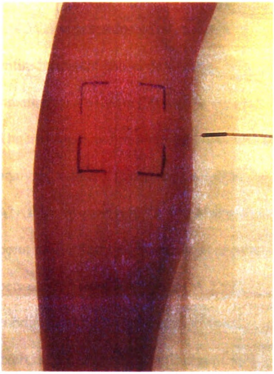
Ice Massage

If ice massage was the intervention during that testing session, a 6x6 cm square was centered and drawn on the leg over the tip of where the temperature probe would be after insertion (Figure 3). The ice massage treatment consisted of 12 oz of tap water placed in a 12 oz paper cup and frozen. The top of the cup was torn to expose the ice prior to application. Administration of the massage occurred by using overlapping vertical strokes confined to the 6x6 cm square. The same treatment time was used (20 minutes) to allow for equal time of cold application across experimental conditions.

Data Analysis

Means and standard errors were used to determine age, height, weight, lower leg girth, skinfold, and 70% of estimated maximal heart rate of the 18 subjects. Intramuscular tissue temperatures at 1 cm below the subcutaneous adipose layer were recorded for each subject during each of the three conditions. The measurements were

Figure 3: Area for Ice Massage Treatment



recorded in degrees Celsius with all values rounded to the nearest 0.1 °C. The data of the 18 subjects were compared to himself or herself across the three conditions as well as between subjects within the same condition. The comparison of each subject within the three conditions allowed for analysis of rate of temperature change specific to that person or thickness of subcutaneous adipose tissue present. The comparison between subjects looked at the difference in temperature changes with varying thicknesses of subcutaneous adipose tissue.

A 2 time (pre- and post-exercise) x 3 treatment (control, ice pack, ice massage) repeated measures analysis of variance (ANOVA) was conducted to determine if there was an increase in intramuscular tissue temperature due to exercise. A paired t-test was also performed for each condition to determine if a significance difference was present between pre- and post-exercise baseline for each of the three conditions. A 3 treatment (control, ice pack, ice massage) x 41 time (30 second intervals) repeated measures ANOVA was conducted to compare intramuscular tissue temperature throughout the entire treatment phase. In order to compare temperature during re-warming, a 3 (treatment) x 61 time (30 second intervals) repeated measures ANOVA was conducted. The treatment and re-warming phases were then broken down into 5 minute intervals and analyzed with a 3 (treatment) x 5 (time) and 3 (treatment) x 7 (time) repeated measures ANOVA, respectively. A pairwise comparison was performed to determine at what time point a significant difference was present during the treatment and re-warming phases between the three conditions. A 2 (time) x 3 (treatment) repeated measures ANOVA was conducted for both pre-exercise baseline and 20 minutes of treatment along with pre-exercise baseline and 30 minutes of re-warming to determine if a difference occurred.

To determine if gender had an effect on intramuscular temperature change, a 2 gender (male, female) x 3 treatment (control, ice pack, ice massage) x 41 time (30 second intervals) repeated measures ANOVA was performed for the treatment phase. This was also performed for the re-warming phase using a 2 gender (male, female) x 3 treatment (control, ice pack, ice massage) x 61 time (30 second intervals) repeated measures ANOVA.

Effects of gender and subcutaneous adipose thickness were tested using a 2 gender (male, female) x 3 treatment (control, ice pack, ice massage) x 41 time (30 second intervals) repeated measures analysis of covariance (ANCOVA) with skinfold thickness as the covariate. A 2 gender (male, female) x 3 treatment (control, ice pack, ice massage) x 61 time (30 second intervals) repeated measures ANCOVA with skinfold thickness as the covariate was conducted to analyze the effects of gender and skinfold on the re-warming of intramuscular tissue temperature after removal of the cold modality.

CHAPTER 4

RESULTS

The specific aim of this study was to determine the difference in post-exercise intramuscular tissue temperature 1 cm below the subcutaneous adipose layer during the application of a crushed ice pack, an ice massage treatment, or a control period. A secondary specific aim was to determine which cold modality keeps the muscle tissue colder for a longer period of time after removal of the crushed ice pack or ice massage.

Subject Demographics

A total of 24 subjects (12 male, 12 female) volunteered to participate in this study. Five subjects withdrew from the study prior to completion of data collection. Withdrawal occurred due to the following reasons: a) 3 subjects had a conflict in scheduling, b) 1 subject had prolonged soreness in the lower leg, and c) 1 subject developed a cold allergy. Additionally, 1 subject completed all testing sessions but was dropped from the study due to being an outlier in the data collected. An outlier was determined to be anyone that did not follow the normal changes in intramuscular tissue temperature during the different phases of testing. This left 18 subjects (8 male, 10 female) for the final analysis (Table 1).

The mean age for the subjects was 23.06 ± 0.45 years with a range of 20 – 28 years. The subject's height was 171.49 ± 1.69 cm with a range of 158.0 – 186.0 cm. The mean weight was 73.06 ± 2.21 kg with a range of 60.7 – 97.8 kg. Girth measurement of the lower leg ranged from 34.6 – 43.6 cm with a mean of 38.42 ± 0.56 cm. Skinfold thickness was 14.61 ± 1.27 mm with a range of 6.0 – 27.0 mm. The value calculated for

70% of estimated maximal heart rate ranged from 134.4 – 140.0 bpm with a mean of 137.86 ± 0.32 bpm.

Table 1: Subject Demographics

	N	Age (years)	Height (cm)	Weight (kg)	Lower Leg Girth (cm)	Skinfold (mm)	70% Estimated MHR (bpm)
Male	8						
Mean		23.50	175.03	75.80	38.54	10.75	137.55
SE		±0.69	±2.32	±3.30	±0.86	±1.48	±0.48
Female	10						
Mean		22.70	168.65	70.86	38.33	17.70	138.11
SE		±0.61	±2.08	±2.95	±0.77	±1.33	±0.43
Total	18						
Mean		23.06	171.49	73.06	38.42	14.61	137.86
SE		±0.45	±1.69	±2.21	±0.56	±1.27	±0.32

Effect of Exercise on Intramuscular Tissue Temperature

Pre- and post-exercise intramuscular tissue temperature was examined to determine if 10 minutes of exercise on a treadmill induced a significant increase in muscle temperature (Table 2, Figure 4). Baseline intramuscular tissue temperature was calculated by using the average of the last 1 minute of the baseline recording for both pre-exercise and post-exercise. Pre-exercise baseline values for the control, crushed ice pack, and ice massage conditions were 35.03 ± 0.19 °C, 35.13 ± 0.20 °C, and 35.07 ± 0.12 °C, respectively. Post-exercise baseline values for the control, crushed ice pack, and ice massage conditions were 37.15 ± 0.17 °C, 37.06 ± 0.22 °C, and 36.76 ± 0.22 °C, respectively. A 2 (time) x 3 (treatment) repeated measures ANOVA was conducted to determine significant differences between pre- and post-exercise baseline intramuscular tissue temperatures (Table 11). A significant increase in temperature was found between

Table 2: Descriptive Statistics for Pre-Exercise and Post-Exercise Baseline Intramuscular Tissue Temperatures

	N	Mean	SE	95% CI
Control				
Pre-Exercise Baseline	18	35.03	0.19	34.63-35.42
Post-Exercise Baseline	18	37.15*	0.17	36.79-37.52
Ice Pack				
Pre-Exercise Baseline	18	35.13	0.20	34.71-35.56
Post-Exercise Baseline	18	37.06*	0.22	36.59-37.52
Ice Massage				
Pre-Exercise Baseline	18	35.07	0.12	34.81-35.34
Post-Exercise Baseline	18	36.76*	0.22	36.29-37.22

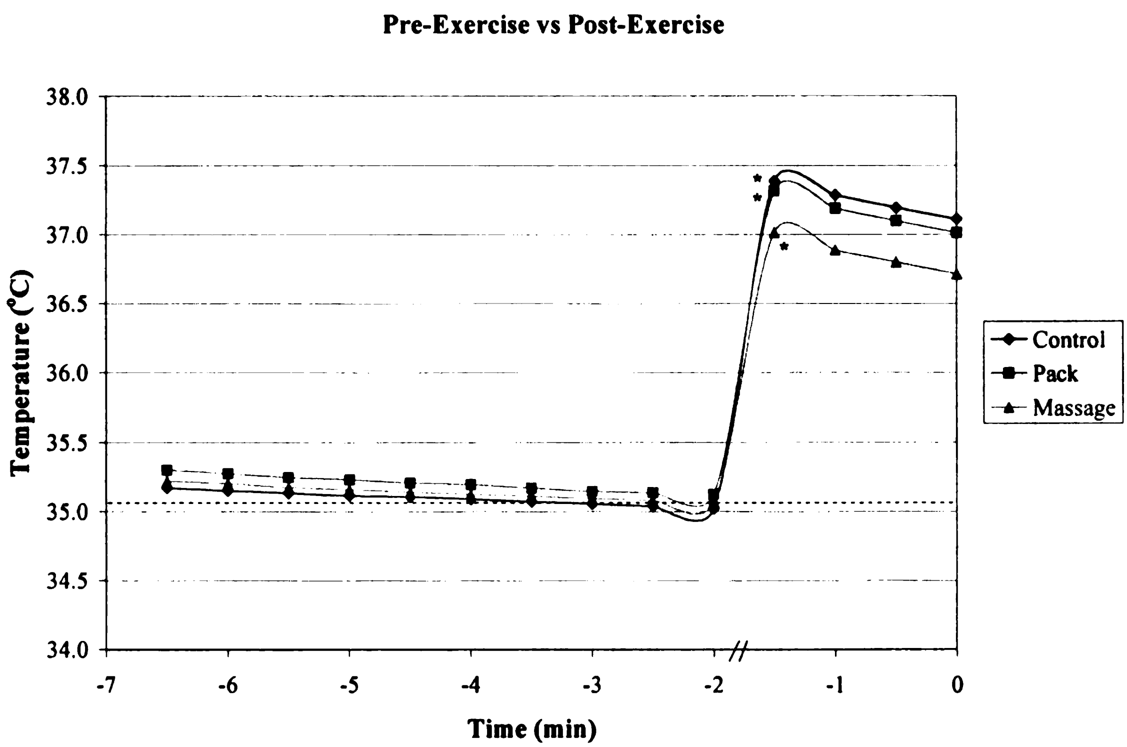
* significant at the $p < .001$ level

the two time points ($p < .001$) with no significant differences for treatment ($p = .44$) or the interaction between time and treatment ($p = .33$). A paired t-test was also performed for each condition and showed a significant difference between pre-exercise and post-exercise baseline for each condition (Table 12). This shows that tissue temperature significantly increased in a similar fashion for all conditions with 10 minutes of exercise on a treadmill.

Effect of Cold Application on Intramuscular Tissue Temperature

Intramuscular tissue temperature began decreasing for each of the three conditions as soon as the treatment phase began (Figure 5, Tables 13, 14, 15). From the beginning of the treatment phase to the end of the 20 minute treatment phase, there was a decrease of 1.19 ± 0.09 °C for the control condition, 7.23 ± 0.99 °C for the crushed ice pack condition, and 10.31 ± 1.24 °C for the ice massage condition. At the end of the 20 minute treatment phase, the intramuscular tissue temperature for the control condition remained higher than the pre-exercise baseline temperature by 0.89 ± 0.19 °C (Tables 3, 17). The temperature for the crushed ice pack and ice massage achieved a lower intramuscular tissue temperature, when compared to baseline, after 20 minutes of cold application and were 5.34 ± 1.07 °C and 8.68 ± 1.35 °C lower than baseline tissue temperature, respectively.

Figure 4: Pre-Exercise versus Post-Exercise Intramuscular Tissue Temperature Comparing Three Treatment Conditions

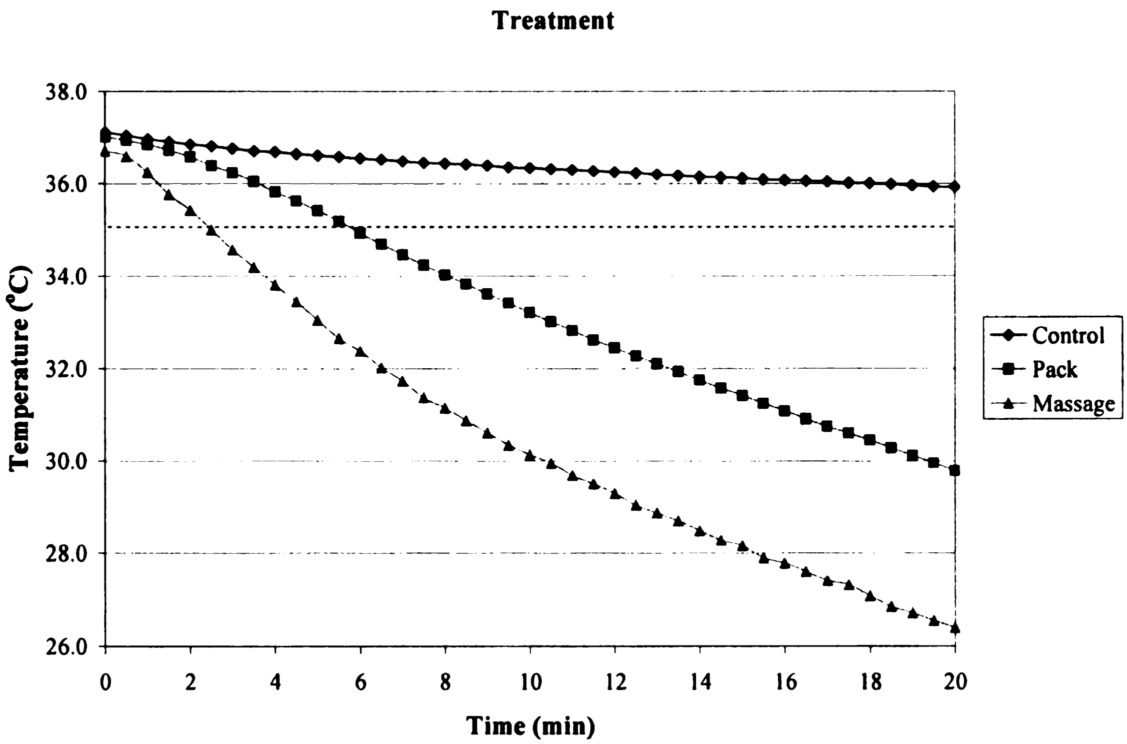


* significant difference between pre-exercise and post-exercise baseline

A 2 (time) x 3 (treatment) repeated measures ANOVA revealed a significant decrease from pre-exercise baseline to 20 minutes of the treatment phase across time ($p < .001$), treatment ($p < .001$), and the interaction between time and treatment ($p < .001$) (Table 16). A pairwise comparison between each of the groups revealed a significant difference in temperature between control and crushed ice pack ($p < .001$), control and ice massage ($p < .001$), and crushed ice pack and ice massage conditions ($p < .001$, Table

4). A paired t-test was also performed for each condition and showed a significant difference between pre-exercise baseline and 20 minutes of the treatment phase for each condition (Table 17). This suggests that the treatment phase had a significant influence on the intramuscular tissue temperature for all conditions.

Figure 5: Intramuscular Tissue Temperature Changes During the Treatment Phase



The temperatures recorded for the treatment phase were separated into 5 minute intervals for further analysis (Table 5). A 3 (treatment) x 5 (time) repeated measures ANOVA was performed for comparison. A significant decrease in temperature was established across time ($p < .001$), treatment ($p < .001$), and the interaction between time and treatment ($p < .001$, Table 18). A paired t-test was performed for every 5 minute interval for each condition and showed a significant difference between each interval for all conditions (Table 19). Additional pairwise comparisons were performed between each of the 5 minute intervals (Table 6). When comparing 0 and 5 minutes of the treatment phase there was no difference between the control and crushed ice pack conditions ($p = .22$), but there was a significant separation in temperatures between control and ice massage ($p = .01$) and crushed ice pack and ice massage ($p < .001$).

Table 3: Descriptive Statistics for Pre-Exercise Baseline and 20 Minutes of Treatment

	N	Mean	SE	95% CI
Control				
Pre-Exercise Baseline	18	35.03	0.19	34.63-35.42
Treatment 20 min	18	35.92*	0.14	35.63-36.21
Ice Pack				
Pre-Exercise Baseline	18	35.13	0.20	34.71-35.55
Treatment 20 min	18	29.79*	1.18	27.30-32.27
Ice Massage				
Pre-Exercise Baseline	18	35.07	0.12	34.81-35.34
Treatment 20 min	18	26.40*	1.43	23.39-29.41

* significant increase from pre-exercise baseline to 20 minutes of the treatment phase at the $p < .001$ level

Table 4: Pairwise Comparison of Pre-Exercise Baseline and 20 Minutes of Treatment

Treatment	Mean Difference	SE	95% CI
Control vs Ice Pack	3.02*	0.59	1.77-4.27
Control vs Ice Massage	4.74*	0.70	3.26-6.21
Ice Pack vs Ice Massage	1.72*	0.37	0.95-2.50

* significant at the $p < .001$ level

Starting at 10 minutes, there was a significant difference between each of the three conditions ($p < .05$, Figure 6). These results show there is a significant decrease in intramuscular tissue temperature following 10 minutes of exercise on a treadmill when a cold modality was applied. A greater decrease in intramuscular tissue temperature occurred during both cold applications when compared to the control condition.

Table 5: Descriptive Statistics for Treatment at 0, 5, 10, 15, and 20 Minutes

	N	Mean	SE	95% CI
Control				
Treatment 0 min	18	37.11	0.18	36.74-37.48
Treatment 5 min	18	36.61*	0.16	36.27-36.94
Treatment 10 min	18	36.34*	0.15	36.02-36.65
Treatment 15 min	18	36.11*	0.14	35.82-36.41
Treatment 20 min	18	35.92*	0.14	35.63-36.21
Ice Pack				
Treatment 0 min	18	37.01	0.22	36.55-37.48
Treatment 5 min	18	35.42†	0.72	33.90-36.93
Treatment 10 min	18	33.21*	1.00	31.10-35.33
Treatment 15 min	18	31.42*	1.12	29.08-33.75
Treatment 20 min	18	29.79*	1.18	27.30-32.27
Ice Massage				
Treatment 0 min	18	36.71	0.22	36.25-37.18
Treatment 5 min	18	33.05*	1.10	30.74-35.37
Treatment 10 min	18	30.14*	1.31	27.38-32.89
Treatment 15 min	18	28.16*	1.37	25.27-31.05
Treatment 20 min	18	26.40*	1.43	23.39-29.41

* significant change from previous 5 minute interval at the $p < .001$ level
† significant change from previous 5 minute interval at the $p = .01$ level

Effect of Re-warming on Intramuscular Tissue Temperature

Baseline intramuscular tissue temperature was 35.03 ± 0.19 °C, 35.13 ± 0.20 °C, and 35.07 ± 0.12 °C for the control, ice pack, and ice massage conditions, respectively. During the 30 minute re-warming phase, the intramuscular tissue temperature either continuously decreased in temperature during the control condition or decreased followed by an increase for the cold modality conditions (Tables 20, 21, 22). For the control condition, there was a constant decrease in temperature of 0.86 ± 0.07 °C during the 30 minute re-warming phase. The crushed ice pack and ice massage conditions showed a continued decrease in temperature after removal of the cold modality that was followed by a gradual increase that never reached pre-exercise baseline temperature (Figure 7). During the re-warming phase, the crushed ice pack condition started at 29.79 ± 1.18 °C, decreased to 28.82 ± 0.89 °C, and ended at 30.62 ± 0.47 °C with an overall increase of 0.83 ± 1.02 °C. An increase of 4.05 ± 1.04 °C occurred in the ice massage condition with a starting temperature of 26.40 ± 1.43 °C and an ending temperature of 30.45 ± 0.48 °C, with the lowest temperature reaching 25.99 ± 1.23 °C.

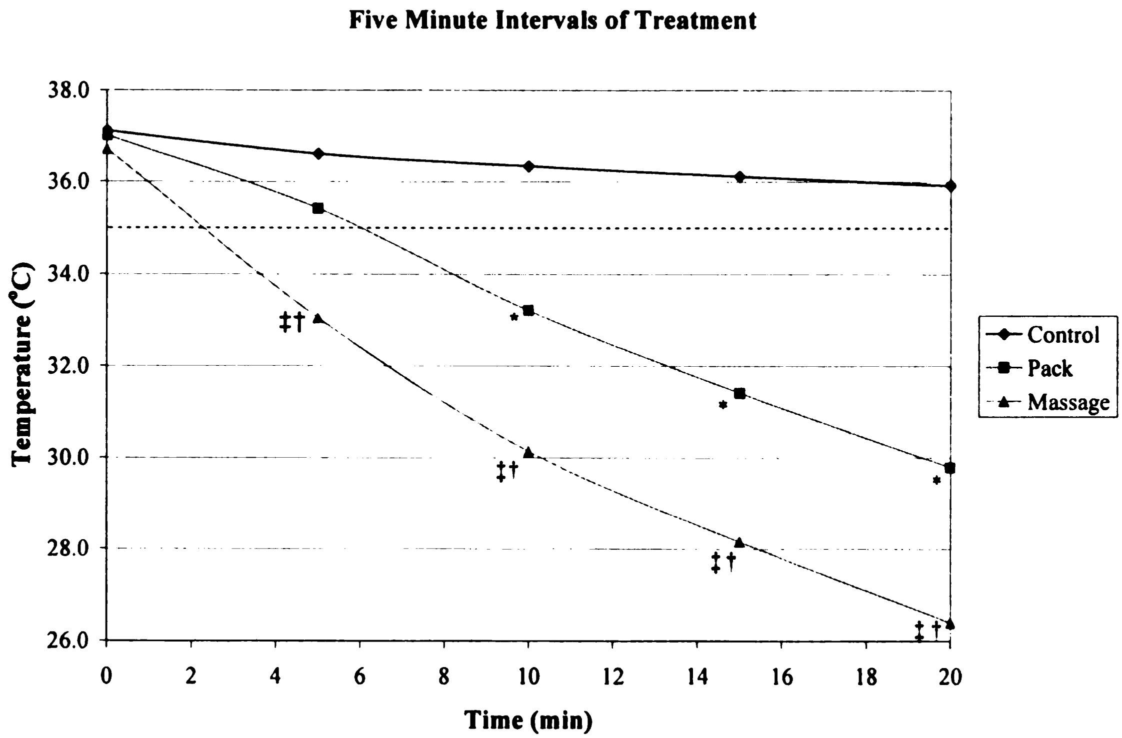
Table 6: Pairwise Comparison for 5 Minute Intervals During the Treatment Phase

Time (min)	Treatment	Mean Difference	SE	95% CI
0 and 5	Control vs Ice Pack	0.65	0.50	-0.42- 1.71
	Control vs Ice Massage	1.98†	0.64	0.63- 3.33
	Ice Pack vs Ice Massage	1.33*	0.39	0.50- 2.16
5 and 10	Control vs Ice Pack	2.16‡	0.87	0.31- 4.00
	Control vs Ice Massage	4.88*	1.18	2.39- 7.36
	Ice Pack vs Ice Massage	2.72*	0.68	1.28- 4.16
10 and 15	Control vs Ice Pack	3.91*	1.06	1.68- 6.14
	Control vs Ice Massage	7.08*	1.31	4.31- 9.84
	Ice Pack vs Ice Massage	3.17*	0.73	1.62- 4.71
15 and 20	Control vs Ice Pack	5.42*	1.13	3.03- 7.81
	Control vs Ice Massage	8.74*	1.37	5.86-11.62
	Ice Pack vs Ice Massage	3.32*	0.75	1.74- 4.90

* significant at the $p < .001$ level
† significant at the $p = .01$ level
‡ significant at the $p = .05$ level

At the end of the 30 minute re-warming phase, the temperature for the control condition remained slightly higher than pre-exercise baseline temperature by a non-significant amount, 0.03 ± 0.17 °C (Table 7). The crushed ice pack and ice massage conditions had a lower temperature than the pre-exercise baseline temperature by 4.51 ± 0.43 °C and 4.62 ± 0.40 °C, respectively (Table 24).

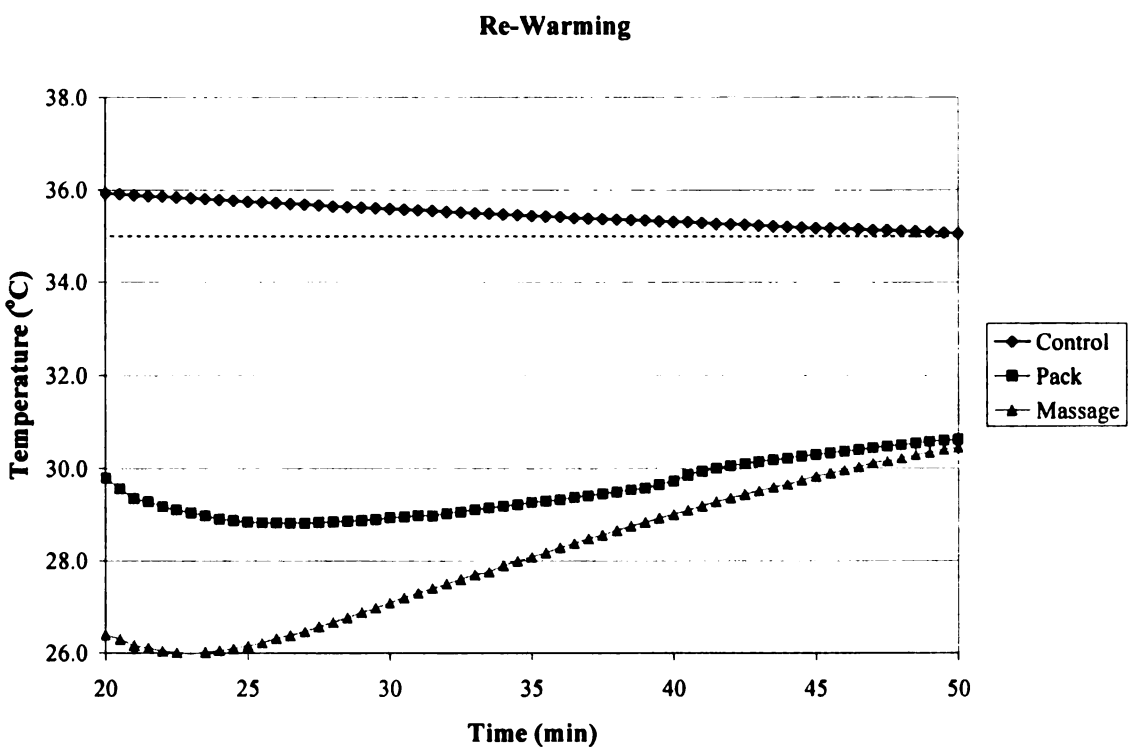
Figure 6: Intramuscular Tissue Temperature Changes Separated Into 5 Minute Intervals During the Treatment Phase Comparing Three Conditions



* significant difference between control and ice pack
† significant difference between control and ice massage
‡ significant difference between ice pack and ice massage

A 2 (time) x 3 (treatment) repeated measures ANOVA indicated a significant difference from pre-exercise baseline to 30 minutes of the re-warming phase across time ($p < .001$), treatment ($p < .001$), and the interaction between time and treatment ($p < .001$) (Table 23). A pairwise comparison between each of the conditions revealed a significant difference in temperature between the control and crushed ice pack ($p < .001$) and control and ice massage ($p < .001$) conditions (Table 8). There were no significant differences between the crushed ice pack and ice massage conditions ($p = .56$). A paired t-test was also performed for each condition and showed a significant difference between pre-exercise baseline and 30 minutes of the re-warming phase for each condition (Table 24). This suggests that the re-warming phase has a significant influence on the intramuscular tissue temperature for both the crushed ice pack and ice massage conditions.

Figure 7: Intramuscular Tissue Temperature Changes During the Re-Warming Phase



The temperatures recorded for the re-warming phase were separated into 5 minute intervals for further analysis (Table 9). A 3 (treatment) x 7 (time) repeated measures ANOVA was performed to compare 5 minute intervals (Table 25). Results revealed variations between conditions (Figure 8). During the 30 minutes, there was a significant change across time ($p < .001$), treatment ($p < .001$), and the interaction between time and treatment ($p < .001$). A paired t-test was performed for every 5 minute interval for each condition and showed a significant difference between each interval for the control condition (Table 26). No significant difference was present between the 5 and 10 minute interval for the ice pack condition and between the 0 and 5 minute interval for the ice massage condition.

Table 7: Descriptive Statistics for Pre-Exercise Baseline and 30 Minutes of Re-Warming

	N	Mean	SE	95% CI
Control				
Pre-Exercise Baseline	18	35.03	0.19	34.63-35.42
Re-warming 30 min	18	35.06	0.15	34.76-35.37
Ice Pack				
Pre-Exercise Baseline	18	35.13	0.20	34.71-35.55
Re-warming 30 min	18	30.62*	0.47	29.64-31.60
Ice Massage				
Pre-Exercise Baseline	18	35.07	0.12	34.81-35.34
Re-warming 30 min	18	30.45*	0.48	29.44-31.45

* significant at the $p < .001$ level

Table 8: Pairwise Comparison of Pre-Exercise Baseline and 30 Minutes of Re-Warming

Treatment	Mean Difference	SE	95% CI
Control vs Ice Pack	2.14*	0.23	1.68-2.66
Control vs Ice Massage	2.29*	0.25	1.76-2.82
Ice Pack vs Ice Massage	0.11	0.19	-0.59-0.52

* significant at the $p < .001$ level

A pairwise comparison was also performed between each of the 5 minute intervals of the re-warming phase (Table 10). This comparison revealed a significant difference between the control and crushed ice pack ($p < .001$) and control and ice massage ($p < .001$) during the entire 30 minutes of the re-warming phase. A significant difference existed between the crushed ice pack and ice massage conditions through the

20th minute ($p = .04$) but reached a level of non-significance beginning at the 25th minute ($p = .16$) and continued through the remainder of the re-warming phase. These results show there is a significant change in intramuscular tissue temperature during the re-warming phase of a cold application. The intramuscular tissue temperatures for each of

Table 9: Descriptive Statistics for Re-Warming at 0, 5, 10, 15, 20, 25, and 30 Minutes

	N	Mean	SE	95% CI
Control				
Re-warming 0 min	18	35.92	0.14	35.63-36.21
Re-warming 5 min	18	35.74*	0.14	35.45-36.03
Re-warming 10 min	18	35.59*	0.14	35.30-35.88
Re-warming 15 min	18	35.44*	0.14	35.16-35.72
Re-warming 20 min	18	35.31*	0.14	35.02-35.60
Re-warming 25 min	18	35.17*	0.14	34.88-35.48
Re-warming 30 min	18	35.06*	0.15	34.76-35.37
Ice Pack				
Re-warming 0 min	18	29.79	1.18	27.30-32.27
Re-warming 5 min	18	28.84†	1.00	26.75-30.93
Re-warming 10 min	18	28.93	0.79	27.28-30.59
Re-warming 15 min	18	29.26‡	0.69	27.82-30.71
Re-warming 20 min	18	29.73†	0.57	28.52-30.93
Re-warming 25 min	18	30.30‡	0.50	29.25-31.34
Re-warming 30 min	18	30.62*	0.47	29.64-31.60
Ice Massage				
Re-warming 0 min	18	26.40	1.43	23.39-29.41
Re-warming 5 min	18	26.16	1.05	23.93-28.38
Re-warming 10 min	18	27.09†	0.80	25.39-28.78
Re-warming 15 min	18	28.08*	0.71	26.58-29.59
Re-warming 20 min	18	29.00*	0.61	27.71-30.29
Re-warming 25 min	18	29.83*	0.54	28.69-30.96
Re-warming 30 min	18	30.45*	0.48	29.44-31.45

* significant change from previous 5 minute interval at the $p < .001$ level
† significant change from previous 5 minute interval at the $p = .01$ level
‡ significant change from previous 5 minute interval at the $p = .05$ level

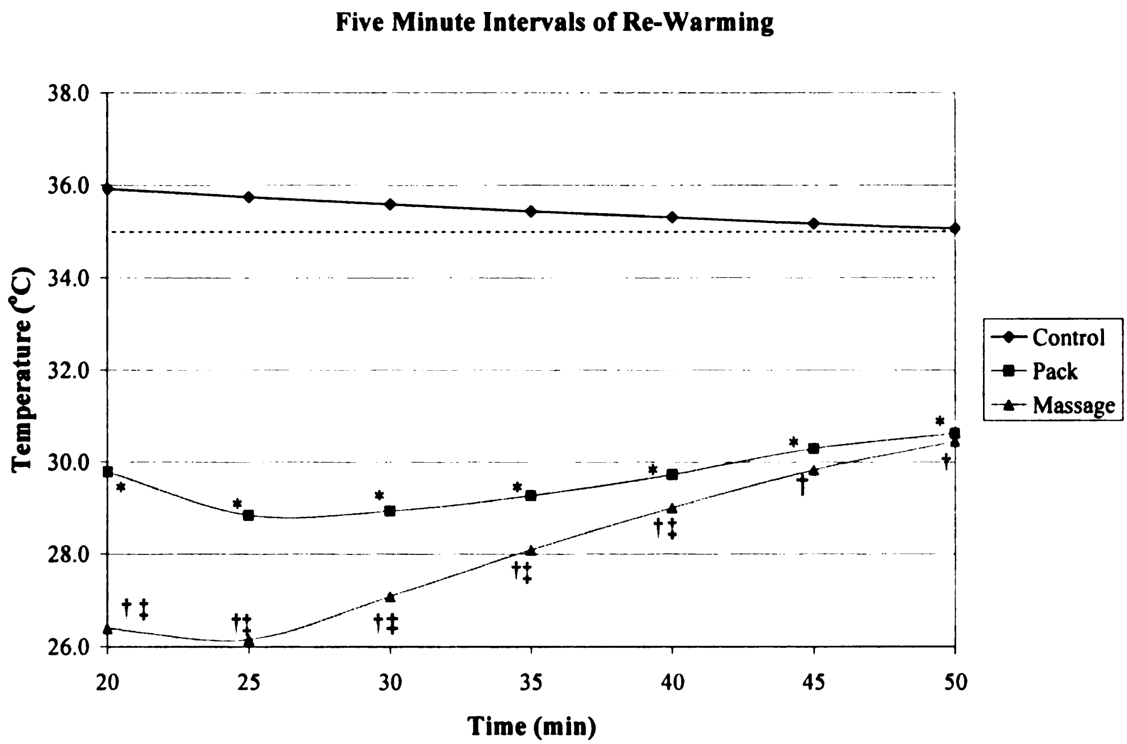
the three conditions examined were showing a trend for returning to pre-exercise baseline temperature. There was a continued decrease in intramuscular tissue temperature for the control condition while the temperature for the crushed ice pack and ice massage conditions showed an increase. The control condition was not significantly different from the pre-exercise baseline intramuscular tissue temperature at the end of the 30 minute re-warming phase.

Table 10: Pairwise Comparison of Treatment Conditions for 5 Minute Intervals During the Re-warming Phase

Time (min)	Treatment	Mean Difference	SE	95% CI
0 and 5	Control vs Ice Pack	6.52*	1.06	4.28- 8.76
	Control vs Ice Massage	9.55*	1.20	7.02-12.09
	Ice Pack vs Ice Massage	3.04*	0.68	1.60- 4.47
5 and 10	Control vs Ice Pack	6.78*	0.87	4.95- 8.61
	Control vs Ice Massage	9.04*	0.90	7.14-10.95
	Ice Pack vs Ice Massage	2.26*	0.57	1.05- 3.47
10 and 15	Control vs Ice Pack	6.42*	0.71	4.91- 7.92
	Control vs Ice Massage	7.93*	0.74	6.37- 9.49
	Ice Pack vs Ice Massage	1.51†	0.48	0.50- 2.53
15 and 20	Control vs Ice Pack	5.88*	0.60	4.62- 7.14
	Control vs Ice Massage	6.83*	0.65	5.47- 8.20
	Ice Pack vs Ice Massage	0.95‡	0.42	0.06- 1.84
20 and 25	Control vs Ice Pack	5.23*	0.49	4.20- 6.26
	Control vs Ice Massage	5.83*	0.56	4.64- 7.01
	Ice Pack vs Ice Massage	0.60	0.40	-0.25- 1.44
25 and 30	Control vs Ice Pack	4.66*	0.45	3.71- 5.61
	Control vs Ice Massage	4.98*	0.49	3.94- 6.02
	Ice Pack vs Ice Massage	0.32	0.41	-0.55- 1.19

* significant at the $p < .001$ level
† significant at the $p = .01$ level
‡ significant at the $p = .05$ level

Figure 8: Intramuscular Tissue Temperature Changes Separated Into 5 Minute Intervals During the Re-Warming Phase Comparing Three Conditions



* significant difference between control and ice pack
† significant difference between control and ice massage
‡ significant difference between ice pack and ice massage

Effect of Gender on Intramuscular Tissue Temperature Changes

A 2 (gender) x 3 (treatment) x 41 (time) repeated measure ANOVA was performed for the 20 minute treatment phase to determine if gender had an effect of changes in intramuscular tissue temperature (Table 27). Results showed a significant difference for time ($p < .001$), treatment ($p < .001$), and the interactions between time and gender ($p < .001$), time and treatment ($p < .001$), and time, treatment, and gender ($p < .001$). There was no significant difference for the interaction between treatment and gender ($p = .06$). This suggests that gender influenced the intramuscular tissue temperature changes that occurred during cold application.

A 2 (gender) x 3 (treatment) x 61 (time) repeated measure ANOVA was performed for the 30 minute re-warming phase as well (Table 28). Results showed a significant difference for time ($p < .001$), treatment ($p < .001$), and the interactions between time and gender ($p < .001$), treatment and gender ($p = .02$), time and treatment ($p = .00$), and time, treatment, and gender ($p = .00$). Not only did gender have an effect on intramuscular tissue temperature changes during cold application, but there was also an effect following removal of the cold modality.

Since skinfold thickness is known to be different between genders and has been shown to influence intramuscular tissue temperature changes with cold application, both skinfold and gender were examined together to determine which factor had a greater influenced. A 2 (gender) x 3 (treatment) x 41 (time) repeated measure analysis of covariance (ANCOVA) was conducted using skinfold as a covariate for the 20 minute treatment phase (Table 29). Results revealed significance differences for time ($p < .001$), treatment ($p < .001$), and the interactions between time and skinfold ($p < .001$), time and treatment ($p < .001$), and time, treatment, and skinfold ($p < .001$). There were no significance differences for the interactions between time and gender ($p = 1.00$), treatment and skinfold ($p = .15$), treatment and gender ($p = .69$), and time, treatment, and gender ($p = 1.00$). This suggests that skinfold thickness, and not gender, causes the differential response between men and women.

A 2 (gender) x 3 (treatment) x 61 (time) repeated measure ANCOVA was conducted using skinfold as a covariate for the 30 minute re-warming phase as well (Table 30). Results revealed significance differences for time ($p < .001$), treatment ($p < .001$), and the interactions between time and skinfold ($p < .001$), time and treatment ($p <$

.001), and time, treatment, and skinfold ($p < .001$). There were no significance differences for the interactions between time and gender ($p = 1.00$), treatment and skinfold ($p = .19$), treatment and gender ($p = .53$), and time, treatment, and gender ($p = 1.00$). This suggests that the gender effect during the re-warming phase resulted from differences in skinfold and subcutaneous adipose tissue thicknesses between males and females.

CHAPTER 5

DISCUSSION

The primary purpose of this study was to determine the difference in post-exercise intramuscular tissue temperature 1 cm below the subcutaneous adipose layer during the application of a crushed ice pack, an ice massage treatment, or a control period. A secondary purpose was to determine which cold modality keeps the muscle tissue colder for a longer period of time after removal of the crushed ice pack or ice massage.

There were three major findings in this study. First, there was a decrease in intramuscular tissue temperature with cold application with the greatest change occurring with use of ice massage. Second, during the re-warming phase, the control condition continued to decrease from post-exercise baseline, almost reaching pre-exercise baseline tissue temperature. The crushed ice pack and ice massage conditions experienced continued cooling after removal of the cold modality followed by an increase in tissue temperature that remained significantly lower than pre-exercise baseline temperature. Third, the overall decrease in intramuscular tissue temperature during cold application was significantly different between the three conditions.

Analysis of Temperature Change During Cold Application

There was a significant difference between each of the three treatment conditions at the end of the 20 minute treatment phase. The temperatures for the crushed ice pack and ice massage conditions were significantly lower than the control condition and ice massage was also significantly lower than crushed ice pack. In this study, there was a significant decrease in intramuscular tissue temperature of $5.34 \pm 1.07\ ^{o}C$ and $8.67 \pm 1.35\ ^{o}C$ from pre-exercise baseline to 20 minutes of the treatment phase for crushed ice pack and ice massage, respectively. From post-exercise baseline to 20 minutes of the treatment phase, there was a significant decrease in intramuscular tissue temperature of 7.22 ± .99 °C and 10.31 ± 1.24 °C. This is consistent with previous research that has shown a significant decrease in intramuscular tissue temperature during cold application (Bocobo et al., 1991; Johnson et al., 1979; Long et al., 2005; Lowdon & Moore, 1975; McMaster et al., 1978; Merrick et al., 1993; Myrer et al., 1997; Myrer et al., 1998; Myrer et al., 2001; Petajan & Watts; 1962; Waylonis, 1967; Zemke et al., 1998). When comparing the absolute tissue temperature change, McMaster et al. (1978) examined a crushed ice pack to three other cold modalities during application to tissue at rest. The crushed ice pack was the most effective of the four in decreasing tissue temperature, producing a change of 11.3 °C after 1 hour of application. In the present study, a similar decrease in temperature was induced with only 20 minutes of cold application. With a longer application time, the temperature change that occurred in this study could have continued to decline and surpassed the temperature change that took place in the study done by McMaster et al. (1978). This supports previous findings that warmed tissue cools faster than non-warmed tissue (Long et al., 2005).

The present study showed a greater decrease in intramuscular tissue temperature at 1 cm below the subcutaneous adipose layer during application of ice massage (8.67 ± 1.35 °C) when compared to a crushed ice pack (5.34 ± 1.07 °C). Myrer et al. (1998) examined intramuscular tissue temperature changes at the same depth and same application time as this study and determined the ice pack condition (7.1 ± 4.1 °C) created a greater decrease in temperature than the cold whirlpool (5.1 ± 1.8 °C). Subjects in this study took part in one of the two treatment conditions and subcutaneous adipose thickness was not included. The intramuscular tissue temperature change that occurred between the present study and the Myrer et al. study showed similar changes in the overall decrease in intramuscular tissue temperature during a 20 minute cold application.

While most previous research on cold application has examined intramuscular tissue temperature changes with tissues at rest, changes in temperature of tissue warmed in response to exercise was the focus of this study. A decrease of 5.34 ± 1.07 °C for crushed ice pack and 8.67 ± 1.35 °C for ice massage occurred from the pre-exercise baseline temperature in the warmed tissue during 20 minutes of cold application. Long et al. (2005) showed that tissue warmed in response to exercise decreases at a faster rate than non-exercised tissue. At 30 minutes of cold application, McMaster et al. (1978) achieved the greatest decrease in temperature of 6.9 °C from tissues at rest. A decrease of 8.44 °C was recorded by Merrick et al. (2003) after 30 minutes of cold application while a 9.7 °C decrease occurred after 30 minutes of ice pack application for Merrick et al. (1993). It is hypothesized that the greater decrease in intramuscular tissue temperature in the previous research was due to the longer application duration. With the additional 10 minutes of cold application in the research done by Merrick et al. (1993, 2003), there is only a difference of 3 – 4.5 °C when compared to the current study. If cold application continued in the current study, a greater decrease in intramuscular tissue temperature may have occurred and resulted in a similar change as this previous research.

The intramuscular tissue temperature reached during the ice massage condition in the present study was significantly lower and decreased at a faster rate when compared to the crushed ice pack condition. The finding regarding rate of temperature change is congruent with that of Zemke et al. (1998), intramuscular tissue temperature decreases at a faster rate during application of ice massage. The difference between this study and the present study was the level of significance regarding overall change in intramuscular tissue temperature between application of an ice pack and ice massage. Zemke et al. (1998) showed no difference between the two conditions at the end of the 15 minute cold application while the present study showed a significant difference at the 15 minute time point. Zemke et al. (1998) did not use a repeated measure design for his study and only had 14 subjects split between two cold application conditions. No control condition was examined in his study and the few number of subjects may have created a low power calculation. The use of a cubed ice pack instead of crushed ice pack may have produced this difference. Also, the starting temperature of the intramuscular tissue prior to cold application, at rest or post-exercise, may have influenced the change that occurred. The constant stimulation of the ice massage on the skin following exercise may have created a prolonged period of blood flow in the area causing the greater decrease in temperature than when the ice massage was applied to the tissues at rest.

The findings of the present study showed significant differences beginning at 5 minutes of treatment between the ice massage and control as well as the ice massage and crushed ice pack conditions. Once the significance occurred, it remained for the 20 minute treatment phase. A significant difference in intramuscular tissue temperature occurred at the 10^{th} minute between the crushed ice pack and control conditions that remained for the duration of the treatment phase. A significant decrease in intramuscular tissue temperature from baseline occurred at 5 minutes of ice pack application by Myrer et al. (1997) and 5 minutes of ice massage application by Zemke et al. (1998) and Waylonis (1967). A potential reason for the crushed ice pack to take 10 minutes to significantly differ from the control condition may be due to the development of a temperature gradient between the crushed ice pack and the skin. A similar technique performed by Mancuso and Knight (1992) could have been instituted in the present study to decrease the likelihood of temperature gradient development; shaking the ice pack every 5 minutes during application.

This study demonstrated a significant difference between every 5 minute interval of ice massage application during the treatment phase when compared to the control condition. Lowdon and Moore (1975) also produced a significant decrease in intramuscular tissue temperature after 5 minutes of ice massage application, but the continued decrease of temperature at 10 and 15 minutes was not significantly different. This difference may be attributed to the starting temperature of the intramuscular tissue. The tissue warmed in response to exercise had a greater range of available temperature change due to a higher starting value than the tissues at rest.

The present study showed that gender had an influence on intramuscular tissue temperature change that was related to skinfold thickness. Males overall had a lower skinfold thickness when compared to females, creating the gender effect for temperature change. The data showed the greater the skinfold thickness, the slower the intramuscular tissue temperature change. The effect of skinfold thickness is consistent with previous work by Johnson et al. (1979) showing a significant inverse relationship between temperature and body composition. Jutte et al. (2001) showed a weak inverse relationship between these same factors. Myrer et al. (2001) determined that a longer cold application was needed for an individual with a thick subcutaneous adipose layer in order to achieve the same temperature decrease when compared to an individual with a thin layer. Not only does skinfold thickness affect temperature change, but also the depth of the tissue being cooled, on the amount of time needed for a decrease to occur (Long et al., 2005); the deeper the tissue, the longer the application time. Differences in significance between studies may be due to the subjects used for research and the skinfold thickness examined.

Analysis of Temperature Change During Re-warming After Removal of the Cold Modality

A continuation in temperature decrease after removal of a cold modality occurred in the present study for both the crushed ice pack and ice massage conditions and was consistent with previous research (Bocobo et al., 1991; Jutte et al., 2001; Merrick et al., 1993; Myrer et al., 1998; Myrer et al., 2001). In contrast to this study, Myrer et al. (1998) showed no temperature decrease following removal of a 20 minute ice pack application. The present study was similar to research performed by Johnson et al. (1979) and Merrick et al. (1993), once the cold modality was removed the intramuscular temperature eventually began to increase but never returned to resting temperature. There are several reasons these findings may have occurred. First, the depth of intramuscular tissue temperature being examined effects the temperature change. Second, the type of cold modality analyzed creates variation in temperature readings. Third, the length of time examined for the treatment and re-warming phases creates differences in the findings.

In the current study, the temperatures during the 30 minute re-warming phase were significantly different between the crushed ice pack and ice massage conditions until the 25th minute. Zemke et al. (1998) noted no difference in intramuscular tissue temperature during re-warming between the ice pack and ice massage conditions.

Differences between the two studies may be credited to the intramuscular tissue temperature prior to application of the cold modality, the skinfold thickness of the subjects, or the length of the treatment phase.

Utilization and Clinical Incorporation of Ice Pack and Ice Massage Treatments

Incorporation of cold application is common among members of the athletic training profession for treatment and rehabilitation of acute injuries (Airaksinen et al., 2003; Best, 1997; Bleakley et al., 2004; Bocobo et al., 1991; Curl et al., 1997; Jutte et al., 2001; Karunakara et al., 1999; Kellett, 1986; Lee et al., 2005; Lowdon & Moore, 1975; Mancuso & Knight, 1992; McMaster et al., 1978; Merrick et al., 2003; Merrick et al., 1993; Merrick et al., 1999; Morsi, 2002; Myrer et al., 1997; Myrer et al., 1998; Myrer et al., 2001; Otte et al., 2002; Starkey, 1976; Thorsson et al., 1985; Waylonis, 1967; Zemke et al., 1998). A significant decrease in intramuscular tissue temperature from baseline measurements was reached with a 20 minute crushed ice pack or ice massage application. Using ice massage is recommended if the goal of cold application is to decrease intramuscular tissue temperature at a faster rate or to reach a colder temperature, when compared to a crushed ice pack. Comparing the current results to those of other researchers can be difficult due to the application time and cold modality examined, however there are similar trends between ice pack and ice massage for the current and previous research. Ice massage has been shown to create a greater decrease in intramuscular tissue temperature when compared to ice pack, non-significantly (Zemke et al, 1998). A continued decrease in intramuscular tissue temperature occurred with a longer ice massage application time (Lowdon & Moore, 1975; Waylonis, 1967). No matter which type of cold modality is chosen to decrease tissue temperature, a significant decrease occurs when compared to pre-application baseline temperature (Bender et al., 2005; Bocobo et al., 1991; Johnson et al., 1979; Jutte et al., 2001; Long et al., 2005; Lowdon & Moore, 1975; Mancuso & Knight, 1992; McMaster et al., 1978; Merrick et al., 2003; Merrick et al., 1993; Merrick et al., 1999; Myrer et al., 1997; Myrer er al., 1998; Myrer et al., 2001; Petajan & Watts, 1962; Waylonis, 1967; Zemke et al. 1998)

Even though the ice massage condition decreased intramuscular tissue temperature to a greater degree and at a faster rate, there was also a more rapid increase of temperature after removal of the cold modality. Application of a crushed ice pack has shown a slower rate of intramuscular tissue temperature increase after cooling has ceased. During the re-warming phase, the ice massage condition increased at a faster rate compared to the crushed ice pack. The difference between the two conditions reached a non-significant difference at 25 minutes of re-warming. The rate of change past 30 minutes of re-warming was not examined, but an assumption can be made that the rate of temperature increase would continue along the same path until the pre-exercise baseline temperature was achieved. This path would show a similar for both the ice massage and crushed ice pack condition, showing a leveling off of the temperature and continued increase to the pre-exercise baseline temperature.

Limitations

There were 18 subjects analyzed in this study, 8 males and 10 females, however, power calculations showed a power of 0.96 – 1.00 where significant differences in temperature were shown (Table 31). The subjects were all college aged, 20-28 years, with most of them being students at a Division I University. These factors are fairly homogenous to the collegiate population which allows for some generalization of the findings to other populations. When examining the data, a majority of the subjects with a small skinfold measurement were males while those with a larger skinfold measurement were females. Using skinfold as a covariate in data analysis negated gender effects on intramuscular tissue temperature change.

Additional limitations that were not controlled for include: hydration status, physical fitness level, changes in fitness level between testing sessions, amount of sleep prior to testing, and nutrition. An attempt should be made to control these limitations in future studies examining changes in intramuscular tissue temperature during application of a cold modality.

An attempt to control some of these items could have been undertaken in this study. Requirements could have been made on hydration, nutrition, and sleep. This would have made finding subjects much more difficult and increase the time needed for data collection. Subjects lied prone on the table for about 15 minutes prior to temperature recording while the equipment and leg was prepared. Having the subjects report to the lab 30-60 minutes prior to testing would allow for intramuscular tissue temperature to stabilize for an equal amount of time for each subject prior to recording a baseline temperature. Also, water could have been consumed prior to testing so a set amount of fluid was in the body ensuring a state of hydration. Testing two more males could have been done as well to even the groups with an equal number of males and females for a total of 20 subjects instead of 18.

Future Research Implications

Future research should continue to examine changes in intramuscular tissue temperature post-exercise and post-injury. This study examined post-exercise intramuscular tissue temperature changes, but the relationship between how temperature changes in post-exercise versus post-injury tissues is unknown. Also, muscle tissue was the only thing examined, but ligaments and tendons are also injured and could be examined in future research. Different cold modalities, such as cold whirlpool and ice pack, should be examined to determine which form produces the greatest change in temperature, decreases temperature the quickest, and re-warms at the slowest rate.

Additional factors to be considered are time frames for the treatment and re-warming phases as well as the amount of exercise performed prior to cold application. Determining the most effective and reasonable cold application time for the athletic population should be established in order to provide appropriate care. Performing a VO_2max on a treadmill would generally last longer than the 10 minutes of exercise performed in this study. The area of the body tested should also vary. Different types and densities of muscle tissue are located throughout the body. It would be beneficial to examine multiple muscle groups to determine where and if a difference takes place.

Research could also examine the effect of two types of consecutive cold modality application. Since the ice massage condition decreased the temperature at a faster rate and the crushed ice pack condition has a slower rate of increase after removal, it would be interesting to examine what occurred to intramuscular tissue temperature from 10 minutes of ice massage application immediately followed by 10 to 20 minutes of a crushed ice pack.

Conclusion

This study examined changes in intramuscular tissue temperature during post-exercise application of a cold modality. More specifically, post-exercise intramuscular tissue temperature 1 cm below the subcutaneous adipose layer was observed during the application of a crushed ice pack, an ice massage treatment, and a control period as well as after removal of the cold modality. This was one of the first studies to examine the affect of cold application on intramuscular tissue temperature changes in warmed muscle post-exercise.

This study revealed a more rapid decrease in intramuscular tissue temperature during application of an ice massage application compared to a crushed ice pack. It was demonstrated that a slower increase in temperature occurred during re-warming following a crushed ice pack application compared to an ice massage. Both cold modalities created a significant decrease in intramuscular tissue temperature compared to the control condition after 20 minutes of application.

Future studies should continue to examine intramuscular tissue temperature changes post-exercise and post-injury to better understand the use of cold modalities within an athletic environment.

APPENDIX A: TABLES

Table 11: Repeated Measures Analysis of Variance for Pre-Exercise and Post-Exercise Baseline Intramuscular Tissue Temperatures Comparing Time and Condition

	SS	df	MS	F
Treatment	0.75	2	0.38	0.85
Time	98.46	1	98.46	196.89*
Treatment x Time	0.88	2	0.44	1.16

* significant at the $p < .001$ level

Table 12: T-Test Comparing Pre-Exercise and Post-Exercise Baseline Intramuscular Tissue Temperature

	Mean Difference	SE	95% CI
Control	-2.12*	0.24	-2.62--1.62
Pack	-1.92*	0.22	-2.39--1.46
Massage	-1.68*	0.19	-2.08--1.28

* significant at the $p < .001$ level

Table 13: Descriptive Statistics for the Treatment Phase of the Control Condition

	N	Mean	SE	95% CI
Control				
Treatment 0.0 min	18	37.11	0.14	36.74-37.48
Treatment 0.5 min	18	37.05	1.09	36.68-37.41
Treatment 1.0 min	18	36.97	0.14	36.60-37.33
Treatment 1.5 min	18	36.91	0.99	36.55-37.27
Treatment 2.0 min	18	36.85	0.83	36.50-37.20
Treatment 2.5 min	18	36.81	0.85	36.46-37.16
Treatment 3.0 min	18	36.76	0.82	36.41-37.11
Treatment 3.5 min	18	36.71	0.83	36.36-37.05
Treatment 4.0 min	18	36.69	0.14	36.35-37.03
Treatment 4.5 min	18	36.64	0.80	36.31-36.98
Treatment 5.0 min	18	36.61	0.82	36.27-36.94
Treatment 5.5 min	18	36.58	0.14	36.25-36.91
Treatment 6.0 min	18	36.55	0.78	36.22-36.87
Treatment 6.5 min	18	36.52	0.80	36.19-36.85
Treatment 7.0 min	18	36.48	0.14	36.16-36.81
Treatment 7.5 min	18	36.45	0.77	36.13-36.78
Treatment 8.0 min	18	36.43	0.80	36.11-36.75
Treatment 8.5 min	18	36.42	0.14	36.10-36.74
Treatment 9.0 min	18	36.39	0.76	36.07-36.70
Treatment 9.5 min	18	36.35	0.79	36.04-36.66
Treatment 10.0 min	18	36.34	1.05	36.02-36.65
Treatment 10.5 min	18	36.31	0.14	36.00-36.62
Treatment 11.0 min	18	36.29	0.96	35.99-36.60
Treatment 11.5 min	18	36.27	1.01	35.96-36.58
Treatment 12.0 min	18	36.25	0.14	35.95-36.55
Treatment 12.5 min	18	36.23	0.94	35.93-36.53
Treatment 13.0 min	18	36.19	0.98	35.89-36.50
Treatment 13.5 min	18	36.17	0.14	35.88-36.47
Treatment 14.0 min	18	36.15	0.92	35.85-36.45
Treatment 14.5 min	18	36.14	0.95	35.84-36.44
Treatment 15.0 min	18	36.11	0.14	35.82-36.41
Treatment 15.5 min	18	36.09	0.89	35.79-36.38
Treatment 16.0 min	18	36.07	0.91	35.78-36.37
Treatment 16.5 min	18	36.06	0.14	35.76-36.35
Treatment 17.0 min	18	36.04	0.87	35.75-36.34
Treatment 17.5 min	18	36.01	0.89	35.72-36.30
Treatment 18.0 min	18	36.00	0.14	35.71-36.30
Treatment 18.5 min	18	35.99	0.85	35.69-36.28

Table 13 (cont'd)

Treatment 19.0 min	18	35.96	0.87	35.67-36.25
Treatment 19.5 min	18	35.94	0.14	35.65-36.22
Treatment 20.0 min	18	35.92	0.14	35.63-36.21

Table 14: Descriptive Statistics for the Treatment Phase of the Ice Pack Condition

	N	Mean	SE	95% CI
Ice Pack				
Treatment 0.0 min	18	37.01	0.20	36.55-37.48
Treatment 0.5 min	18	36.94	1.17	36.48-37.39
Treatment 1.0 min	18	36.85	0.15	36.29-37.41
Treatment 1.5 min	18	36.72	0.82	36.02-37.43
Treatment 2.0 min	18	36.58	0.98	35.71-37.45
Treatment 2.5 min	18	36.39	1.29	35.38-36.40
Treatment 3.0 min	18	36.24	1.00	35.10-37.38
Treatment 3.5 min	18	36.05	1.31	34.79-37.30
Treatment 4.0 min	18	35.83	0.15	34.46-37.19
Treatment 4.5 min	18	35.63	1.02	34.20-37.06
Treatment 5.0 min	18	35.42	1.31	33.90-36.93
Treatment 5.5 min	18	35.19	0.14	33.59-36.78
Treatment 6.0 min	18	34.93	1.03	33.20-36.66
Treatment 6.5 min	18	34.70	1.33	32.88-36.51
Treatment 7.0 min	18	34.46	0.15	32.59-36.33
Treatment 7.5 min	18	34.24	1.04	32.33-36.15
Treatment 8.0 min	18	34.03	1.33	32.07-35.99
Treatment 8.5 min	18	33.83	0.14	31.83-35.83
Treatment 9.0 min	18	33.62	1.05	31.58-35.66
Treatment 9.5 min	18	33.42	1.35	31.34-35.49
Treatment 10.0 min	18	33.21	1.18	31.10-35.33
Treatment 10.5 min	18	33.01	0.16	30.87-35.16
Treatment 11.0 min	18	32.82	0.86	30.65-34.99
Treatment 11.5 min	18	32.62	1.21	30.42-34.82
Treatment 12.0 min	18	32.45	0.15	30.23-34.67
Treatment 12.5 min	18	32.27	0.89	30.04-34.49
Treatment 13.0 min	18	32.11	1.25	29.85-34.36
Treatment 13.5 min	18	31.93	0.15	29.67-34.19
Treatment 14.0 min	18	31.75	0.91	29.47-34.04
Treatment 14.5 min	18	31.58	1.25	29.26-33.90
Treatment 15.0 min	18	31.42	0.15	29.08-33.75
Treatment 15.5 min	18	31.25	0.93	28.89-33.60
Treatment 16.0 min	18	31.08	1.27	28.72-33.44
Treatment 16.5 min	18	30.91	0.15	28.53-33.29
Treatment 17.0 min	18	30.75	0.95	28.35-33.14
Treatment 17.5 min	18	30.60	1.28	28.18-33.04
Treatment 18.0 min	18	30.45	0.15	28.02-32.87
Treatment 18.5 min	18	30.28	0.97	27.85-32.71

Table 14 (cont'd)

Treatment 19.0 min	18	30.12	1.29	27.66-32.57
Treatment 19.5 min	18	29.95	0.15	27.49-32.42
Treatment 20.0 min	18	29.79	0.15	27.30-32.27

Table 15: Descriptive Statistics for the Treatment Phase of the Ice Massage Condition

	N	Mean	SE	95% CI
Ice Massage				
Treatment 0.0 min	18	36.71	0.13	36.25-37.18
Treatment 0.5 min	18	36.59	0.55	36.11-37.07
Treatment 1.0 min	18	36.24	0.14	35.45-37.03
Treatment 1.5 min	18	35.77	0.50	34.50-37.04
Treatment 2.0 min	18	35.43	0.48	33.90-36.95
Treatment 2.5 min	18	35.00	0.50	33.25-36.75
Treatment 3.0 min	18	34.57	0.48	32.64-36.50
Treatment 3.5 min	18	34.19	0.50	32.17-36.22
Treatment 4.0 min	18	33.82	0.14	31.70-35.93
Treatment 4.5 min	18	33.45	0.48	31.24-35.67
Treatment 5.0 min	18	33.05	0.49	30.74-35.37
Treatment 5.5 min	18	32.65	0.14	30.19-35.12
Treatment 6.0 min	18	32.38	0.47	29.88-34.87
Treatment 6.5 min	18	32.02	0.49	29.46-34.58
Treatment 7.0 min	18	31.74	0.15	29.10-34.37
Treatment 7.5 min	18	31.37	0.47	28.73-34.01
Treatment 8.0 min	18	31.15	0.48	28.48-33.82
Treatment 8.5 min	18	30.88	0.15	28.17-33.58
Treatment 9.0 min	18	30.61	0.47	27.89-33.33
Treatment 9.5 min	18	30.34	0.48	27.62-33.07
Treatment 10.0 min	18	30.14	0.55	27.38-32.89
Treatment 10.5 min	18	29.95	0.14	27.19-32.71
Treatment 11.0 min	18	29.69	0.50	26.88-32.50
Treatment 11.5 min	18	29.51	0.54	26.69-32.32
Treatment 12.0 min	18	29.29	0.14	26.44-32.14
Treatment 12.5 min	18	29.03	0.50	26.19-31.87
Treatment 13.0 min	18	28.87	0.54	26.03-31.71
Treatment 13.5 min	18	28.69	0.14	25.83-31.56
Treatment 14.0 min	18	28.49	0.49	25.60-31.37
Treatment 14.5 min	18	28.28	0.53	25.35-31.20
Treatment 15.0 min	18	28.16	0.14	25.27-31.05
Treatment 15.5 min	18	27.90	0.49	24.98-30.82
Treatment 16.0 min	18	27.78	0.52	24.85-30.71
Treatment 16.5 min	18	27.60	0.14	24.63-30.58
Treatment 17.0 min	18	27.41	0.49	24.46-30.36
Treatment 17.5 min	18	27.32	0.51	24.36-30.29
Treatment 18.0 min	18	27.09	0.14	24.09-30.08
Treatment 18.5 min	18	26.85	0.48	23.86-29.84

Table 15 (cont'd)

Treatment 19.0 min	18	26.72	0.51	23.71-29.73
Treatment 19.5 min	18	26.55	0.14	23.55-29.56
Treatment 20.0 min	18	26.40	0.14	23.39-29.41

Table 16: Repeated Measures Analysis of Variance for Pre-Exercise Baseline and 20 Minutes of the Treatment Phase Comparing Time and Condition

	SS	df	MS	F
Time	517.08	1	517.08	34.35*
Treatment	414.34	2	207.17	35.40*
Time x Treatment	424.72	2	212.36	35.40*

* significant at the $p < .001$ level

Table 17: T-Test Comparing Pre-Exercise Baseline and 20 Minutes of the Treatment Phase

	Mean Difference	SE	95% CI
Control	0.89*	0.19	0.49- 1.30
Pack	-5.34*	1.07	-7.60--3.09
Massage	-8.68*	1.35	-11.53--5.83

* significant at the $p < .001$ level

Table 18: Repeated Measures Analysis of Variance for the Treatment Phase at 0, 5, 10, 15, and 20 Minutes Comparing Time and Condition

	SS	df	MS	F
Time	1330.97	4	332.74	68.49*
Treatment	1378.84	2	689.42	21.35*
Time x Treatment	500.63	8	62.58	37.35*

* significant at the $p < .001$ level

Table 19: T-Test Comparing 5 Minute Intervals During the Treatment Phase

	Mean Difference	SE	95% CI
Control			
Treatment 0-5	0.51*	0.04	0.43-0.59
Treatment 5-10	0.27*	0.03	0.21-0.33
Treatment 10-15	0.22*	0.02	0.18-0.27
Treatment 15-20	0.19*	0.02	0.16-0.23
Ice Pack			
Treatment 0-5	1.60†	0.51	0.52- 2.67
Treatment 5-10	2.20*	0.32	1.54- 2.87
Treatment 10-15	1.80*	0.17	1.44- 2.15
Treatment 15-20	1.63*	0.12	1.38- 1.88
Ice Massage			
Treatment 0-5	3.66*	0.91	1.74- 5.58
Treatment 5-10	2.91*	0.27	2.35- 3.48
Treatment 10-15	1.98*	0.16	1.64- 2.32
Treatment 15-20	1.76*	0.17	1.40- 2.13

* significant at the $p < .001$ level
† significant at the $p = .01$ level

Table 20: Descriptive Statistics for the Re-warming Phase of the Control Condition

	N	Mean	SE	95% CI
Control				
Re-warming 0.0 min	18	35.92	0.14	35.63-36.21
Re-warming 0.5 min	18	35.91	1.39	35.62-36.19
Re-warming 1.0 min	18	35.88	0.14	35.60-36.17
Re-warming 1.5 min	18	35.86	1.11	35.58-36.15
Re-warming 2.0 min	18	35.86	1.15	35.57-36.14
Re-warming 2.5 min	18	35.83	1.42	35.54-36.13
Re-warming 3.0 min	18	35.82	1.33	35.53-36.11
Re-warming 3.5 min	18	35.80	0.14	35.51-36.09
Re-warming 4.0 min	18	35.78	1.28	35.49-36.07
Re-warming 4.5 min	18	35.77	0.14	35.48-36.06
Re-warming 5.0 min	18	35.74	1.11	35.45-36.03
Re-warming 5.5 min	18	35.74	1.22	35.45-36.02
Re-warming 6.0 min	18	35.72	0.14	35.43-36.00
Re-warming 6.5 min	18	35.70	1.08	35.41-35.99
Re-warming 7.0 min	18	35.69	1.18	35.40-35.97
Re-warming 7.5 min	18	35.67	0.14	35.38-35.96
Re-warming 8.0 min	18	35.64	1.05	35.36-35.93
Re-warming 8.5 min	18	35.63	1.14	35.34-35.92
Re-warming 9.0 min	18	35.62	0.14	35.33-35.91
Re-warming 9.5 min	18	35.61	1.02	35.32-35.89
Re-warming 10.0 min	18	35.59	1.37	35.30-35.88
Re-warming 10.5 min	18	35.58	0.14	35.29-35.86
Re-warming 11.0 min	18	35.56	1.12	35.28-35.85
Re-warming 11.5 min	18	35.55	1.38	35.26-35.83
Re-warming 12.0 min	18	35.53	0.14	35.24-35.81
Re-warming 12.5 min	18	35.51	1.12	35.23-35.80
Re-warming 13.0 min	18	35.49	1.39	35.21-35.78
Re-warming 13.5 min	18	35.49	0.14	35.20-35.78
Re-warming 14.0 min	18	35.47	1.13	35.18-35.75
Re-warming 14.5 min	18	35.46	1.41	35.17-35.74
Re-warming 15.0 min	18	35.44	0.14	35.16-35.72
Re-warming 15.5 min	18	35.43	1.14	35.14-35.72
Re-warming 16.0 min	18	35.42	1.40	35.13-35.71
Re-warming 16.5 min	18	35.39	0.14	35.10-35.68
Re-warming 17.0 min	18	35.38	1.14	35.09-35.67
Re-warming 17.5 min	18	35.37	1.41	35.08-35.66
Re-warming 18.0 min	18	35.36	0.14	35.07-35.64
Re-warming 18.5 min	18	35.35	1.15	35.06-35.64
Re-warming 19.0 min	18	35.34	1.42	35.05-35.63
Re-warming 19.5 min	18	35.33	0.14	35.04-35.61

Table 20 (cont'd)

Re-warming 20.0 min	18	35.31	0.14	35.02-35.60
Re-warming 20.5 min	18	35.31	1.16	35.01-35.60
Re-warming 21.0 min	18	35.29	1.43	35.00-35.58
Re-warming 21.5 min	18	35.27	0.14	34.98-35.56
Re-warming 22.0 min	18	35.26	1.17	34.96-35.55
Re-warming 22.5 min	18	35.25	1.42	34.96-35.54
Re-warming 23.0 min	18	35.23	0.14	34.93-35.53
Re-warming 23.5 min	18	35.21	1.18	34.92-35.51
Re-warming 24.0 min	18	35.20	1.43	34.91-35.50
Re-warming 24.5 min	18	35.19	0.14	34.89-35.48
Re-warming 25.0 min	18	35.17	1.21	34.88-35.47
Re-warming 25.5 min	18	35.17	1.43	34.87-35.47
Re-warming 26.0 min	18	35.17	0.14	34.87-35.46
Re-warming 26.5 min	18	35.15	1.20	34.85-35.45
Re-warming 27.0 min	18	35.13	1.41	34.83-35.43
Re-warming 27.5 min	18	35.13	0.13	34.83-35.42
Re-warming 28.0 min	18	35.11	1.19	34.81-35.41
Re-warming 28.5 min	18	35.10	1.37	34.80-35.40
Re-warming 29.0 min	18	35.09	0.14	34.79-35.40
Re-warming 29.5 min	18	35.08	1.17	34.77-35.38
Re-warming 30.0 min	18	35.06	1.14	34.76-35.37

Table 21: Descriptive Statistics for the Re-warming Phase of the Ice Pack Condition

	N	Mean	SE	95% CI
Ice Pack				
Re-warming 0.0 min	18	29.79	0.15	27.30-32.27
Re-warming 0.5 min	18	29.56	0.13	27.01-32.12
Re-warming 1.0 min	18	29.35	0.19	26.81-31.89
Re-warming 1.5 min	18	29.28	0.21	26.76-31.80
Re-warming 2.0 min	18	29.17	0.22	26.71-31.63
Re-warming 2.5 min	18	29.10	0.22	26.69-31.50
Re-warming 3.0 min	18	29.04	0.91	26.69-31.39
Re-warming 3.5 min	18	28.98	0.16	26.70-31.26
Re-warming 4.0 min	18	28.90	0.96	26.69-31.11
Re-warming 4.5 min	18	28.87	0.16	26.72-31.02
Re-warming 5.0 min	18	28.84	0.65	26.75-30.93
Re-warming 5.5 min	18	28.82	1.00	26.80-30.85
Re-warming 6.0 min	18	28.82	0.16	26.85-30.80
Re-warming 6.5 min	18	28.82	0.68	26.88-30.76
Re-warming 7.0 min	18	28.82	1.05	26.94-30.69
Re-warming 7.5 min	18	28.83	0.16	26.99-30.66
Re-warming 8.0 min	18	28.84	0.72	27.04-30.64
Re-warming 8.5 min	18	28.86	1.10	27.10-30.62
Re-warming 9.0 min	18	28.88	0.16	27.15-30.60
Re-warming 9.5 min	18	28.89	0.76	27.20-30.59
Re-warming 10.0 min	18	28.93	0.13	27.28-30.59
Re-warming 10.5 min	18	28.95	0.19	27.32-30.58
Re-warming 11.0 min	18	28.98	0.20	27.38-30.57
Re-warming 11.5 min	18	28.97	0.13	27.40-30.55
Re-warming 12.0 min	18	29.02	0.19	27.47-30.58
Re-warming 12.5 min	18	29.06	0.20	27.53-30.59
Re-warming 13.0 min	18	29.11	0.13	27.59-30.62
Re-warming 13.5 min	18	29.15	0.19	27.65-30.64
Re-warming 14.0 min	18	29.18	0.20	27.70-30.66
Re-warming 14.5 min	18	29.22	0.13	27.76-30.67
Re-warming 15.0 min	18	29.26	0.19	27.82-30.71
Re-warming 15.5 min	18	29.29	0.20	27.87-30.71
Re-warming 16.0 min	18	29.32	0.12	27.92-30.72
Re-warming 16.5 min	18	29.37	0.16	27.98-30.76
Re-warming 17.0 min	18	29.41	0.23	28.03-30.78
Re-warming 17.5 min	18	29.44	0.22	28.09-30.80
Re-warming 18.0 min	18	29.49	0.17	28.15-30.82
Re-warming 18.5 min	18	29.53	0.23	28.20-30.87
Re-warming 19.0 min	18	29.57	0.22	28.26-30.88
Re-warming 19.5 min	18	29.65	0.17	28.40-30.91

Table 21 (cont'd)

Re-warming 20.0 min	18	29.73	0.17	28.52-30.93
Re-warming 20.5 min	18	29.85	0.22	28.70-30.99
Re-warming 21.0 min	18	29.94	0.22	28.83-31.05
Re-warming 21.5 min	18	30.00	0.17	28.90-31.30
Re-warming 22.0 min	18	30.06	0.22	28.97-31.14
Re-warming 22.5 min	18	30.10	0.23	29.02-31.17
Re-warming 23.0 min	18	30.15	0.17	29.08-31.22
Re-warming 23.5 min	18	30.18	0.26	29.12-31.24
Re-warming 24.0 min	18	30.22	0.38	29.16-31.28
Re-warming 24.5 min	18	30.26	0.17	29.20-31.32
Re-warming 25.0 min	18	30.30	0.33	29.25-31.34
Re-warming 25.5 min	18	30.33	0.60	29.29-31.37
Re-warming 26.0 min	18	30.37	0.17	29.33-31.40
Re-warming 26.5 min	18	30.39	0.41	29.37-31.42
Re-warming 27.0 min	18	30.44	0.72	29.43-31.45
Re-warming 27.5 min	18	30.47	0.17	29.46-31.48
Re-warming 28.0 min	18	30.50	0.48	29.49-31.51
Re-warming 28.5 min	18	30.54	0.83	29.53-31.54
Re-warming 29.0 min	18	30.57	0.17	29.57-31.57
Re-warming 29.5 min	18	30.60	0.54	29.60-31.59
Re-warming 30.0 min	18	30.62	0.59	29.64-31.60

Table 22: Descriptive Statistics for the Re-warming Phase of the Ice Massage Condition

	N	Mean	SE	95% CI
Ice Massage				
Re-warming 0.0 min	18	26.40	0.14	23.39-29.41
Re-warming 0.5 min	18	26.30	0.74	23.29-29.31
Re-warming 1.0 min	18	26.17	0.14	23.20-29.14
Re-warming 1.5 min	18	26.11	0.70	23.23-29.00
Re-warming 2.0 min	18	26.04	0.64	23.24-28.84
Re-warming 2.5 min	18	26.02	0.66	23.31-28.72
Re-warming 3.0 min	18	25.99	0.59	23.41-28.58
Re-warming 3.5 min	18	26.02	0.14	23.52-28.51
Re-warming 4.0 min	18	26.06	0.59	23.66-28.45
Re-warming 4.5 min	18	26.10	0.14	23.79-28.41
Re-warming 5.0 min	18	26.16	0.51	23.93-28.38
Re-warming 5.5 min	18	26.23	0.58	24.09-28.36
Re-warming 6.0 min	18	26.32	0.14	24.25-28.39
Re-warming 6.5 min	18	26.39	0.51	24.39-28.38
Re-warming 7.0 min	18	26.47	0.57	24.54-28.39
Re-warming 7.5 min	18	26.57	0.14	24.70-28.44
Re-warming 8.0 min	18	26.67	0.51	24.85-28.50
Re-warming 8.5 min	18	26.77	0.56	24.98-28.56
Re-warming 9.0 min	18	26.88	0.14	25.12-28.64
Re-warming 9.5 min	18	26.98	0.50	25.25-28.72
Re-warming 10.0 min	18	27.09	0.73	25.39-28.78
Re-warming 10.5 min	18	27.20	0.14	25.52-28.88
Re-warming 11.0 min	18	27.30	0.69	25.64-28.96
Re-warming 11.5 min	18	27.40	0.72	25.76-29.04
Re-warming 12.0 min	18	27.50	0.13	25.87-29.12
Re-warming 12.5 min	18	27.60	0.69	26.00-29.20
Re-warming 13.0 min	18	27.70	0.71	26.11-29.28
Re-warming 13.5 min	18	27.76	0.14	26.19-29.33
Re-warming 14.0 min	18	27.90	0.67	26.35-29.44
Re-warming 14.5 min	18	27.99	0.70	26.46-29.52
Re-warming 15.0 min	18	28.08	0.14	26.58-29.59
Re-warming 15.5 min	18	28.18	0.66	26.69-29.66
Re-warming 16.0 min	18	28.28	0.69	26.82-29.75
Re-warming 16.5 min	18	28.38	0.14	26.94-29.82
Re-warming 17.0 min	18	28.48	0.66	27.06-29.90
Re-warming 17.5 min	18	28.56	0.68	27.16-29.95
Re-warming 18.0 min	18	28.65	0.14	27.28-30.02
Re-warming 18.5 min	18	28.75	0.65	27.40-30.11
Re-warming 19.0 min	18	28.83	0.67	27.50-30.17
Re-warming 19.5 min	18	28.92	0.14	27.61-30.23

Table 22 (cont'd)

Re-warming 20.0 min	18	29.00	0.14	27.71-30.29
Re-warming 20.5 min	18	29.09	0.63	27.82-30.36
Re-warming 21.0 min	18	29.19	0.65	27.94-30.44
Re-warming 21.5 min	18	29.28	0.14	28.05-30.52
Re-warming 22.0 min	18	29.36	0.63	28.14-30.58
Re-warming 22.5 min	18	29.44	0.64	28.23-30.64
Re-warming 23.0 min	18	29.51	0.14	28.33-30.70
Re-warming 23.5 min	18	29.59	0.62	28.43-30.76
Re-warming 24.0 min	18	29.66	0.63	28.50-30.82
Re-warming 24.5 min	18	29.74	0.14	28.60-30.88
Re-warming 25.0 min	18	29.83	0.60	28.69-30.96
Re-warming 25.5 min	18	29.90	0.62	28.78-31.01
Re-warming 26.0 min	18	29.96	0.14	28.86-31.06
Re-warming 26.5 min	18	30.04	0.57	28.96-31.12
Re-warming 27.0 min	18	30.12	0.61	29.04-31.19
Re-warming 27.5 min	18	30.16	0.14	29.11-31.22
Re-warming 28.0 min	18	30.23	0.54	29.18-31.28
Re-warming 28.5 min	18	30.29	0.60	29.25-31.33
Re-warming 29.0 min	18	30.34	0.14	29.32-31.37
Re-warming 29.5 min	18	30.41	0.53	29.39-31.42
Re-warming 30.0 min	18	30.45	0.52	29.44-31.45

Table 23: Repeated Measures Analysis of Variance for Pre-Exercise Baseline and 30 Minutes of the Re-warming Phase Comparing Time and Condition

	SS	df	MS	F
Time	248.60	1	248.60	190.29*
Treatment	119.35	2	59.67	64.75*
Time x Treatment	127.17	2	63.59	62.02*

* significant at the $p < .001$ level

Table 24: T-Test Comparing Pre-Exercise Baseline and 30 Minutes of the Re-Warming Phase

	Mean Difference	SE	95% CI
Control	0.03	0.17	-0.33- 0.40
Pack	-4.51*	0.43	-5.41--3.61
Massage	-4.63*	0.40	-5.47--3.78

* significant at the $p < .001$ level

Table 25: Repeated Measures Analysis of Variance for Re-Warming at 0, 5, 10, 15, 20, 25, and 30 Minutes Comparing Time and Treatment

	SS	df	MS	F
Time	141.69	6	23.62	7.91*
Treat	3768.86	2	1884.43	72.39*
Time x Treat	223.06	12	18.59	16.54*

* significant at the $p < .001$ level

Table 26: T-Test Comparing 5 Minute Intervals of the Re-Warming Phase

	Mean Difference	SE	95% CI
Control			
Re-Warming 0-5	0.18*	0.02	0.14-0.22
Re-Warming 5-10	0.15*	0.01	0.13-0.17
Re-Warming 10-15	0.15*	0.02	0.12-0.18
Re-Warming 15-20	0.13*	0.02	0.10-0.16
Re-Warming 20-25	0.14*	0.01	0.11-0.17
Re-Warming 25-30	0.11*	0.01	0.09-0.13
Ice Pack			
Re-Warming 0-5	0.95†	0.30	0.32- 1.57
Re-Warming 5-10	-0.10	0.24	-0.61- 0.42
Re-Warming 10-15	-0.33‡	0.12	-0.59--0.07
Re-Warming 15-20	-0.47†	0.16	-0.81--0.12
Re-Warming 20-25	-0.57‡	0.24	-1.07--0.07
Re-Warming 25-30	-0.33*	0.04	-0.42--0.23
Ice Massage			
Re-Warming 0-5	0.24	0.48	-0.77- 1.25
Re-Warming 5-10	-0.93†	0.31	-1.58--0.28
Re-Warming 10-15	-1.00*	0.13	-1.28--0.71
Re-Warming 15-20	-0.92*	0.12	-1.18--0.66
Re-Warming 20-25	-0.82*	0.09	-1.01--0.64
Re-Warming 25-30	-0.62*	0.07	-0.76--0.48

* significant at the $p < .001$ level
† significant at the $p = .01$ level
‡ significant at the $p = .05$ level

Table 27: Repeated Measures Analysis of Variance for the Treatment Phase Comparing Time by Condition with a Between Subjects Factor of Gender

	SS	df	MS	F
Time	8098.89	40	202.47	96.87*
Time x Gender	322.76	40	8.07	3.86*
Treat	12694.25	2	6347.12	23.37*
Treat x Gender	1674.29	2	837.15	3.08
Time x Treat	3116.13	80	38.95	49.37*
Time x Treat x Gender	195.55	80	2.44	3.10*

* significant at the $p < .001$ level

Table 28: Repeated Measures Analysis of Variance for the Re-Warming Phase Comparing Time by Condition with a Between Subjects Factor of Gender

	SS	df	MS	F
Time	1284.17	60	21.40	11.15*
Time x Gender	284.75	60	4.75	2.47*
Treat	34805.40	2	17402.70	95.93*
Treat x Gender	1707.36	2	853.68	4.71‡
Time x Treat	1754.93	120	14.62	18.74*
Time x Treat x Gender	145.55	120	1.21	1.55*

* significant at the $p < .001$ level
‡ significant at the $p = .05$ level

Table 29: Repeated Measures Analysis of Covariance for the Treatment Phase Comparing Time by Condition with a Between Subjects Factor of Gender and Covariate of Skinfold

	SS	df	MS	F
Time	1626.98	40	40.67	23.15*
Time x Skinfold	283.43	40	7.09	4.03*
Time x Gender	9.02	40	0.23	0.13
Treat	3673.41	2	1836.71	7.18*
Treat x Skinfold	1022.23	2	511.12	2.00
Treat x Gender	193.68	2	96.84	0.38
Time x Treat	762.34	80	9.53	13.71*
Time x Treat x Skinfold	175.92	80	2.20	3.16*
Time x Treat x Gender	9.61	80	0.12	0.17

* significant at the $p < .001$ level

Table 30: Repeated Measures Analysis of Covariance for the Re-Warming Phase Comparing Time by Condition with a Between Subjects Factor of Gender and Covariate of Skinfold

	SS	df	MS	F
Time	508.49	60	8.47	4.65*
Time x Skinfold	202.92	60	3.38	1.86*
Treat x Gender	13.34	60	0.22	0.12
Treat	5345.36	2	2672.68	15.41*
Treat x Skinfold	602.95	2	301.48	1.74
Treat x Gender	224.29	2	112.15	0.65
Time x Treat	546.53	120	4.55	6.19*
Time x Treat x Skinfold	173.32	120	1.44	1.96*
Time x Treat x Gender	30.23	120	0.25	0.34

* significant at the $p < .001$ level

Table 31: Power Calculations for Every 5 Minute Interval

Time	Power Calculation
Treatment	
0 min	0.27
5 min	0.96
10 min	1.00
15 min	1.00
20 min	1.00
Re-warming	
5 min	1.00
10 min	1.00
15 min	1.00
20 min	1.00
25 min	1.00
30 min	1.00

All calculations done at an alpha = .05

APPENDIX B: FORMS

Changes in Intramuscular Temperature During Post-Exercise Application of a Cold Modality

Informed Consent

For questions regarding this study, Please contact:
Dr. John Powell, ATC
Department of Kinesiology
Michigan State University
Phone: (517) 432-5018
E-mail: powellj4@msu.edu or

Julie Homuth, ATC
Graduate Assistant
Michigan State University
Email: homuthju@msu.edu
Phone: (517) 775-6606
Work: (517) 355-1627

For questions regarding your rights as a research participant, please contact:
Peter Vasilenko, Ph.D.
Committee on Research Involving Humans
Michigan State University
202 Olds Hall
East Lansing, MI 48824
ucrihs@msu.edu
Phone: (517) 355-2180
Fax: (517) 432-4503

The purpose of this study is to determine the difference in intramuscular tissue temperature post-exercise at 1 centimeter below the subcutaneous adipose layer during the application of a crushed ice pack, an ice massage treatment, or a control. The study will use a treadmill and a Physitemp MT-26 temperature probe of multiple lengths that will be attached to a Bailey's Instrument BAT-12 digital monitor.

Your participation in this study will consist of one initial 30 minute orientation and three 90 minute testing sessions. The testing sessions will include brief treadmill exercise and insertion of a temperature probe into the left lower leg. You will be informed of how to care for the insertion site once the temperature probe has been removed. The first session will be used as an orientation opportunity to explain testing procedures and allow for estimation of maximal heart rate, determination of 70% estimated maximal heart rate, and find out what treadmill intensity keeps you at this heart rate. You will participate in all three intervention groups; two experimental and one control, with random assignment of the order. Each intervention session will consist of an eight minute warm-up on the treadmill followed by a 20 minute treatment application and 30 minutes of re-warming. A baseline intramuscular tissue temperature will be determined prior to exercise on a treadmill. Intervention session will be separated by at least 48 hours.

Upon arrival, you will lie on a table and a temperature probe will be inserted into your left calf. A baseline temperature will be recorded and the probe will be removed. The exercise warm-up will be done on a motorized treadmill. You will begin the test with 2 minutes of walking or running at a pace you select. After the 2-minute stage, the speed will be increased to the predetermined speed found during the initial orientation session. You will continue at this speed for 8 minutes. Immediately following the exercise, you will return to the table and the temperature probe will be reinserted into your left calf. You will remain on the table for 50 minutes, motionless lying down on your stomach, during data collection. The probe will then be removed and the site will be bandaged.

It is impossible for the risk of injury to be completely eliminated during physical activity. The risk associated with the exercise portion of the protocol includes dizziness, muscle and/or joint pain, shortness of breath and, in extremely rare cases, heart attack, stroke, or death. Measures will be taken during the test to ensure your safety throughout the research protocol. A certified athletic trainer will be on-site at all times during the testing session. An automated external defibrillator will also be on hand. If there is any point during the treadmill warm-up when you feel like you cannot continue please let the investigator know and the test will be terminated. The risk associated with temperature probe insertion includes pain, soreness, bruising, or infection. Decreasing these physical symptoms will be done by sterilizing the temperature probes using an autoclave after data collection with each subject. The skin will be sanitized prior to, and after, insertion of the temperature probe and the insertion site will also be bandaged to aid in preventing infection. The site will be injected with 2 cc 1% lidocaine prior to probe insertion to decrease the amount of pain experienced.

The benefits that come from your participation include contribution to the understanding of intramuscular tissue temperature changes during and after application of a cold modality. It will also begin examining how intramuscular tissues react to application of a cold modality post-exercise. Knowing how the intramuscular tissues respond to cold modality application will allow for improved treatment of injuries that occur during activity. Subjects participating in this study will also be given their estimated maximal heart rates and skinfold thicknesses of the posterior calf.

Participation in this study is completely voluntary. Your identity and information recorded during the study will remain confidential. Confidentiality will be protected by; (a) results will be presented in aggregate form in any presentations and publications; and (b) all data will be stored in a computer that has a password necessary to see confidential data. Your privacy will be protected to the maximum extent allowable by law. You may also discontinue participation at any time without penalty. Your participation in this research project will not involve any additional costs to you or your health care insurer. At the completion of data collection, there will be a monetary payment of $20.00 to cover any potential risks that may be present during data collection.

If you are injured as a result of your participation in this research project, Michigan State University will assist you in obtaining emergency care, if necessary, for your research related injuries. If you have insurance for medical care, your insurance carrier will be billed in the ordinary manner. As with any medical insurance, any costs that are not covered or in excess of what are paid by your insurance, including deductibles, will be your responsibility. Financial compensation for lost wages, disability, pain or discomfort is not available. This does not mean that you are giving up any legal rights you may have.

Any questions concerning participation in this study should be directed to Julie Homuth (517) 775-6606 or Dr. John Powell (517) 432-5018. If you have any additional questions concerning your rights as a volunteer or are dissatisfied at any time with any aspect of this study you may contact – anonymously, if you wish – Peter Vasilenko, PhD, Michigan State University's Chair of the Committee on Research Involving Human Subjects by phone: (517) 355-2180, fax: (517) 432-4503, e-mail: ucrihs@msu.edu, or regular mail: 202 Olds Hall, East Lansing, MI 48824.

INFORMED CONSENT

Your signature below indicates your voluntary agreement to participate in this study.

I, ______________________________ have read and agree to participate in this study as
(Please Print Your Name)
described above.

____
(Please Print Your Name)

______________________________ ____/____/____
(Please Sign Your Name) *(Date)*

Changes in Intramuscular Temperature During Post-Exercise Application of a Cold Modality

Contact Information Form

Subject Name: ______________________________ **Age:** ____________

Contact Phone Number: ____________________ **Height:** __________

Email Address: _____________________________ **Weight:** __________

Exclusion Criteria Questionnaire

Please answer the following questions regarding your health history.

Have you: (Circle your response)

Had a lower extremity injury within the last six months? Y N

Had a lower extremity surgery within the last year? Y N

Ever been diagnosed with peripheral vascular disease? Y N

Had hypothermia? Y N

Had deep vein thrombosis or blood clots? Y N

Had cold allergy? Y N

Ever been diagnosed with asthma? Y N

Been diagnosed or hospitalized for a cardiovascular condition? Y N

Been hospitalized for a respiratory illness? Y N

Ever been diagnosed with hypertension? Y N

Is there any reason that you can identify that you would not be able to complete the treadmill activity related to this project? Y N

Thank you for your participation. Answers to this questionnaire will remain confidential. If you are not selected for this study, or choose not to participate your questionnaire will be shredded.

Signature: _________________________ Date: ______________

MICHIGAN STATE UNIVERSITY
38 IM SPORTS CIRCLE
EXERCISE PROGRAM/TESTING READINESS QUESTIONNAIRE

Every participant must fill out this questionnaire and sign a release before he/she will be allowed to participate in an exercise program and/or measuring intramuscular tissue temperature.

Name ________________________ Phone _______________ Date __________

Address _____________________________ Date of Birth __________

Email _____________________________ Ht ______ Wt ______

___Yes ___No 1. Has your doctor ever said you have heart trouble?

___Yes ___No 2. Have you ever had chest pain or heavy pressure in your chest as a result of exercise, walking, or other physical activity, such as climbing a flight of stairs? (Note: This does not include the normal out-of-breath feeling that results from vigorous exercise)

___Yes ___No 3. Do you often feel faint or experience severe dizziness?

___Yes ___No 4. Has a doctor ever told you that you have high blood pressure or diabetes?

___Yes ___No 5. Have you ever had a real or suspected heart attack or stroke?

___Yes ___No 6. Do you have any physical condition, impairment or disability, including any joint or muscle problem that should be considered before you undertake an exercise program?

___Yes ___No 7. Have you ever taken medication to reduce your blood pressure or cholesterol levels?

___Yes ___No 8. Are you excessively overweight?

___Yes ___No 9. Is there any good physical reason not mentioned here why you should not follow an exercise program even if you wanted to?

___Yes ___No 10. Are you over age 40, or not accustomed to vigorous exercise?

If you answered YES to one or more questions, and if you have not recently done so, consult with your physician BEFORE entering an exercise program or participating in an exercise test. After medical evaluation or consultation, have your physician sign this form indicating your suitability for the following activity:

____

____

____

Signature of Physician	Date	Phone

Changes in Intramuscular Temperature During Post-Exercise Application of a Cold Modality

Treadmill Test

Date: ____________________ Subj# ____________________

Name ____________________ Age ____________________

Weight ____________________ Calf Girth ____________________

Height ____________________ Skinfold ____________________

Estimated HRmax ____________________ Adipose Thickness ____________________

70% Estimated HRmax ____________________

Time (minutes)	Speed	Grade	Heart Rate
0-1	3.0	0	________
1-2	3.5	0	________
2-3	4.0	0	________
3-4	4.5	0	________
4-5	5.0	0	________
5-6	5.5	0	________
6-7	6.0	0	________
7-8	6.0	3	________
8-9	6.0	6	________
9-10	6.0	9	________
10-11	6.0	12	________
11-12	6.0	15	________
12-13	6.0	18	________
13-14	6.0	21	________
14-15	6.0	24	________
15-16	6.0	27	________
16-17	6.0	30	________
17-18	6.0	33	________
18-19	6.0	36	________
19-20	6.0	39	________

Speed of 70% HRmax ____________________

Grade of 70% HRmax ____________________

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