2011

The Effect of Exercise before an Ice Bag Treatment on Quadriceps Interface and Intramuscular Temperature Following Application

Toshiro Hirano

The Effect of Exercise before an Ice Bag Treatment on Quadriceps Interface and Intramuscular Temperature Following Application

EFFECT OF EXERCISE BEFORE AN ICE BAG TREATMENT ON QUADRICEPS INTERFACE AND INTRAMUSCULAR TEMPERATURE FOLLOWING APPLICATION

An Abstract of a Research Project

Submitted

in Partial Fulfillment

of the Requirements for the Degree

Master of Science

Toshiro Hirano

University of Northern Iowa

July 2011

ABSTRACT

Context: Ice bags are often applied following exercise. It is known that exercise before cooling speeds heat removal, but does this exercise affect rewarming trends? Objective: Determine if exercise before an ice bag treatment effects interface (IF) and intramuscular (IM) during a 120-minute post-treatment period. Setting: Laboratory. Participants: Twelve physically active males (21.8 ± 1.7 y, ht: 183.3 ± 8.8 cm, mass: 87.4 ± 12.2 kg: skinfold: 23.6 ± 3.3 mm). Intervention: The exercise condition consisted of stationary cycling at 70% to 80% of their Karvonen predicted exercise heart rate, while the rest condition was supine lying. Each condition lasted 30 minutes. Treatment consisted of wetted ice bag (2000mL ice with 300mL water) compressed to the right anterior mid-thigh until the intramuscular temperature was 10°C below baseline. Rewarming temperatures were collected every 10 minutes for 120 minutes beginning immediately after treatment removal. Main Outcome Measures: IF and IM (2cm + ½ skinfold) temperatures to the nearest 0.1°C. Results: Considering both the IF and IM rewarming trends separately, they are both affected by the exercise condition and time interaction ($P < .00001$). All conditions and treatment temperatures changed during the rewarming ($P < .00001$). Interface temperatures following exercise rewarmed faster and were higher than the rest condition at all times ($P < .05$ and smaller). Intramuscular temperatures where similar at the immediate, 10-, and 120-minutes times, while the exercise condition were higher than the rest at all of the other times ($P = .042$ and smaller). Conclusion: Following a 30-minute cardiovascular exercise bout both the interface and intramuscular

rewarming trends after cooling the tissues 2 cm deep in the quadriceps to 10°C below baseline using a wetted ice bag treatment are different than no exercise before cooling.
Key Words: cold, cryotherapy, exercise, wetted ice-bag

EFFECT OF EXERCISE BEFORE AN ICE BAG TREATMENT ON QUADRICEPS INTERFACE AND INTRAMUSCULAR TEMPERATURE FOLLOWING APPLICATION

A Research Project

Submitted

in Partial Fulfillment

of the Requirements for the Degree

Master of Science

Toshiro Hirano

University of Northern Iowa

July 2011

APPROVAL PAGE

This Study by: Toshiro Hirano

Entitled: Effect of exercise before an ice bag treatment on quadriceps interface and intramuscular temperature following application.

has been approved as meeting the research project requirement for the

Degree of Master of Science in Athletic Training

July 4, 2011
Date — Dr. Jody B. Brucker, Chair, Project Committee

7-5-2011
Date — Dr. Todd A. Evans, Project Committee Member

7-13-2011
Date — Dr. Peter J. Neibert, Project Committee Member

7-7-11
Date — Dr. Mickey G. Mack, Director, School of Health, Physical Activity, and Leisure Services

ACKNOWLEGEMENTS

I would like to say thank you to Dr. Jody Brucker who served as chair of this research project. I would also like to say thank you for the help and support of my research committee and other special people; Dr. Todd Evans, Dr. Peter J. Neibert, and Brenda Cooper.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

FIGURE PAGE

INTRODUCTION

Ice bags are often applied to body parts following physical activity as a means of controlling discomfort and pain,[1-4] and other physiological responses[2-3,5-13] related to potential micro-trauma, or injury. Although clinicians do not know the efficacy of cooling on outcomes, basing our treatment practices on data derived from rested tissue may be flawed. Specifically, as clinicians we should know how cooling and its residual effect are affected by exercise before ice bag application in order to achieve treatment goals with the hopes of improving the health care of the athletes.

Contrary to the belief that it should take longer to focally cool a heated muscle group following activity, it actually takes less time.[14] For example, when the goal is to decrease 2 cm deep tissue 10°C below baseline temperatures, a 30 minute cardiovascular workout decreases cooling time by 14 minutes as compared to 30 minutes resting. This 14 minute difference is equal to 25% of the total cooling time, which is considered valuable. The reason noted for the reduced time to cool an exercised muscle group is that whole body cools as recovery from exercise, albeit slowly.[7] To indicate the gradual cooling back to baseline without using cold modality, the same musculature was monitored after a 30 minute cardiovascular workout to determine that it takes the body 54 minutes to return to pre-exercise temperature.[14]

Although the aforementioned discussion may help determine treatment length, the lasting effect of the treatment is also a concern, which may cause a change in how long treatments should be applied. Because the whole body continues to cool for near 1 hour,[14] it could be assumed that residual temperatures could be rewarmed faster, especially if the ice is removed before the body's cooling process has not been completed. According to my understanding of the post-exercise recovery effects on the metabolic and thermoregulatory system, the body as a whole system will keep creating heat to recover the energy storage[7] and dissipate heat until it returns to its baseline temperature.[7]

One group of investigators[15] report 1 cm deep residual intramuscular temperatures following cold application when applied to exercised muscle. The clinical applicability is suspect because the exercise bout was short, although maximal, but more importantly the ice bag application was only 15 minutes. Therefore, clinicians do not have clear expectations about deep residual cooling temperatures following ice bag treatments after cardiovascular workouts.

In addition, the body uses the superficial tissue to cool,[7] and cooling this tissue with an ice bag is different from deep tissue cooling,[3,15-19] which is possibly why two groups[20-21] reports higher residual ankle skin temperatures after removal of an ice bag following running[20] or biking[21] versus following resting. Because the ankle is a small body part, which does not have a lot of deep soft tissues that generate heat like the thigh does, there is a concern of using this data to reflect efficacy on larger and more muscular body areas. One group[21] that investigated thigh residual interface temperatures after ice bag applications as long as 40 minutes only exercised the muscle for 15 minutes, which seems short based on my experience and practice of maintaining cardiovascular fitness. To maintain cardiovascular fitness one should complete at least 30 minutes of continuous exercise.[22] Due to the link between temperature and discomfort,[1,3,23-24] understanding how superficial tissue temperatures react after ice bag application following exercise helps clinicians determine differences in pain management efficacy versus following rest.

Therefore, the purpose of this study is to investigate if exercise before an ice bag treatment that decreases intramuscular temperature 10°C below baseline affects the interface and intramuscular tissue temperatures as compared to rest before treatment during 120 minutes following the application.

METHODS

Design

A 2 X 2 X 13 cross-over design was used to guide this study. The independent variables were tissue depth [interface (IF) and intramuscular (IM; 2 cm plus ½ the skinfold tissue thickness)], exercise condition (Rest and Bike) before cooling, and time (immediately, 10, 20, 30, 40, 50, 60, 70, 80, 90, 100, 110, and 120 minutes) after ice bag cools IM tissue 10°C below baseline. The dependent variable was temperature measured to the nearest 0.1°C.

Participants

Twelve healthy and physically active males (21.8 ± 1.7 y, ht: 183.3 ± 8.8 cm, mass: 87.4 ± 12.2 kg: skinfold: 23.6 ± 3.3 mm) participated. Both lower extremities of the participants served as independent samples, as described later. All participants completed the informed consent document and health history questionnaire and were familiarized with the procedures. Participants were excluded if they reported a history of circulatory problems, hypersensitivity to cold or cold-related allergy, or having an anterior mid-thigh skinfold measurement of outside the 20 and 30 mm range. In addition, if participants reported lower extremity injury within 3 months prior to data collection, had any blood borne or clotting diseases, were taking certain medicine related to anticoagulation or anti-platelet agent, then they could not partake in this study. University Institutional Review Board approved this study.

Instrumentation

The same investigator performed the data collection measurement. Custom made 30-gauge non-implantable Type-T thermocouples were used to collect interface temperatures, while intramuscular temperatures were collected using custom made 36-guage implantable Type-T thermocouples inserted through an intravenous Autoguard BD catheter. The thermocouples were connected to a 7-channel THERMES-USB computer based thermometer temperature data acquisition system (Physitemp Instruments, Inc., Clifton, NJ). The data from this device were electronically transferred to a desktop computer and then to a spreadsheet for statistical analysis.

Reliability and Validity

In order to make sure the system provides comparable data a measure was collected every 30 seconds for 5 minutes using the custom made thermocouples and a NIST traceable spirit in-glass thermometer during stable water bath temperatures near 1, 10, 20, 30, and 40°C. All readings will be taken to the nearest 0.1°C. There were 6 interface and 6 intramuscular thermocouples tested. Having 6 of each type of thermocouple allowed participants to be tested without a sterilization delay. Due to system limitations 2 water bath tests were performed with the 6 interface thermocouples tested separate of the 6 intramuscular.

Reliability was determined by taking the standard deviation (SD) of the 10 thermocouple measures at each of the 5 water bath temperatures. The 5 SDs within each thermocouple were then averaged to provide individual thermocouple reliability estimates. Both the interface and intramuscular thermocouple reliability ranged from 0 to 0.01°C.

Validity was determined using an average of the 10 absolute differences between the thermocouple reading and the NIST temperature for each thermocouple at each water bath temperature. The average of the 5 averaged absolute differences for each thermocouple determined a validity score for each thermocouple. The interface thermocouple validity ranged from 0.1 to .25°C, and the intramuscular ranged from .05 to .28°C.

Uncertainty of each thermocouple was the sum of the average reliability and average validity. The uncertainty range and average for the interface thermocouples was 0.15 to 0.16°C, and 0.16°C, respectively. The uncertainty for the intramuscular thermocouples did not range and had an average of 0.16°C. By averaging all of the thermocouple uncertainty values the system uncertainty was the same as the mentioned averages (0.16°C).

Procedures

Participants reported to the Athletic Training Research Laboratory at approximately the same time of day for 2 treatment sessions at least 48 hours apart. At the first session, the participants received explanations about the purpose, methods, and procedure of the study to make sure the participants were familiarized with the study. After providing informed consent, each participant was screened for the inclusion criteria before data was collected. The second session consisted of the data collection only. Each participant was randomly given a participant number, and the treatment order was determined by the number. At the first session, odd numbered participants received the exercise condition while even numbered participants received the rest condition. During the second session the participants received the opposite condition.

Participant preparation began 15 minutes before each treatment condition while resting supine. The investigator measured the midpoints between the base of the patella and the anterior superior iliac supine on both legs, and marked it with a surgical pen. At the midpoints, 3 consecutive vertical skinfold measurements were taken by using a skinfold caliper (Lange C-130, Beta Technology Inc. Cambridge, MD), averaged and divided by 2 to estimate skin and adipose tissue thickness and added to 2 cm so the intramuscular thermocouple insertion depth was correctly determined.[14,16,18] A 10 × 10 cm area centered around the midpoint was shaved with a razor and cleaned with Hibeclens, then swabbed with an alcohol pad. One centimeter superior and inferior to the midpoints was used for intramuscular thermocouple insertion site and interface temperature site, respectively (Figure 1).

To ensure correct insertion depth the intravenous catheter was measured and marked with a sterile maker from the tip of the needle. The intravenous catheter and needle were implanted to the insertion site then the needle was retracted leaving the flexible catheter. To make sure the thermocouple reaches the end of the catheter, the full length of the catheter was marked on the thermocouple with the same surgical pen.

Once the thermocouples were inserted, it was secured to the skin with Dermiclear adhesive tape (Johnson & Johnson, New Bruswick, NJ) and was covered with Bioclussive dressing (Model no: 2461, Johnson & Johnson, Gargrave, North Yorkshire, UK) (Figure 2). The thermocouples were then connected to the data acquisition device and temperature recording was begun. The temperatures were recorded every 30 seconds for the duration of each treatment condition. After reading remains unchanged (± 0.3°C) over 3 minutes, baseline recordings occurred for 5 minutes. The average of these 10 measures was used as the baseline temperature and used in the statistical analysis.

Shortly after the 5-minute resting temperature measures were completed, the exercise condition began. The exercise condition consisted of riding a stationary bike for 30 minutes at 70% to 80% of age predicted maximum heart rate as calculated by the Karvonen method,[14,25] whereas the rest condition consisted of lying supine position on a treatment table for 30 minutes. Temperature recording was started at the onset of the exercise conditions. At the end of the exercise condition the participant quickly moved to the treatment table and laid supine position where the ice bag treatment was applied.

The treatment consisted of applying an ice bag to the right thigh centered overtops of the midpoint while the left thigh was not treated. The ice bag was a 44.0 cm × 25.5 cm 1-mil polyethylene bag filled with 2000mL cubed ice & 300mL water[16] with the excess air manually removed and closed with a tied knot. The ice bag was secured with a 15 × 400cm elastic wrap (Figure3). The treatment duration was determined by the length of time it took the ice bag to cool its respective intramuscular temperature 10°C below baseline temperature.

Once the target temperature was reached the ice bag was removed and the 120 minutes of post application temperature recordings began. During these recordings the participants remained supine on the treatment table.

After the data collection, the thermocouples were withdrawn, cleansed, and steam autoclaved in a Tuttnauer EZ9 (Tuttnauer USA Co. Ltd., NY). The treatment area was cleansed with saline solution, and antibiotic ointment was applied and the area was covered with adhesive bandages. Each participant was given a sheet which described instructions for wound care management and the signs and symptoms of infection.

Data and Statistical Analysis

Understanding that interface and intramuscular temperature always react differently, I chose not to include tissue depth as a factor in the analysis. Therefore, the following statistical analysis was performed twice, once for each depth.

To detect the effect of exercise and time on temperatures a 2 X 13 ANOVA with repeated measures on all factors were used. As needed, subsequent testing for any interactions and main effects consisted of *post-hoc* repeated measures ANOVAs with Tukey-Kramer Multiple Comparison tests. If ANOVA sphericity assumption was not met, correction for the violation was performed using the Geisser-Greenhouse procedure. The *a priori* level of significance was set at $< .05$. The NCSS 2004 (Number Cruncher Statistical Systems, Kaysville, UT) was used for all data analyses.

RESULTS

Figures 4 and 5 depict the IF and IM rewarming trends following each exercise condition and treatment, respectively. The no-ice treatments or the baseline measures for either the IF and IM conditions are not used in the analyses because comparisons to these measures were not important to answer the research questions of interest. Therefore, Tables 1 and 2 summarize the temperatures and statistical results for the IF and IM rewarming measures. It is important to note that the mean and standard error IF and IM baselines are 32.4 ± 0.2°C and 36.4 ± 0.1°C, respectively. Moreover, there were only 2 violations of spherecity, but they did not affect statistical difference testing results. These 2 are in the Interface subsection and are indicated by G-G prior to the F statistics. Otherwise the rest of the data has equal variance and is normally distributed.

<u>Interface</u>

As expected exercise condition and time were interacted on the IF rewarming temperatures ($F_{12,132} = 4.78$, $P < .00001$, $1\text{-}\beta = 1.00$). The two 1 X 13 RMANOVAs used to detect the effect of time on both the Rest and Bike conditions violated the spherecity assumption, but as mentioned the violations are not strong enough to change any inferences. Both the Rest and Bike temperatures changed over time [Rest: (G-G) $F_{12,132} = 498.67$, $P < .00001$, $1\text{-}\beta = 1.00$; Bike: (G-G) $F_{12,132} = 513.00$, $P < 0.00001$, $1\text{-}\beta = 1.00$). It is apparent from the subsequent Tukey-Kramer Multiple Comparison testing (df = 132, MSE = 1.09, CV = 4.77, $P < .05$) that the rewarming trend of the Rest condition is different from the Bike condition. Both temperature trends are reported in Table 1. Each of the thirteen 1 X 2 RMANOVAs indicated the Bike condition temperature was warmer than the Rest at each time, but with differing results. Table 3 summarizes the F-statistics for each of the 1 X 2 RMANOVAS.

<u>Intramuscular</u>

Similar to the interface results, as expected exercise condition and time were interacted on the IM rewarming temperatures ($F_{12,132} = 13.81$, $P < .00001$, $1\text{-}\beta = 1.00$). The two 1 X 13 RMANOVAs detected that both the Rest ($F_{12,132} = 119.86$, $P < .00001$, $1\text{-}\beta = 1.00$) and Bike ($F_{12,132} = 153.38$, $P < .00001$, $1\text{-}\beta = 1.00$) temperatures changed over time. Again, like the interface results, the subsequent Tukey-Kramer Multiple Comparison testing (df = 132, MSE = 1.09, CV = 4.77, $P < .05$) indicated that the rewarming trend of the Rest condition was different from the Bike condition. Both temperature trends are reported in Table 2. However, different from the interface results the temperatures between the Bike and Rest conditions at the immediate, 10-, and 120-minute times are similar, while the Bike condition is warmer than the Rest condition at the other times. Table 4 summarizes the F-statistics for each of the 1 X 2 RMANOVAS.

DISCUSSION

Ice bag treatments are often used for different purposes, and those purposes are achieved by cooling either interface or intramuscular temperature. Cooling interface temperature helps discomfort and pain level,[1-4] while cooling intramuscular temperature alters body's physiological process, such as reduces blood flow,[2,5-6] reduces metabolic rate,[3,7-11] and increases pH level.[12-13] Even though clinicians do not know how cold is cold enough or how injury affects temperature, factors that affect the magnitude of cooling may also affect rewarming trends in the uninjured. Each of these effects is tied to the theory that health care of the athlete will be enhanced.

Currently, we know that it takes the body almost an hour to recover from exercise.[14] As reported by others,[14] exercise before ice bag treatment speeds intramuscular cooling because of the body's physiological response to exercise,[14] which can shorten treatment length. Even though interface and intramuscular temperatures respond differently to ice bag applications, having treatment lengths less than one hour should affect both. Specifically, both the interface and intramuscular temperatures would rewarm faster. Accepting or rejecting these hypotheses needs careful consideration, which will be discussed along with how practical the differences are. For this discussion a 1°C difference is considered practical.[26]

Interface

As hypothesized, exercised interface that goes through 30 minutes of stationary biking before treatment rewarms more rapidly than rested tissue. Although the statistical results support this rewarming trend, a couple of points need discussion to understand the truest impact of exercise before cooling on interface rewarming temperatures. What is interesting is that the greatest differences are within the first 20 minutes suggesting that exercise before cooling creates a more curvilinear return toward baseline.

The belief that the exercised interface is warmer regardless of time point is flawed because the starting temperatures are not equal when the ice bag is removed. If the starting interface temperature at the onset of rewarming is the same, then both rewarming trends seem similar. However, similar does not mean the same. Specifically, taking into account the 2.2°C at the beginning of rewarming there is still a faster rewarming within the first 20 minutes and slower rewarming in the last 10 minutes. Both of these differences may have occurred for different reasons.

Difference in treatment length could be one factor that affects rewarming. In my study, target temperature is 10°C below intramuscular baseline, so length of treatment is different between the conditions. Rested interface has average of 73 minutes treatment and cooled 2.2°C more than exercised temperature which has average treatment duration of 31 minutes. However, as stated the deeper tissues are cooled to the same temperature below baseline. Having the deeper tissues at the same temperature before removing the ice bag means that the faster rewarming in the exercise condition is due to the skin still dissipating heat.

The exercised interface temperature took about 60 minutes to get back to baseline temperature without using the ice bag. Therefore this supports the theory that when the ice bag is removed from exercised interface after 31 minutes of treatment, the body is still dissipating heat; thus, this is the possible reason for the faster rewarming within the first

20 minutes. Moreover, once the body seems to have no longer needed to dissipate heat the interface temperatures between the conditions are similar. Specifically, during the 60 to 90 minute period of rewarming the trend is almost the same because the temperatures averaged only a 0.2°C difference. Just as important the 60 and 70 minute exercise condition temperatures are above the rest condition temperatures, whereas the 80 and 90 minutes temperatures are lower, which means the trends would cross.

Another factor could be temperature gradient, which could affect the rewarming during the last 10 minutes, but not the first 20 minutes. More clearly stated the last 10 minutes occurred at 110 minutes of rewarming, which is twice as long as it took the body to recover naturally following exercise. When considering the 2.2°C difference at the start of rewarming, the exercise condition rewarms slower than the rest condition during this last 10 minutes. This slower rewarming is most likely due to the smaller temperature gradient back to baseline.

The temperature gradient issue mentioned before is not apparent at the beginning of rewarming because the rested interface is 2.2°C cooler, so this condition should have rewarmed faster, especially at the beginning. However, as mentioned the treatment length of the exercise condition was 30 minutes short of the body's natural cooling meaning that the global cooling is still functioning. Therefore, the global cooling affects the initial speed of rewarming. Thus, when considering time to naturally return to baseline following exercise without ice bag application and temperature gradient differences, these could possibly lead to different cooling and rewarming trends if the ice bag is applied for the full exercise recovery duration, or if the treatment length was the same between the conditions.

Considering practical use of this interface rewarming stems from the purpose of cooling. We know it takes 12 to 20 minutes of treatment to get numbing in a rested individual,[3] which definitely occurred in my study, but was not measured. Regardless, it is reported that rested individuals still report sensory effects 2 to 3 minutes after cold treatment removal.[3] This residual sensory deficit may not occur following ice bag treatments after exercise because of the more rapid interface rewarming due to superficial tissues still dissipating heat. Therefore, if a clinician is trying to keep the individual from sensing discomfort it might be best to leave the ice bag on. Leaving the ice bag on also makes sense because most ice bags are applied following exercise to gait discomfort because an injury just occurred.

Intramuscular

Similar to the interface temperatures it was hypothesized that the exercised intramuscular temperature that goes through 30 minutes of stationary biking before ice bag application would rewarm faster than rested tissue. Likewise, this hypothesis seems true, but for a couple of different reasons discussed before. Because the starting temperature is the same, the rewarming trend discussion is more concrete.

The most important factor leading to the differences between the exercised intramuscular and rest rewarming is most likely due to the first 20 minutes. Specifically, instead of continual cooling as is seen in the rested condition the exercised temperature barely decreased through the first 10 minutes before starting to rewarm. In the rest condition there is continual cooling of slightly more than 2°C for 20 minutes after removal of the ice bag. Therefore, by the 30 minute rewarming time the exercise condition is 2°C warmer.

Similar to the interface discussion the knowledge that duration of the treatment on exercised tissue being 31 minutes when it took 50 minutes for the recovery without ice adds support to the theory that the body is still generating heat to recover the oxygen debt.[7] Therefore, treating post exercise tissues until recovery is completed might produce similar rewarming trends to that of rest.

The 50 minutes cooling back to the baseline following exercise without ice bag application is supported by others[14] that reported close to 60 minutes. The differences between my study and theirs could be due to participant demographics because my participants seem to have slightly less skinfold thickness,[3,17,27-29] and could be more fit. The fitness level argument is suspect because Long et al[14] does not report any fitness level. Another difference between the cooling trends between my study and others[14] is that my ice bag is built using 2 L of ice and 300 ml of water versus a simple 1-kg ice bag. This difference in ice bag configuration means that the mass of my ice bag was 1.5 kg. Having this extra 0.5 kg may cause the 15 minute quicker cooling rate due to the added modality or surface contact area. Moreover, the added water could have been a factor because it enhances cooling.[16]

Having the 31 minutes treatment on exercised tissue and 73 minutes treatment on rested tissue which takes twice as long as the exercised intramuscular takes, one might think the shorter treatment causes faster rewarming regardless of pre-application activity level. However, when comparing the rested rewarming trend following my 73 minute treatment duration to others[17-18] that applied ice bags for 30 minutes the trends are the same. Additionally, there are others that indicate residual cooling with treatment less than 30 minutes and on different body parts.[16,28,30-31] Therefore, treatment length is not a factor as mentioned in the interface discussion. Even with this comparative support, and the fact that clinicians apply ice bags for a specific period of time, additional studies are needed using set treatment lengths. From my study and the aforementioned comparisons it seems that treatment lengths of 30 to 40 minutes are needed to substantially cool 2 cm deep tissues in the quadriceps following exercise using at least a 1-kg ice bag. However, longer treatment durations might be more practical to make sure the body has fully recovered from the exercise.

Similar to the interface discussion temperature gradient may be a factor because the exercise intramuscular temperatures rewarm more slowly after the oxygen debt should have been recovered, but differences are still practical until the 120 minute rewarming time. Specifically, the exercised temperatures ranged from 1 to 2°C warmer than the rested throughout the rewarming. Even though the differences testing did not indicate a high probability (95%), the probability that the practical difference would occur is 78%, which is still high enough to consider differences. Therefore, clinicians might need to consider reapplication sooner than the suggested 90 to 120 minutes based on rested muscle.[3] However, the exercised intramuscular temperature is still 4°C below baseline after 120 minutes of rewarming, which is 40% of total cooling that occurred.

In summary, using a 1°C difference as being a practical difference both interface and intramuscular rewarming trends are affected by 30 minutes of stationary biking before a 30-minute ice bag application. This faster rewarming seems to occur while the body is still recovering from exercise, which then affects the later temperature gradient back to baseline. The effect of exercise before cooling on rewarming trends is different between interface and intramuscular depths. Therefore, clinicians should consider this when determining treatment length and residual effectiveness based on the goal/s of the treatment.

CONCLUSION

Following a 30-minute cardiovascular exercise bout both the interface and intramuscular rewarming trends after cooling the tissues 2 cm deep in the quadriceps to 10°C below baseline using a wetted ice bag treatment are different than no exercise before cooling. These differences are apparent for up to 120 minutes and should be considered by the clinician.

REFERENCES

1. Washington LL, Gibson SJ, Helme RD. Age-related differences in the endogenous analgesic response to repeated cold water immersion in human volunteers. *Pain.* 2000;89:89-96.

2. Nadler SF, Weingand K, Kruse RJ. The physiologic basis and clinical applications of cryotherapy and thermotherapy for the pain practitioner. *Pain Physician.* 2004;7:395-399.

3. Knight KL. *Cryotherapy in sport injury management.* Champaign, IL: Human Kinetics; 1995.

4. Bugaj R. The cooling, analgesic, and rewarming effects of ice massage on localized skin. *Phys Ther.* 1975;55:11-19.

5. Thorsson O, Lilja B, Ahlgren L, Hemdal B, Westlin N. The effect of local cold application on intramuscular blood flow at rest and after running. *Med Sci Sports Exerc.* 1985;17:710-713.

6. Ho SSW, Illgen RL, Meyer RW, Torok PJ, Cooper MD, Reider B. Comparison of various icing times in decreasing bone metabolism and blood flow in the knee. *Am J Sports Med.* 1995;23:74-76.

7. Brooks GA, Fahey TD. *Exercise physiology : human bioenergetics and its applications.* New York: Wiley; 1984.

8. Merrick MA, Rankin JM, Andres FA, Hinman CL. A preliminary examination of cryotherapy and secondary injury in skeletal muscle. *Med Sci Sports Exerc.* 1999;31:1516-1521.

9. Nordstrom CH, Rehncrona S. Reduction of cerebral blood flow and oxygen consumption with a combination of barbiturate anaesthesia and induced hypothermia in the rat. *Acta Anaesthesiol Scand.* 1978;22:7-12.

10. Rao KS, Schutz RW, Feinberg H, Levitsky S. Metabolic evidence that regional hypothermia induced by cold saline protects the heart during ischemic arrest. *J Surg Res.* 1976;20:421-425.

11. Blair E. *Clinical hypothermia.* New York,: Blakiston Division; 1964.

12. Yanagisawa O, Niitsu M, Takahashi H, Goto K, Itai Y. Evaluations of cooling exercised muscle with MR imaging and P-31 MR spectroscopy. *Med Sci Sports Exerc.* 2003;35:1517-1523.

13. Sapega AA, Heppenstall RB, Sokolow DP, et al. The bioenergetics of preservation of limbs before replantation. The rationale for intermediate hypothermia. *J Bone Joint Surg.* 1988;70:1500-1513.

14. Long BC, Cordova ML, Brucker JB, Demchak TJ, Stone MB. Exercise and quadriceps muscle cooling time. *J Athl Train.* 2005;40:260-263.

15. Mars M, Hadebe B, Tufts M. The effect of ice pack cooling on skin and muscle temperature at rest and after exercise. *S African J Sports Med.* 2006;18:60-66.

16. Dykstra JH, Hill HM, Miller MG, Cheatham CC, Michael TJ, Baker RJ. Comparisons of cubed ice, crushed ice, and wetted ice on intramuscular and surface temperature changes. *J Athl Train.* 2009;44:136-141.

17. Jutte LS, Merrick MA, Ingersoll CD, Edwards JE. The relationship between intramuscular temperature, skin temperature, and adipose thickness during cryotherapy and rewarming. *Arch Phys Med Rehabil.* 2001;82:845-850.

18. Merrick MA, Knight KL, Ingersoll CD, Potteiger JA. The effects of ice and compression wraps on intramuscular temperatures at various depths. *J Athl Train.* 1993;28:236-245.

19. Petajan JH, Watts N. Effects of cooling on the triceps surae reflex. *Am J Phys Med Rehabil.* 1962;41:240-251.

20. Mancuso DL, Knight KL. Effects of prior physical activity on skin surface temperature response of the ankle during and after a 30-minute ice pack application. *J Athl Train.* 1992;27:242-249.

21. Palmer JE, Knight KL. Ankle and thigh skin surface temperature changes with repeated ice pack application. *J Athl Train.* 1996;31:319-323.

22. Housh TJ, Housh DJ, DeVries HA. *Applied exercise & sport physiology.* 2nd ed. Scottsdale, Ariz.: Holcomb Hathaway; 2006.

23. Belitsky RB, Odam SJ, Hubley-Kozey C. Evaluation of the effectiveness of wet ice, dry ice, and cryogenic packs in reducing skin temperature. *Phys Ther.* 1987;67:1080-1084.

24. Knight KL, Brucker JB, Stoneman PD, Rubley MD. Muscle injury management with cryotherapy. *Athl Ther Today.* 2000;5:26-30.

25. Casten CMS, Jordan P. *Aerobics today.* 2nd ed. Belmont, CA: Wadsworth/Thomson Learning; 2002.

26. Starkey C. *Therapeutic modalities.* 3rd ed. Philadelphia: F.A. Davis Co.; 2004.

27. Merrick MA, Jutte LS, Smith ME. Cold modalities with different thermodynamic properties produce different surface and intramuscular temperatures. *J Athl Train.* 2003;38:28-33.

28. Myrer JW, Myrer KA, Measom GJ, Fellingham GW, Evers SL. Muscle temperature is affected by overlying adipose when cryotherapy is administered. *J Athl Train.* 2001;36:32-36.

29. Otte JW, Merrick MA, Ingersoll CD, Cordova ML. Subcutaneous adipose tissue thickness alters cooling time during cryotherapy. *Arch Phys Med Rehabil.* 2002;83:1501-1505.

30. Myrer JW, Measom G, Fellingham GW. Temperature changes in the human leg during and after two methods of cryotherapy. *J Athl Train.* 1998;33:25-29.

31. Myrer JW, Measom GJ, Fellingham GW. Exercise after cryotherapy greatly enhances intramuscular rewarming. *J Athl Train.* 2000;35:412-416.

Table 1. Interface Rewarming Temperatures (°C) by Time (min), Conditions, and Condition Differences. (n=12, mean ± SE)

Time	Bike-Ice	Rest-Ice	Δ
Imd[a]	5.2 ± 0.7[b]	3.0 ± 0.3[b]	2.2
10[a]	21.4 ± 1.1[c]	17.1 ± 0.6[c]	4.3
20[a]	23.9 ± 0.8[d]	20.7 ± 0.4[d]	3.2
30[a]	25.2 ± 0.7[e]	22.4 ± 0.4[e]	2.8
40[a]	26.2 ± 0.6[f]	23.4 ± 0.3[m]	2.8
50[a]	26.8 ± 0.5[g]	24.2 ± 0.3[g]	2.6
60[a]	27.4 ± 0.5[h]	25.0 ± 0.3[n]	2.4
70[a]	27.9 ± 0.4[i]	25.6 ± 0.4[o]	2.3
80[a]	28.3 ± 0.4[j]	26.2 ± 0.4[p]	2.1
90[a]	28.6 ± 0.3[j]	26.8 ± 0.5[k]	1.8
100[a]	28.9 ± 0.3[k]	27.3 ± 0.5[l]	1.6
110[a]	29.1 ± 0.3[k]	27.8 ± 0.6[q]	1.3
120[a]	29.4 ± 0.3[l]	28.2 ± 0.6[q]	1.2

[a] = Bike-Ice > Rest-Ice
[b] = < 10, 20, 30, 40, 50, 60, 70, 80, 90, 100, 110, 120
[c] = > Imd; & < 20, 30, 40, 50, 60, 70, 80, 90, 100, 110, 120
[d] = > Imd, 10; & < 30, 40, 50, 60, 70, 80, 90, 100, 110, 120
[e] = > Imd; 10, 20; & < 50, 60, 70, 80, 90, 100, 110, 120
[f] = > Imd, 10, 20; & < 70, 80, 90, 100, 110, 120
[g] = > Imd, 10, 20; 30, & < 80, 90, 100, 110, 120
[h] = > Imd, 10, 20, 30; & < 100, 110, 120
[i] = > Imd, 10, 20, 30 40; & < 120
[j] = > Imd, 10, 20, 30, 40, 50
[k] = > Imd, 10, 20, 30, 40, 50, 60
[l] = > Imd, 10, 20, 30, 40, 50, 60, 70
[m] = > Imd, 10, 20; & < 60, 70, 80, 90, 100, 110, 120
[n] = > Imd, 10, 20, 30, 40; & < 90, 100, 110, 120
[o] = > Imd, 10, 20, 30, 40; & < 100, 110, 120
[p] = > Imd, 10, 20, 30, 40, 50; & < 110, 120
[q] = > Imd, 10, 20, 30, 40, 50, 60, 70, 80

Table 2. Intramuscular Rewarming Temperatures (°C) by Time, Conditions, and Condition Differences. (n=12, mean ± SE)

Time	Bike-Ice	Rest-Ice	Δ
Imd	26.1 ± 0.1[b]	26.4 ± 0.1[m]	.3
10	25.9 ± 0.4[b]	25.5 ± 0.4[n]	.4
20[a]	27.1 ± 0.4[c]	25.4 ± 0.2[o]	1.7
30[a]	28.1 ± 0.4[d]	26.0 ± 0.2[p]	2.1
40[a]	28.9 ± 0.4[e]	26.7 ± 0.2[q]	2.2
50[a]	29.6 ± 0.3[f]	27.5 ± 0.2[r]	2.1
60[a]	30.1 ± 0.3[f]	28.2 ± 0.3[s]	1.9
70[a]	30.6 ± 0.2[g]	28.8 ± 0.3[t]	1.8
80[a]	31.1 ± 0.2[h]	29.4 ± 0.4[u]	1.7
90[a]	31.4 ± 0.2[i]	30.1 ± 0.4[v]	1.3
100[a]	31.8 ± 0.2[j]	30.6 ± 0.5[w]	1.2
110[a]	32.2 ± 0.2[k]	31.0 ± 0.5[x]	1.2
120	32.5 ± 0.2[l]	31.5 ± 0.5[x]	1.0

[a] = Bike-Ice > Rest-Ice
[b] = < 20, 30, 40, 50, 60, 70, 80, 90, 100, 110, 120
[c] = > Imd, 10; & < 30, 40, 50, 60, 70, 80, 90, 100, 110, 120
[d] = > Imd, 10, 20; & < 50, 60, 70, 80, 90, 100, 110, 120
[e] = > Imd, 10, 20; & < 60, 70, 80, 90, 100, 110, 120
[f] = > Imd, 10, 20, 30; & < 70, 80, 90, 100, 110, 120
[g] = > Imd, 10, 20, 30, 40, 50; & < 100, 110, 120
[h] = > Imd, 10, 20, 30, 40, 50, 60; & <, 110, 120
[i] = > Imd, 10, 20, 30, 40, 50, 60; & < 120
[j] = > Imd, 10, 20, 30, 40, 50, 60, 70
[k] = > Imd, 10, 20, 30, 40, 50, 60, 70, 80
[l] = > Imd, 10, 20, 30, 40, 50, 60, 70, 80, 90
[m] = < 20, 50, 60, 70, 80, 90, 100, 110, 120
[n] = < 40, 50, 60, 70, 80, 90, 100, 110, 120
[o] = < Imd, 40, 50, 60, 70, 80, 90, 100, 110, 120
[p] = < 50, 60, 70, 80, 90, 100, 110, 120
[q] = > 10, 20; & < 60, 70, 80, 90, 100, 110, 120
[r] = > Imd, 10, 20, 30; & < 70, 80, 90, 100, 110, 120
[s] = > Imd, 10, 20, 30; & < 40, 80, 90, 100, 110, 120
[t] = > Imd, 10, 20, 30, 40, 50; & < 90, 100, 110, 120
[u] = > Imd, 10, 20, 30, 40, 50, 60; & < 100, 110, 120
[v] = > Imd, 10, 20, 30, 40, 50, 60, 70; & < 110, 120
[w] = > Imd, 10, 20, 30, 40, 50, 60, 70, 80
[x] = > Imd, 10, 20, 30, 40, 50, 60, 70, 80, 90

Table 3. Summary Of Interface 1 X 2 RMANOVAs $F_{1,11}$-Statistics At Each Time. (n=12)

Time	F-Ratio	P-value	1-β
Imd	16.44	.002	.96
10	14.82	.003	.94
20	11.98	.005	.88
30	14.56	.003	.93
40	19.85	.001	.98
50	23.29	.0005	.99
60	25.46	.0003	1.00
70	23.13	.0005	.99
80	16.15	.002	.95
90	10.24	.008	.83
100	7.41	.02	.70
110	5.32	.041	.56
120	4.88	.049	.52

Table 4. Summary Of Intramuscular 1 X 2 RMANOVAs $F_{1,11}$-Statistics At Each Time. (n=12)

Time	F-Ratio	P-value	1-β
Imd	2.38	.15	.29
10	1.04	.33	.15
20	13.24	.004	.91
30	22.99	.0005	.99
40	33.08	.0001	1.00
50	27.31	.0003	1.00
60	21.91	.0007	.99
70	17.40	.002	.97
80	11.70	.006	.88
90	7.82	.017	.72
100	6.58	.026	.65
110	5.28	.042	.55
120	3.79	.078	.43

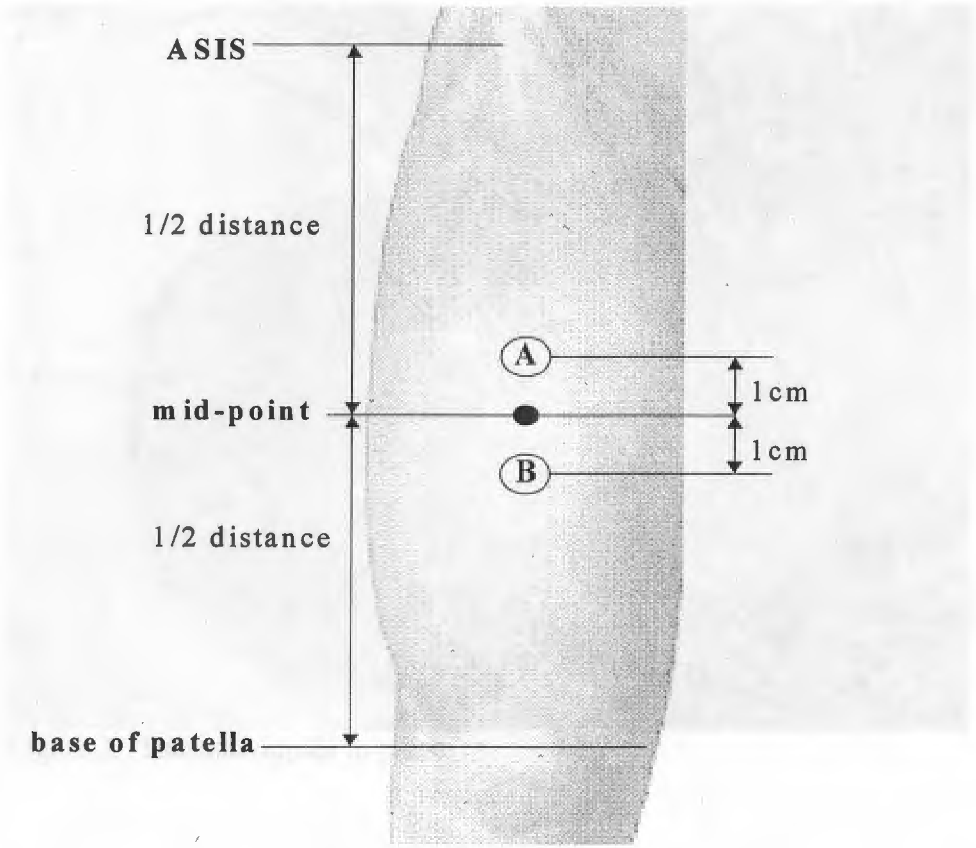

Figure 1. Thermocouple insertion sites. (A=Intramuscular and B=Interface)

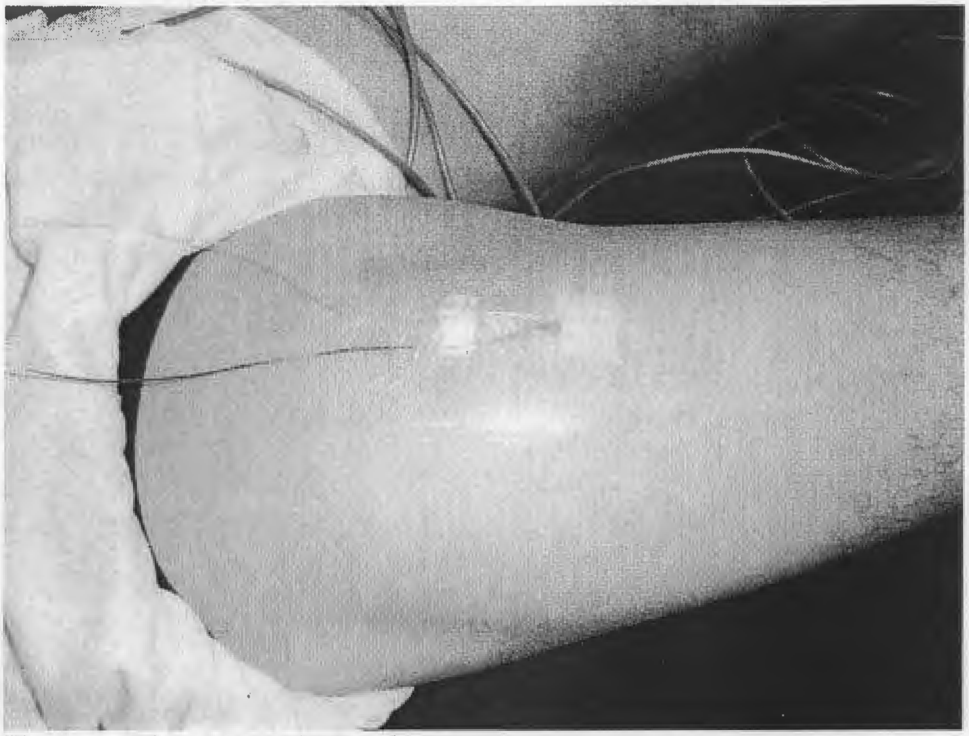

Figure 2. Thermocouples in place.

Figure 3. Ice bag treatment.

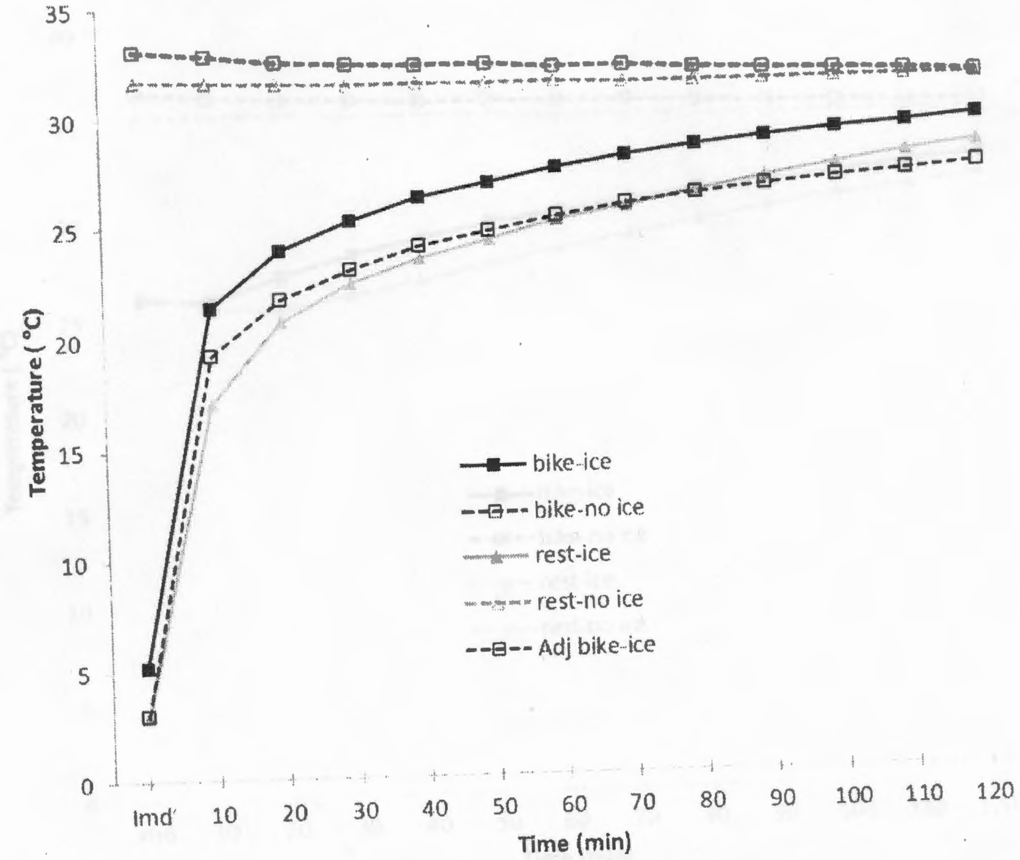

Figure 4. Interface rewarming temperatures.

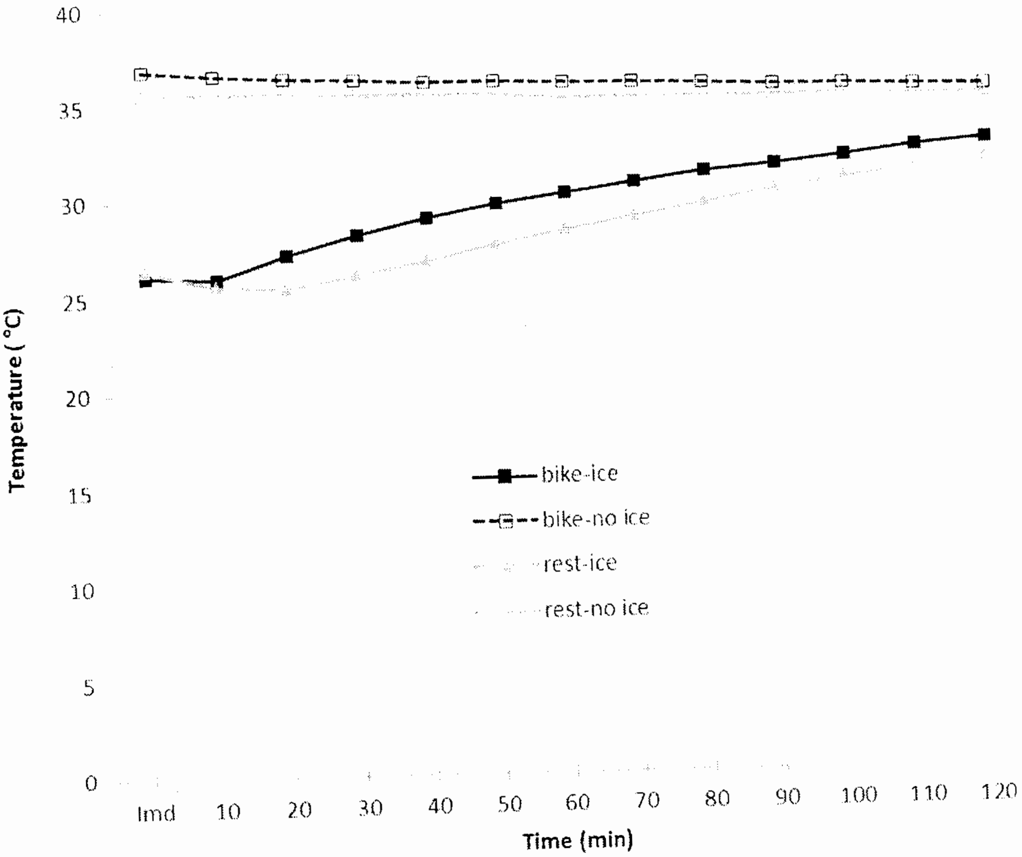

Figure 5. Intramuscular rewarming temperatures.

APPENDIX A

EXTENDED RATIONAL & PURPOSE

THE PROBLEM

Statement of the Problem

Ice bags are often applied following activity for various reasons. The treatment needs repeating, but the decision of when to reapply is based on the initial application being applied to rested muscle. Currently, I understand that exercise speeds the focal cooling effect compared to rest. The reason for the exercise speeding the cooling could also affect post treatment temperatures; however, the effect of exercise on tissue temperature following cold application is still not fully understood. If post treatment tissue temperatures are affected by exercise prior to cooling, then clinicians should consider this when timing the reapplication. Therefore, the purpose of this study is to investigate if exercise before an ice bag treatment that decreases intramuscular temperature 10°C below baseline affects the interface and intramuscular tissue temperatures as compared to rest before treatment during 120 minutes following the application.

Research Questions

This study will attempt to answer the following:

1. Does exercise before cooling intramuscular tissue to 10 °C below baseline affect interface temperature during 120 minutes following treatment?
2. Does exercise before cooling intramuscular tissue to 10 °C below baseline affect intramuscular temperature during 120 minutes after the treatment?

Experimental Hypotheses

The following hypotheses will guide this study:

1. Exercise before cooling will cause the interface temperatures to rewarm faster during 120 minutes following treatment.
2. Exercise before cooling will cause the intramuscular temperatures to rewarm faster during 120 minutes following treatment.

Assumptions

The following assumptions will be made in this study:

1. Subjects will report current health status honestly and accurately.
2. Thermocouple will stay at the determined depth throughout the study.

Delimitations

This study will be delimited to the following:

1. Physically active college-aged male.
2. Quadriceps muscle group.
3. Interface and Intramuscular tissue temperature.
4. 30 minutes exercise with stationary cycle ergometer at 70% to 80% of the age-pre-decided maximum heart rate.
5. Treatment duration based on cooling intramuscular temperature to 10°C below baseline temperature.
6. Measures taken 120 minutes following the application.

Limitations

Limitation for this study will include:

1. The temperature measurement nearest to 0.1°C.

Operational Definitions

The following definition will be used:

1. College-Aged – Individuals who are between 18 and 26 years of age.
2. Physically-Active – Individual who has engaged in aerobic or anaerobic activity at least 2 times per week for 30 minutes for the past 2 months or longer.
3. Healthy – Individual who has not been taking any prescription medication, not diagnosed with an illness or illnesses or has no allergy to ice.
4. Uninjured – No injury to the lower extremities for the past 3 months.
5. Ice-Bag – 2000mL of cubed ice and 300mL of 22 °C water a 44.0 cm X 25.5 cm plastic bag with no excess air.
6. Interface Depth – Interface between the skin and the environment.
7. Intramuscular Depth – 2 cm plus ½ skinfold thickness.
8. Rest – Lying supine without any type of excess movement.
9. Exercise – Riding stationary cycle ergometer for 30 minutes at 70% to 80% of the age-pre-decided maximum heart rate.
10. Baseline Temperature – Average of the temperature that measured for 5 minutes before the exercise condition begin.

11. Application Time – The length of wetted-ice bag application to 10 °C below to the baseline temperature at 2 cm beneath adipose tissue.
12. Post-Application Time – 120 minutes from the end of application time.

Significance of the Study

An ice bag is often applied to a body part following strenuous physical activity, which increases tissue temperature as compared to rested tissue. It is important for athletic trainers to know how exercise affect on tissue rewarming after cold application, because exercised tissue might rewarm differently than rested tissue following cold application. Therefore the athletic trainer should consider timing of the reapplication depending on physical status of target tissue to increase effect of treatment. The present study will investigate rewarming trend with exercised tissue and might give new idea of appropriate timing for cold reapplication to athletic trainers.

APPENDIX B

EXTENDED LITERATURE REVIEW

REVIEW OF LITERATURE

The following review discusses the purpose of cryotherapy, current evidence on prophylactic use of cryotherapy, pathophysiological events of micro-trauma, physiological effect of cryotherapy, factors that affect on the efficacy of cryotherapy, superficial and intramuscular tissue temperature during cryotherapy, residual temperature following cryotherapy, exercise and physiological effect on human body, as they relate to superficial and intramuscular temperatures after an ice bag treatment following rest and exercise.

Purpose of Cryotherapy

Cryotherapy is defined as the therapeutic application of cold to the body that removes heat from the body decreasing tissue temperature.[2] The common purposes of decreasing tissue temperature is to decrease pain, muscle spasm, minimize inflammation and secondary injury effects.[3] Thus, it is commonly used immediately after injury, which is not a part of my study. But just as important cryotherapy is commonly used prophylactically following exercise to help reduce the risk of chronic injuries, which do not go through the inflammatory process. The rationale and support for the prophylactic use of cold will be discussed.

Current Evidence on Prophylactic Use of Cryotherapy

There is one report[32] that highlights the issues of the cryotherapy efficacy on treatment outcomes following injury or surgery. Even though the focus of my study is not directly related to injury or surgery, the support for using cryotherapy for modulating discomfort and metabolism following a workout may still apply. Moreover, I am interested in tissue temperatures because discomfort and metabolism change when tissue temperature decreases. Decreasing tissue temperatures following exercise may help reduce any secondary effects due to microtrauma.

Currently, it is stated that skin temperature needs to be below 13.6°C to have local analgesia,[4] whereas tissue temperatures need to be lowered between 10°C and 15°C to reduce metabolism,[13] which should maximize therapeutic benefits. The 10°C level of cooling is also supported by the Q_{10} effect on metabolism.[3,7] Therefore, the decrease of deep tissues to 10°C below baseline is my therapeutic goal. Achieving this goal following exercise and rest is possible.[14]

Even though sport medicine research on outcomes is still very young, it has mostly focused on treating patients with injuries and following surgeries there is some support that it does work. I feel that once there is more evidence to support cryotherapy we may see a shift in focus about its use prophylactically. Therefore the evidence for cryotherapy use following an exercise bout is anecdotal at best.

Pathophysiological events of micro-trauma

It is important to understand how the body responds to focal cooling, which is how athletic trainers rationalize their prophylactic cryotherapy practice. To date, athletic trainers state that cold reduces ischemic injury, which in theory grounds the prophylactic use of ice bag application. Even though ischemic damage is most often related to secondary injury, it still could be present as result of micro-trauma, but on a smaller scale. Because the micro-trauma and ischemic injuries are on a smaller scale they do not cause an inflammatory response making chronic injuries difficult to predict.

Related to the effect cold has on ischemic processes athletic trainers cool the body part in hopes of reducing cell death. Ischemic injury could be the result of either inadequate supply of oxygen, supply of fuel substrates, and waste removal.[33] With micro-trauma, very small vessels could be disrupted thus all 3 of the above are a concern.

If healthy cells no longer have the supply of oxygen they need, they will die, which is called hypoxic death. Hypoxia does directly cause of cell death, but it does limit the production of ATP. Without adequate ATP production the cell can no longer keep sodium-potassium pumps functioning, which cause the sodium concentration in the cell to rise. As sodium concentrations rise, so does the water volume, leading to eventual cell bursting.

Related to decreased oxygen supply is the reduced available fuel substrate. Again if the cell does not have the fuel to burn it cannot produce ATP and bursting will again be the result. Because the cell is no longer using aerobic processes to produce ATP the cell converts to glycolytic processes. The glycoltic pathway does not produce a large number of ATP and has a short supply, even within a normal tissue without any micro-trauma. Combined with a lack of fuel supply to the cell, the cell stands no chance of staying alive. In addition, gylcolysis produces lactic acid and this build up decreases pH.

Because the body uses the gylcolytic pathways to supply energy at the onset of exercise and to turn on the aerobic pathway there is a large amount of lactic acid and waste. As lactic acid builds the decreased pH enhances waste removal by the lysomes, which will be discussed in more detail later. On the other hand, as waste products build within the cell so does the inhibition of metabolic pathways again leading to fewer ATP being produced. Healthy tissues that have good supply to and from the cells can deal with the waste accumulation. As suspected, if micro-trauma effects waste removal then toxicity and acidity increase in the cell and it can no longer function leading to death.

Although lysomes function well in reduced pH environments they may not be able to keep up with the increase in waste products of a cell that is trying to survive using nothing but glycolytic pathways. If a lysome ingests more waste than it can hold then it will burst inside the cell releasing it phagocytic enzymes, which will breakdown the structure of the cell. Once the structure of the cell is broken down it dies. A secondary concern to lysome activity is related to when a cell bursts and releases its contents into the extracellular space along with the acidic environment it was in. As the pH level drops in the extracellular space, lysome activity may still be active. With active lysomes in this space there is nothing stopping them from digesting healthy cell membranes causing those cells to die, too. Again, if the lysomes continue to digest waste in the extracellular space they will swell and burst; thus, releasing their enzymes causing even more damage.

Although I have presented very grim and cyclical cell response to micro-trauma, again there is not enough damage to cause an inflammatory response. However, it is apparent that these processes could exist following a workout, and support why an athletic trainer would prescribe cryotherapy.

Physiological Effects of Cryotherapy

Although my study does not involve injury or pain, it is still important to understand physiological effects of cryotherapy because the theory of prophylactic tissue cooling is tied to acute use of cryotherapy. Therefore, the same physiological responses are expected to occur because goal of prophylactic cooling is to reduce risk of micro-trauma, if present. The effects most connected to cooling following exercise are related to blood flow and metabolism.

Effect of Cold on Blood Flow

Cryotherapy decreases tissue blood flow by causing vasoconstriction.[2] Specifically, an application of an ice wrap on the knee for 25 minutes decreases arterial blood flow by 26% and capillary blood flow by 30%,[6] where as when cooling is applied over muscular body parts a reduction of blood flow after rest and exercise following a 20-minute application could equal a 66% to 69% in a rested or exercised muscle, respectively.[5] Therefore, it easy to understand why you would want to reduce blood flow, and to cool the area as soon as possible, if any micro-trauma is present.

Effect of Cold on Metabolism

The effects of cooling on metabolism and pH are understood.[11] The following review highlights some of the important specific effects.

Markers used to detect metabolism rates are indicated by oxygen use and product levels. Oxygen consumption decreases of an average of 2.5 times per 10°C decrease in uninjured human forearms when cooled are noted.[9] In addition, oxygen uptake of myoglobin in rat hindlimbs at 15°C is one third of that at 35°C.[34] The effect of cooling on metabolic product levels are also noted by the evidence that higher level of fuel substrates, such as ATP, creatine phosphate, and glycogen, were found in canine hearts at 5°C during 1 hour of no blood supply than in hearts at normal temperature.[10] Moreover, by reducing the metabolic demand of cells by cooling tissues organs being transplanted can survive substantially longer.[3]

These metabolic effects of cooling on metabolism may also be responsible for increases in pH, which indicates alkalinization.[12-13] Exercised and injured tissue have decreased pH; therefore, cryotherapy could help maintain the tissue in alkali resulting in reduced delayed muscle edema and muscle cell damage.

Although it is still unknown how cold is cold enough to make practical changes, and with deeper cooling there is a more profound effect on metabolism,[11] I could expect that cooling exercised tissue helps reduce risk of micro-trauma.

Factors That Affect Cooling

The efficacy of cryotherapy is related to its heat storage capacity,[3] which is dependent on the temperature,[35] type,[35-37] amount,[3] duration of the treatment, [38-39] treatment area,[35] compression,[18] adipose tissue thickness.[17,27-29]

The greater heat is absorbed by modalities with lower temperature. A 1°C ice bath reduces tissue temperatures greater than a 10°C ice bath.[35] Moreover, type of modality effects on how much heat can be absorbed. Modalities that undergo a phase change (solid to liquid), such as ice packs and slush buckets, have a greater ability to absorb heat energy than those that do not, like a gel pack.[37,40]

Heat absorption capacity is also increased when more of the modality is used. For example, if all else is equal, a 1-kg ice bag has better heat absorption capacity than a ½-kg ice bag.[3]

The length of application directly affects the amount of heat absorbed from deeper tissues.[39,41] Because when two different temperature surfaces are in contact with one another for longer, the more heat energy could be transferred through conduction. If the goal of the treatment is to reduce tissue metabolism immediately after injury, at least 30 minutes of ice bag application is required.[3] However, if the target tissues are very muscular or deep, then a longer duration of treatment may be required.[24]

Perhaps one of the most commonly used cryotherapy techniques is crushed ice bag, which is easy, inexpensive, and widely available. Currently, it is known that a wetted ice bag, which is made with 2000mL of cubed ice and 300mL of water, is more effective in both superficial and deep tissue cooling than crushed ice bag.[16] The greater efficacy of wetted ice bag is due to increasing surface contact area between the ice bag and the skin, and water also has higher ability to conduct thermal energy than air within ice bag.[16]

Because cryotherapy with compression increases the rate of temperature decrease compared with no compression,[18] consistent compression of each ice bag application is needed. Although I do not have the ability to measure the amount of compression; nor do I wish to affect ice bag contact surface area by having something else between the ice bag and skin, or something else within the wrap, each ice bag will be wrapped with elastic wrap by me throughout the study. Having a little more than five years experience applying ice bags, my procedures should be considered consistent.

The adipose tissue thickness has great influence on effectiveness of cryotherapy: therefore, should be considered when applying cold.[26,28-29,42-45] There is an inverse relationship between skinfold thickness and intramuscular temperature decrease because adipose tissue reduces the ability of the cold modality to induce intramuscular temperature change. Therefore, treatment times are extended when person with thicker adipose tissue receive treatment.[26,28,44] However, it is uncertain if the amount of adipose tissue affects residual temperatures, which needs investigating. On the other hand, by keeping my participant skinfold thickness measurement between 20 and 30 mm I will reduce any temperature variance because of participant variability.

Temperatures During Application

After Rest

The following discussion summarizes the effects of focal cooling rested body parts using a variety of conductive cold modalities. It is apparent that superficial (Table B1) and intramuscular (Table B2) tissues react differently to cold; additionally, it easy to see how the aforementioned factors can affect the amount of heat removal. More importantly this section justifies the temperatures expected with my study.

Superficial tissue - It is known that rested superficial tissue cools rapidly when an ice bag is applied. Specifically, tissue temperatures rapidly decrease to anywhere between 22.1°C to 6.24°C depending on amount, duration, and type of modalities. What is not noticeable in Table B1 is that these temperatures are usually reached by the 10 minute duration time point, and then are held constant. When considering all of the factors related to ice bag application in my study, I would expect a similar cooling trend that will reach single digits.

Table B1. Summary of Reports Regarding Cooling Effects on Rested Superficial Temperatures.*

1st Author, Yr	Modality	Tx Dur (Min.)	Body Part	Post-Tx Temp. (°C)	Re-Warm Dur (Min.)	Final Rewarming Temp. (°C)
Dykstra, 2009[16]	-2000 ml crushed ice bag -2000ml cubed ice bag -2000ml ice w/300ml H_2O bag	20	Calf	15.9 16.3 13.3	120	26.6 26.1 25.6
Kennet, 2007[46]	-1L crushed ice bag, -Gel pack -Frozen peas -Immersion(6L H_2O/1L ice)	20	Ankle	9.24 16.01 14.61 13.01	30	20.5 24 23 20.5 (Estimated from graph)
Mars, 2006[15]	Crushed ice in a wet towel	15	Thigh	8.1	45	25.6
Merrick, 2003[27]	-1 kg crushed ice bag -Wet-ice -Flex-i-cold	30	Thigh	6.47 6.24 9.86	NA	NA
Jutte, 2001[17]	500g cubed ice bag	30	Thigh	27 decrease from the baseline	120	30 (Estimated from graph)
Myrer, 1998[30]	-1.8 kg crushed ice bag, -Cold whirlpool (10°C)	20	Calf	13.8 19.0	30	26.1 26.4
Merrick, 1993[18]	1 kg crushed ice bag	30	Thigh	7.24	20	26 (Estimated from graph)
Belitsky, 1987[23]	-500g ice in wet towel -500 g ice bag in wet towel -Cryogen pack	15	Calf	17.9 20.1 22.1	15	Range 27.0 to 28.2
Petajan, 1962[19]	Immersion (12.5-13°C H_2O)	30	Calf	18.5 (Estimated from graph)	220	24 (Estimated from graph)

* English articles only.

Table B2. Summary of Reports Regarding Cooling Effects on Rested Intramuscular Temperatures.*

1st Author, Year	Modality	Tx Dur (Min.)	Body Part & Depth Treated	Post-Tx Temp. (°C)	Re-Warm Dur (Min.)	Final Rewarming Temp. (°C)
Dykstra, 2009[16]	-2000 ml crushed ice bag	20	Calf; 2 cm + ½ skinfold (12.8 mm)	32.4	120	31.8
	-2000ml cubed ice bag			31.1		30.9
	-2000ml ice w/300ml H_2O bag			30.3		30.4
Mars, 2006[15]	A pack of crushed ice in a wet towel	15	Thigh; 1 cm + adipose thickness (0.43 cm)	26.2	45	29.4
Long, 2005[14]	1-kg ice bag	45.0	-Thigh; 1 cm + ½ skinfold (25.4mm)	27 (Estimated from graph)	NA	NA
		53.6	-Thigh; 2 cm + ½ skinfold (25.4mm)	27.8 (Estimated from graph)		
Merrick, 2003[27]	1-kg crashed ice bag	30	-Thigh; 1 cm + ½ skinfold (19.3 mm)	27.77	NA	NA
			-Thigh; 2 cm + ½ skinfold (19.3 mm)	31.82		
	Wet-ice			-27.21 -30.59		
	Flex-i-cold			-29.46 -32.07		
Otte, 2002[29]	750g crushed ice bag	58.6	Thigh; 1 cm + ½ Skinfold (31-40mm)	7 °C below baseline	NA	NA
		37.8	Thigh; 1 cm + ½ Skinfold (21-30mm)			
		23.3	Thigh; 1 cm + ½ Skinfold (11-10mm)			
		8.0	Thigh; 1 cm + ½ Skinfold (0-10mm)			
Jutte, 2001[17]	500g bag of cubed ice	30	Thigh; 2 cm + ½ skinfold (21.2mm)	8 decreased from baseline	120	33 (Estimated from graph)

Table B2. Continued.

1st Author, Year	Modality	Tx Dur (Min.)	Body Part & Depth Treated	Post-Tx Temp. (°C)	Re-Warm Dur (Min.)	Final Rewarming Temp. (°C)
Myrer, 2001[28]	1.8-kg crushed-ice pack	20	-Calf ; 1 cm + ½ skinfold (6.5 mm)	20.81	30	26.2
			-Calf ; 3 cm + ½ skinfold (6.5 mm)	30.04		28.41
			-Calf ; 1 cm + ½ skinfold (14.1 mm)	26.48		28.70
			-Calf ; 3 cm + ½ skinfold (14.1 mm)	32.67		30.84
			-Calf ; 1 cm + ½ skinfold (25.7 mm)	30.54		30.06
			-Calf ; 3 cm + ½ skinfold (25.7 mm)	33.94		31.84
Myrer, 2000[31]	1.8-kg crushed-ice pack	20	Calf; 1 cm + ½ skinfold (16.6 mm)	29.67	30	28.91
Myrer, 1998[30]	-1.8-kg crushed-ice pack	20	Calf; 1 cm + ½ skinfold	27.8	30	29.8
	-Cold whirlpool (10°C)		(not reported)	28.2		26.4
Zemke, 1998[45]	-2 cups ice bag -Ice cup	15	-Calf; 1 cm + subcutaneous thickness (0.78 cm)	29.67	NA	NA
			-Calf; 1 cm + subcutaneous thickness (0.59 cm)	29.67		
Merrick, 1993[18]	1-kg crushed ice bag	30	-Thigh; 1 cm + ½ skinfold (15.8 mm)	26.58	20	28.5 (Estimated from graph)
			-Thigh; 2 cm + ½ skinfold	28.21		29.5 (Estimated from graph)
Johnson, 1979[47]	10°C water bath	30	Calf ; 25.3mm	22.2	240	~ 32.5° (estimated from graph)
Petajan, 1962[19]	Immersion (12.5-13°C H_2O)	30	Calf (N/A)	29.3	220	28 (Estimated from graph)

* English articles only.

Intramuscular tissue - Because thermal energy is transferred from muscle to adipose tissue, adipose tissue to skin and then skin to cold agent, removal of heat from deep tissues is more gradual, which is not evident in Table B2. However, also noting that deep tissue temperatures do not get as cold as superficial tissues, therefore I can be certain of that the two depths of tissues react differently to conductive cold modalities, which is why I will not compare superficial effects to deep effects.

More to the point, considering this research and the treatment condition chosen for my study, I could hypothesize that the 2 cm deep tissue temperature will reach 26 °C, which is 10 °C below baseline temperature, a few minutes shy of 1 hour.

After Exercise

The following discussion will summarize the limited findings regarding the effect of exercise before cooling has applied on superficial (Table B3) and intramuscular (Table B4) tissue. Even though these reports vary greatly, with none of them directly related to my study regarding superficial tissue, and only one[14] related to my intramuscular interest, thereby I cannot strongly predict my possible results.

Superficial tissue - Although there is not a report (Table B3) that directly relates to my study because either the treatment length is not long enough, and if the treatment duration is close to what I will use, it was applied to a different body part, the effect an ice bag has on superficial temperatures may not be greatly affected by prior exercise.

When comparing all of the previously mentioned rested superficial tissue results to the results stated below, it seems that superficial temperatures will reach a similar level of cooling. This could be due to the direct contact with the modality, which causes a

Table B3. Summary of Reports Regarding Cooling Effects on Exercised Superficial Temperatures.*

1st Author, Year	Exercise condition	Modality	Tx Dur (Min.)	Body Part	Post-Tx Temp. (°C)	Re-Warm Dur (Min.)	Final Rewarming Temp. (°C)
Mars, 2006[15]	Treadmill VO2 max	A pack of crushed ice in a wet towel	15	Thigh	7.0	45	26.4
Palmer, 1996[21]	15min of stationary cycle ergometer at 60-80% maximum heart rate	Ice pack	20 30 40	Ankle	5.9 5.2 4.4	20min simulated showering & 40min lying:	29.2 29.0 26.9
	same	same	same	Thigh	4.8 4.2 3.5	same	31.1 30.2 29.2
Mancuso, 1992 [20]	15min & 30min 60-80% VO2 treadmill	2.5-lb crushed ice bag	30	Ankle	8.5 10.3	90min w/ elastic wrap & elevation	29.7 30.9

* English articles only.

Table B4. Studies Illustrating Cooling Effects on Exercised Intramuscular Temperatures.*

1st Author, Year	Exercise condition	Modality	Tx Dur (Min.)	Body Part & Depth Treated	Post-Tx Temp. (°C)	Re-Warm Dur (Min.)	Final Rewarming Temp. (°C)
Mars, 2006[15]	Treadmill VO2 max	A pack of crushed ice in a wet towel	15	Thigh; 1 cm + adipose thickness (0.43 cm)	27.0	45	31.0
Long, 2005[14]	30min. of stationary cycle ergometer at 70-80%maximum heart rate	1-kg ice bag	32.2	-Thigh; 1 cm + ½ skinfold (25.4mm)	26.9 (Estimated from graph)	N/A	N/A
			39.6	-Thigh; 2 cm + ½ skinfold (25.4mm)	28.1 (Estimated from graph)	N/A	N/A

* English articles only.

rapid cooling effect that levels out. Therefore, I would expect to see single digit temperatures on the skin. But because the body uses the skin to help dissipate heat following exercise, the exercised skin may be slightly warmer. With 1°C being a practical and meaningful difference[26] I hope to detect this difference if present.

Intramuscular tissue - Unlike the above discussion, the only researchers[14-15] that have investigated intramuscular temperatures during ice bag application following exercise (Table B4) did so using the thigh, which is why I am also using the same body part. Again the results vary greatly because different subjects, cooling modalities, application parameters used. Moreover, the differences are noted between the studies one group[15] reports similar cooling trend compared to rested muscle, while the other group[14] reports faster cooling following exercise.

Because Mars et al[15] did not cool for longer than 15 minutes the effect of the exercise on cooling may have been missed. This statement is supported by Long et al,[14] who indicated that after 15 minutes of cooling the heat removed from the exercised muscle occurs faster than the rested thereafter. Secondarily, knowing that the tissues will cool to 10°C below baseline within an hour, which is well past the 15 minute time point, the effect of exercise will be noticeable. Lastly, having the tissues at the same temperature before collecting residual measures means the temperature gradient will be equal according to baseline. Therefore, I will use similar methods as reported by Long et al.[14]

Post Treatment Temperatures

After Treating Rested Tissues

Superficial tissue – After reviewing the superficial residual temperatures related to the studies presented (Table B1), it is noticeable most of the reported temperature after residual measurement are anywhere between 25°C to 30°C regardless duration of residual measures. What is not represented in the table is the rapid rewarming after removal of the cold modalities, as well as the slow return to baseline during the last few degrees.[15-18,46]

Therefore, I could expect temperature after 120 minutes of post treatment in my study will be anywhere between 25°C to 30°C, even though treatment condition and the body part do not match reported studies.

Intramuscular tissue - Regarding the deep tissue temperatures following treatment (Table B2), it is evident that the tissues rewarm more slowly as compared to the superficial tissues, which helps once again justify keeping the tissue depth out of the analysis. This slow change in temperatures following modality removal is again due to temperature gradients surrounding the area. The tissue around the treatment site will be cooled as well, so rewarming may not occur instantly. Additionally, instead of rewarming immediately upon removal of the cold modality, like the superficial tissues do, 8[15-19,28,30-31] of the 13 investigators reported that cooling continues following the cold application. Specifically, the continuous cooling reported seems to last from 5 to 25 minutes depending on treatment condition. Because I am using similar cooling methods with an ice bag, and making sure that I cool to 10°C below baseline, I am expected to see some similar residual cooling after the ice bag is removed.

In respect to end of study temperatures, and the reason I choose to stop data collection 2 hours after ice bag removal is because the groups[16-17,19,47]that report 2 hours or more worth of residual temperatures state that majority of the heat was regained within this period. Specifically, one group[47] reports nearly a 7°C gain in heat within the first 2 hours and only a 3°C over the last 2 hours; however, this was done on the calf. Others authors[17] that tracked residual temperatures for 2 hours after 30 minutes cooling on thigh used only a 500 g ice bag, which ¼ the size that I will use, therefore I would expect my temperatures at the end of the study will not reach 33°C, but would expect a similar rewarming trend. In addition, because the deep tissues rewarm slowly especially last few degrees, it may be why the superficial tissues also slowly regain the temperature last few degrees back to baseline.

After Treating Exercised Tissues

As noticed there are even fewer investigations reporting residual treatment effects on tissue temperatures, and these do not present a clear understanding of what could occur following exercise. Moreover, each of those previous studies are either not clinically applicable, use a short exercise duration, not providing sufficient tissue rewarming trend data, or investigate a different body part from my interest. Even though my study will have some major differences, there are some points of interest worth noting.

Superficial tissue - Reviewing residual temperature of past studies (Table B3), all three studies[15,20-21] suggested temperature after their residual period increased close to or little over 30°C. As stated previously I do not expect superficial temperature with my study will reach these temperatures at the same time points. However, after 2 hours following treatment, the exercised thigh should be near this temperature because the skin is assisting with heat removal. Moreover, as previously mentioned also when cold agent is removed from the body part, the tissue temperature increase rapidly. This has been reported following exercise as well.[15]

Intramuscular tissue – Although one group[15] looked at residual intramuscular temperature after treating exercised muscle (Table B4), they used a VO_2max test for the exercise condition, which is short in duration, but still intense enough to bring about physiological responses to aid removing heat. Even though this would be similar to my study, I don't consider it clinically applicable because most often exercise bouts are not this intense or short. Additionally, they applied an ice bag for only 15 minutes, which is also not clinically applicable because we are instructed to apply ice for at least twice that duration. Lastly, the depth of the tissue used to detect exercise effects on residual cooling temperatures was only 1 cm deep to the skinfold thickness.

Because I am going to use longer cardiovascular exercise and cooling durations, and report deeper tissue temperatures similar to others,[14] I am not able to predict residual temperatures 120 minutes following ice bag application.

APPENDIX C

EXTENDED METHODS

Table C1. Informed Consent Form

CONSENT TO PARTICIPATE IN RESEARCH

RESEARCH TITLE: Effect of exercise before an ice bag treatment on quadriceps interface and intramuscular temperature following application

NAME OF INVESTIGATORS: Toshiro Hirano, and Dr. Jody B. Brucker

INVITATION TO PARTICIPATE:
You have been asked to participate in a research study conducted by Toshiro Hirano, as part of a research project for a Masters of Science Degree in Athletic Training. Your participation in this study is entirely voluntary. Please read the information below and ask questions about anything you do not understand, before deciding whether or not to participate.

You have been invited to participate in this study because you are physically active male and are between the age 18 to 26 years. In order to participate in this study, you must perform physical activity for a minimum of 30 consecutive minutes a day, 2 days a week over past 2 months prior to the study. You will also be excluded if you have a history of circulation problems, or develop an adverse or allergic reaction to a cold treatment or latex. Moreover, you will be excluded if you have or had a leg injury (e.g, sprain an ankle, knee, or hip) within 3 months prior to data collection, or have mitral valve prolapse. Furthermore, you must be free of any blood borne infectious diseases (i.e. hepatitis, HIV, AIDS), and blood clotting disorders (e.g., hemophilia). Certain prescription and over the counter medicines or supplements related to anticoagulation or anti-platelet agents, such as blood thinner (warfarin), Aspirin, or nonsteroidal anti-inflammatory drugs (NSAIDs), ibuprofen (e.g., Motrin, Advil), ketop (e.g., Orudis), naproxen (e.g., Naprosyn, Aleve) may also exclude you from this study. Additionally, herbal supplements including, but not limited to, Ginkgo Biloba, Vitamin E, Garlic capsules, Green tea, and some protein supplements may exclude you because their effect on the blood. Lastly, if your skinfold measures at either anterior thigh measures is outside 20 to 30 mm thickness, you will be excluded.

NATURE AND PURPOSE:
The purpose of this study is to determine if exercise before an ice bag treatment affects the interface and intramuscular tissue temperature as compared to rest before treatment during 120 minutes following the application.

EXPLANATION OF PROCEDURES:
If you volunteer to participate in this study, you will be asked to do the following things:

Report to the Athletic Training Research Laboratory dressed in shorts, t-shirt and athletic shoes for two sessions, lasting about 3½ hours each session. Each test session will be at the same time each day, with sessions separated by a minimum of 48 hours.

During the first session, you will be asked to fill out a health history questionnaire to assure your qualification and safety for this study. In addition, you will be introduced to the instrumentation, testing procedures, the risks, and methods in this study. The first session will also consist of surface tissue thickness measurements, determining a treatment order. The order in which you receive the treatments will be determined by balanced order. The second treatment will be the

Table C1. Continued.

opposite from the first, so you will complete both treatments in two days. The skinfold thickness on both of your thighs will be measured three times at the midpoint of thigh. The average of the three measurements will be calculated.

The second session will consist of data collection only. Data collection sessions will include insertion of a small fine wire thermometer, exercise condition (30 minute biking or resting), application of an ice bag (continue until muscle temperature reach 10°C below baseline), and temperature measurements before exercise condition, during exercise, during ice bag application, and 120 minutes after removal of the ice bag. Then, the location of the thigh temperatures collection sites will be identified using tape measure and mark with surgical pen at the midpoint of anterior thigh. From the midpoint, 1cm above will be used for intramuscular temperature measurement as well as 1 cm below will be used for surface temperature measurement.

Sterile techniques will be used during all procedures. A 10 cm X 10 cm area around the insertion site will be clipped and cleansed with chlorhexidine gluconate solution for 3 minutes. The insertion depth will be 2 cm below superficial tissue thickness. A hollow needle will be implanted, and then removed, leaving a tube in which the thermometer will be inserted. The skin thermometer will be secured 2 cm below the implantable thermometer site. Both thermometers and the catheter will then be secured to the skin with dressing tape. After thermometers are connected to the data acquisition device, temperature recording will begin.

Administration of each condition will be as follows: 1) Baseline temperature will be measured for 5 minutes in lying face up position, and then you will be riding stationary bike for 30 minutes at 70-80% of predicted maximum heart rated. An ice bag will then be applied on right thigh whereas left thigh will not receive any treatment. 2) Baseline temperature will be measured for 5 minutes in lying face up position, and then you will be lying on treatment table for another 30 minutes in the same position. An ice bag will then be applied on right thigh whereas left thigh will not receive any treatment. With both condition, the ice bag treatment will continue until the iced thigh intramuscular temperature reach 10 °C baseline, and muscle and skin temperature will be recorded for 120 minutes after the end of treatment. Following each session, the thermometer will be removed and the area will be cleaned to prevent infection. You will be provided informational document stating signs and symptoms of infection as well as directions and contact numbers.

DISCOMFORTS AND RISKS:

There are some risks associated with this study, which are considered similar to and no greater than giving blood. Short-term risks to you include some tenderness in both thighs immediately after thermocouple insertion. Bleeding and local infection might also occur. Possible long-term risks of the study include a systemic infection, or having a small amount of tissue damage due to the instrument insertion.

Special precautions will be taken to decrease the potential of these risks. Sterile technique will be used during instrument and tissue handling for thermocouple insertion. Any soreness from the thermocouple insertion should be minimal, and not affect your daily activities. Since ice will be applied to the site, this will help to reduce muscle soreness caused by instrument insertion. These methods have been commonly used over the past decade, particularly for cryotherapy research.

Table C1. Continued.

In addition the PI, there will be at least one additional CPR/First AID certified individual in our building during data collection.

QUALIFICATIONS OF INVESTIGATORS:
The primary investigator has been properly trained and practiced sterile techniques, correct thermocouple insertion, and participant care by the faculty sponsor. The faculty sponsor has been involved in 20 similarly IRB approved studies totaling near 400 consenting participants within the past decade. Both the primary investigator and faculty sponsor have passed IRB training for biomedical research, and are licensed to practice athletic training in the state of Iowa. Knowledge of this information should help you feel comfortable that any medical concern will be handled quickly and properly.

Any costs that result from participating in this study, whether or not they are related to medical attention will be participants' responsibility. The investigators and the University of Northern Iowa will not pay for any services related to an individual's participation in this study.

BENEFITS AND COMPENSATION:
Your temperature results will assist in determining the effects of exercise on quadriceps tissue rewarming following ice bag treatment. This is important in the clinical use of ice bag, specifically determining reapplication timing, and may lead to change in clinical protocols.

CONFIDENTIALITY:
Any information that is obtained in connection with this study and that can be identified with you will remain confidential and will be disclosed only with your permission or as required by law. Confidentiality will be maintained by means of assigning you a participant number after you sign a completed a health history questionnaire shortly after giving informed consent. The participant number will only be recorded on the Health History Questionnaire. All references to you will be made by your participant number. The principle investigator, faculty committee members, laboratory supervisor, and department chairperson will be the only individuals who will have access to the informed
consent, health history, and data collection sheets for this study. The informed consent, health history questionnaire, and data will be stored in the Athletic Training Research Laboratory for 10 years following participation in a locked cabinet with the signed documents and data being separated. All data, coded with participant numbers, will be stored on electronic media, paper, or both when possible. We intend to publish the results of this study, but we will publish only summary data and there will be no way for anyone to identify participants who participated in this study.

RIGHT TO REFUSE OR WITHDRAWAL:
You can choose whether or not to be in this study. If you volunteer to be in this study, you may withdraw at any time without consequences of any kind or loss of benefits to which you are otherwise entitled. You may also refuse to answer any questions you do not want to answer. There is no penalty if you withdraw from the study and you will not lose any benefits to which you are otherwise entitled.

The investigators may withdraw you from this research if circumstances arise which warrant doing so. Some of those circumstances have been previously mentioned.

Table C1. Continued.

QUESTIONS:
If you have any questions or concerns about your rights as a research participant related to this study or the study itself, now or in the future, please contact:

Principle Investigator Toshiro Hirano, LAT ATC 003H HPC University of Northern Iowa	Faculty Sponsor Jody Brucker, PhD, LAT, ATC 003E HPC University of Northern Iowa

Furthermore, this research is on record and has been reviewed by the University of Northern Iowa Institutional Review Board. Therefore, you may also contact the Institutional Review Board Administrator, Anita Gordon, by mail at Office of Sponsored Programs, 213 East Bartlet, University of Northern Iowa, Cedar Falls, Iowa, 50614-3094, by phone at (319) 273-6148, or by e-mail for answers to questions about rights of research participants and the participant review process.

STATEMENT OF AGREEMENT:
I am fully aware of the nature and extent of my participation in this project as stated above and the possible risks arising from it. I herby agree to participate in this project. I acknowledge that I have received a copy of this consent statement. I am 18 years of age or older.

______________________________ __________________
Signature of Participant Date

____
Printed Name of Participant

______________________________ __________________
Signature of Investigator Date

______________________________ __________________
Signature of Instructor/Advisor Date

Table C2. Health History Questionnaire

Please answer the following questions to the best of your knowledge. Please place a check in the appropriate box. All information from this questionnaire will be kept confidential.

1. Do you regularly exercise for at least 30 minutes 2 times a week?	Yes	No
2. Have you injured either one of your legs in the last 3 months?	Yes	No
3. Do you know or suspect having a blood clot disorder such as hemophilia?	Yes	No
4. Do you know of or suspect having any circulatory abnormalities?	Yes	No
5. Have you ever been rejected for giving blood?	Yes	No
6. Do you have, or suspect that you have, any form of blood borne disease (hepatitis, HIV, AIDS) or vascular disorder (problems with your veins or arteries)?	Yes	No
7. Do you know or suspect having a vascular disorder?	Yes	No
8. Are you presently under the care of a Physician, or on any prescription medication?	Yes	No
9. Do you know of or have any medical conditions that might aggravate you during the study?	Yes	No
10. Have you had allergic reaction to ice or any adverse reactions to the cold application?	Yes	No
11. Have you ever had an allergic reaction to adhesives, latex, antibiotic creams or disinfectants (chlorhexidine, rubbing alcohol, etc.)?	Yes	No
12. Do you experience numbness, tingling, or decreased sensation in extremities, or have other neurological problems, conditions, disorders, or diseases?	Yes	No

If you answered "YES", to any questions, EXCEPT #1, or you are unsure about any of your answers, you will be asked for more detail to help the investigator better assess whether your condition increases your risk for participation.

I certify that the information above is correct.

______________________________ __________________

Participant's signature Date

Table C3. Balanced Latin Square for Treatment Order for All Participants.

Participant #	Day 1	Day 2
1,3,5,7,9,11	Exercise	Rest
2,4,6,8,10,12	Rest	Exercise

Table C4. Data Collection Sheet.

Participant #:___________		
Skinfold (mm)	Right	Left
1		
2		
3		
Average (mm)		
½ Average		
Plus 20mm = *Target depth*		

Karvonen Formula:	
RHR	
220 – age = MHR	
MHR – RHR = HRR	
(HRR × 0.7) + RHR = *Target HR*	70% =
(HRR × 0.8) + RHR = *Target HR*	80% =

Baseline Temperature & Target Temperature

	Day 1	Day2
0:30		
1:00		
1:30		
2:00		
2:30		
3:00		
3:30		
4:00		
4:30		
5:00		
Ave.		
Target Temp.		

Exercise Intensity & Heart Rate		
10 min		
20 min		
30 min		

Key Times		
	Day 1	Day 2
Bike/Rest (30min) & total		
Ice - to target temp. & total		
Post app. (120min) & total		

NOTES:

Table C5. Wound Care Instructions

1. Keep your wound covered with the bandage for at least 2 hours after the end of the treatment session.

2. Clean the wound with soap and water twice a day until it is completely healed.

3. Apply a new bandage after you clean the area.

4. Contact the primary investigator if you experience unusual signs or symptoms (refer to the list below).

5. Report emergent problems to the UNI Student Health Clinic located on 1600 West 23rd Street by calling 319-273-2009 between 8:00 AM and 4:30 PM, or call 911 to activate Emergency Medical Services.

SIGNS AND SYMPTOMS OF INFECTION:

- Redness and pain over the wound site
- Red streaks up and or down your leg originating from the wound
- Gross swelling of the calf
- Swollen and or painful lumps in your groin, neck, or armpit regions
- Fever over 100°F

If you have any conditions above, contact primary investigator:
Toshiro Hirano 402-617-7311

If there is an emergency, call:
UNI Student Health Clinic 319-273-2009
EMS 911

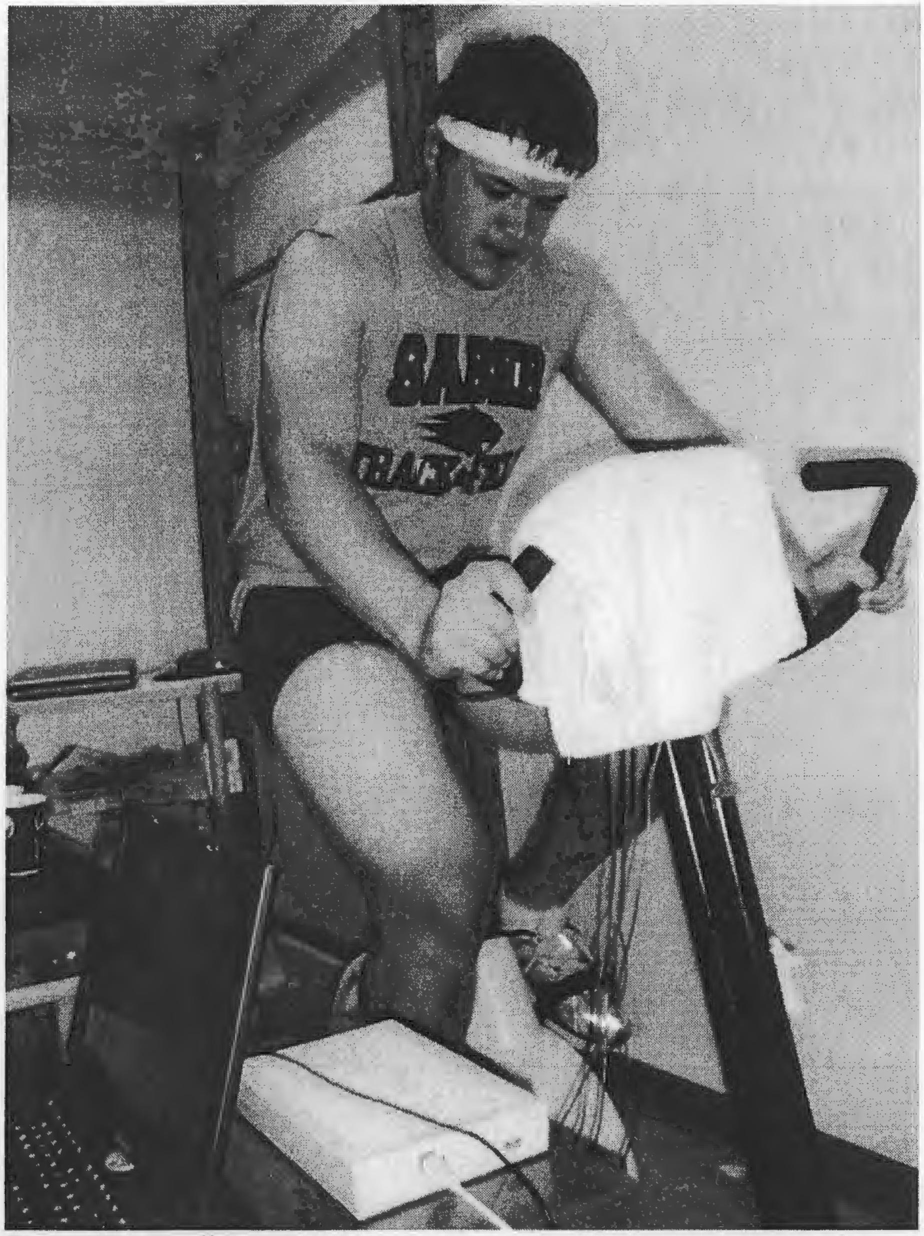

Figure C1. Cycling set-up.

APPENDIX D

ADDITIONAL RESULTS

Table D1. Interface Thermocouple Water Bath Testing Results.

Temp/ *time*	IFTC1	ABSdif	IFTC2	ABSdif	IFTC3	ABSdif	IFTC4	ABSdif	IFTC5	ABSdif	SiGT	Ave uncert
1°C												
0	1.12	0.12	1.11	0.11	1.08	0.08	1.09	0.09	1.11	0.11	1.0	
0.5	1.16	0.16	1.14	0.14	1.12	0.12	1.11	0.11	1.12	0.12	1.0	
1	1.15	0.15	1.15	0.15	1.11	0.11	1.11	0.11	1.11	0.11	1.0	
1.5	1.16	0.16	1.14	0.14	1.11	0.11	1.12	0.12	1.11	0.11	1.0	
2	1.16	0.16	1.14	0.14	1.11	0.11	1.12	0.12	1.11	0.11	1.0	
2.5	1.16	0.16	1.14	0.14	1.11	0.11	1.12	0.12	1.11	0.11	1.0	
3	1.16	0.16	1.13	0.13	1.11	0.11	1.12	0.12	1.11	0.11	1.0	
3.5	1.16	0.16	1.13	0.13	1.11	0.11	1.12	0.12	1.11	0.11	1.0	
4	1.16	0.16	1.13	0.13	1.11	0.11	1.12	0.12	1.11	0.11	1.0	
4.5	1.16	0.16	1.13	0.13	1.11	0.11	1.12	0.12	1.11	0.11	1.0	
5	1.16	0.16	1.13	0.13	1.11	0.11	1.12	0.12	1.11	0.11	1.0	
SD/*ave*	0.01216	*0.155455*	0.010269	*0.133636*	0.009816	*0.108182*	0.009342	*0.115455*	0.003015	*0.110909*		
uncert		0.16759		0.143905		0.117998		0.124797		0.113924		0.133643
10°C												
0	9.66	0.14	9.66	0.14	9.66	0.14	9.68	0.12	9.62	0.18	9.8	
0.5	9.65	0.15	9.65	0.15	9.65	0.15	9.67	0.13	9.64	0.16	9.8	
1	9.66	0.14	9.65	0.15	9.65	0.15	9.67	0.13	9.65	0.15	9.8	
1.5	9.67	0.13	9.65	0.15	9.65	0.15	9.67	0.13	9.65	0.15	9.8	
2	9.67	0.13	9.65	0.15	9.65	0.15	9.67	0.13	9.65	0.15	9.8	
2.5	9.67	0.13	9.65	0.15	9.64	0.16	9.66	0.14	9.65	0.15	9.8	
3	9.67	0.13	9.65	0.15	9.65	0.15	9.67	0.13	9.65	0.15	9.8	
3.5	9.68	0.12	9.65	0.15	9.64	0.16	9.66	0.14	9.65	0.15	9.8	
4	9.68	0.12	9.65	0.15	9.64	0.16	9.66	0.14	9.65	0.15	9.8	
4.5	9.68	0.12	9.65	0.15	9.64	0.16	9.66	0.14	9.65	0.15	9.8	
5	9.68	0.12	9.65	0.15	9.64	0.16	9.66	0.14	9.65	0.15	9.8	
SD/*ave*	0.01	*0.13*	0.003015	*0.149091*	0.006742	*0.153636*	0.006742	*0.133636*	0.009244	*0.153636*		
uncert		0.14		0.152106		0.160378		0.140378		0.162881		0.151149
20°C												
0	19.7	0.2	19.69	0.21	19.64	0.26	19.7	0.2	19.65	0.25	19.9	
0.5	19.69	0.21	19.69	0.21	19.63	0.27	19.7	0.2	19.65	0.25	19.9	
1	19.69	0.21	19.69	0.21	19.64	0.26	19.7	0.2	19.65	0.25	19.9	
1.5	19.69	0.21	19.69	0.21	19.64	0.26	19.7	0.2	19.65	0.25	19.9	
2	19.69	0.21	19.69	0.21	19.64	0.26	19.7	0.2	19.65	0.25	19.9	
2.5	19.69	0.21	19.69	0.21	19.64	0.26	19.69	0.21	19.65	0.25	19.9	
3	19.69	0.21	19.69	0.21	19.64	0.26	19.69	0.21	19.65	0.25	19.9	
3.5	19.69	0.21	19.69	0.21	19.64	0.26	19.69	0.21	19.65	0.25	19.9	
4	19.69	0.21	19.68	0.22	19.64	0.26	19.69	0.21	19.65	0.25	19.9	
4.5	19.69	0.21	19.68	0.22	19.64	0.26	19.68	0.22	19.65	0.25	19.9	
5	19.68	0.22	19.68	0.22	19.64	0.26	19.68	0.22	19.65	0.25	19.9	
SD/*ave*	0.004472	*0.21*	0.004671	*0.212727*	0.003015	*0.260909*	0.007862	*0.207273*	3.73E-15	*0.25*		
uncert		0.214472		0.217398		0.263924		0.215135		0.25		0.232186
30°C												
0	29.53	0.17	29.53	0.17	29.5	0.2	29.52	0.18	29.52	0.18	29.7	
0.5	29.54	0.16	29.53	0.17	29.5	0.2	29.52	0.18	29.52	0.18	29.7	
1	29.54	0.16	29.53	0.17	29.5	0.2	29.52	0.18	29.52	0.18	29.7	
1.5	29.54	0.16	29.52	0.18	29.5	0.2	29.51	0.19	29.52	0.18	29.7	
2	29.54	0.16	29.52	0.18	29.5	0.2	29.51	0.19	29.52	0.18	29.7	
2.5	29.54	0.16	29.51	0.19	29.5	0.2	29.51	0.19	29.52	0.18	29.7	
3	29.54	0.16	29.52	0.18	29.5	0.2	29.51	0.19	29.52	0.18	29.7	
3.5	29.54	0.16	29.52	0.18	29.5	0.2	29.52	0.18	29.52	0.18	29.7	
4	29.55	0.15	29.52	0.18	29.5	0.2	29.52	0.18	29.52	0.18	29.7	

Table D1. continued.

4.5	29.55	0.15	29.52	0.18	29.5	0.2	29.52	0.18	29.52	0.18	29.7	
5	29.55	0.15	29.52	0.18	29.5	0.2	29.52	0.18	29.52	0.18	29.7	
SD/*ave*	0.00603	*0.158182*	0.00603	*0.178182*	0	*0.2*	0.005045	*0.183636*	3.73E-15	*0.18*		
uncert		0.164212		0.184212		0.2		0.188682		0.18		0.183421
40°C												
0	39.49	0.09	39.51	0.11	39.47	0.07	39.52	0.12	39.48	0.08	39.4	
0.5	39.49	0.09	39.5	0.1	39.47	0.07	39.5	0.1	39.48	0.08	39.4	
1	39.48	0.08	39.49	0.09	39.46	0.06	39.49	0.09	39.48	0.08	39.4	
1.5	39.48	0.08	39.5	0.1	39.46	0.06	39.49	0.09	39.47	0.07	39.4	
2	39.49	0.09	39.5	0.1	39.45	0.05	39.5	0.1	39.47	0.07	39.4	
2.5	39.49	0.09	39.49	0.09	39.45	0.05	39.5	0.1	39.47	0.07	39.4	
3	39.49	0.09	39.49	0.09	39.45	0.05	39.49	0.09	39.47	0.07	39.4	
3.5	39.49	0.09	39.49	0.09	39.45	0.05	39.49	0.09	39.47	0.07	39.4	
4	39.49	0.09	39.48	0.08	39.45	0.05	39.49	0.09	39.47	0.07	39.4	
4.5	39.49	0.09	39.48	0.08	39.45	0.05	39.49	0.09	39.47	0.07	39.4	
5	39.49	0.09	39.48	0.08	39.44	0.04	39.49	0.09	39.47	0.07	39.4	
SD/*ave*	0.004045	*0.088182*	0.009816	*0.091818*	0.009342	*0.054545*	0.009342	*0.095455*	0.004671	*0.072727*		
uncert		0.092227		0.101635		0.063887		0.104797		0.077398		0.087989
Ave uncert		0.1557		0.159851		0.161238		0.154758		0.156841		**0.157677**

SiGT = Spirit in Glass Thermometer
IFTC = Interface Thermocouple (°C)
SD = Standard deviation of IFTC temps
ABSdif = Absolute difference from SiG Temperature at same Time
ave = Average of ABSdif
uncert = Uncertainty is SD + ave (°C)

Table D2. Intramuscular Thermocouple Water Bath Testing Results.

Temp/ *time*	IMTC1	ABSdif	IMTC2	ABSdif	IMTC3	ABSdif	IMTC4	ABSdif	IMTC5	ABSdif	SiGT	Ave uncert
1°C												
0	1.12	0.12	1.08	0.08	1.03	0.03	1.08	0.08	1.08	0.08	1	
0.5	1.11	0.11	1.08	0.08	1.04	0.04	1.08	0.08	1.08	0.08	1	
1	1.11	0.11	1.07	0.07	1.03	0.03	1.08	0.08	1.08	0.08	1	
1.5	1.11	0.11	1.07	0.07	1.03	0.03	1.08	0.08	1.08	0.08	1	
2	1.11	0.11	1.07	0.07	1.03	0.03	1.08	0.08	1.08	0.08	1	
2.5	1.11	0.11	1.07	0.07	1.03	0.03	1.08	0.08	1.07	0.07	1	
3	1.1	0.1	1.06	0.06	1.03	0.03	1.07	0.07	1.07	0.07	1	
3.5	1.1	0.1	1.06	0.06	1.03	0.03	1.07	0.07	1.07	0.07	1	
4	1.1	0.1	1.06	0.06	1.03	0.03	1.07	0.07	1.07	0.07	1	
4.5	1.1	0.1	1.06	0.06	1.03	0.03	1.07	0.07	1.07	0.07	1	
5	1.1	0.1	1.05	0.05	1.03	0.03	1.07	0.07	1.07	0.07	1	
SD/*ave*	0.006742	*0.106364*	0.009244	*0.066364*	0.003015	*0.030909*	0.005222	*0.075455*	0.005222	*0.074545*		
uncert		0.113106		0.075608		0.033924		0.080677		0.079768		0.076616
10°C												
0	9.64	0.06	9.62	0.08	9.61	0.09	9.62	0.08	9.62	0.08	9.7	
0.5	9.64	0.06	9.62	0.08	9.6	0.1	9.62	0.08	9.63	0.07	9.7	
1	9.65	0.05	9.62	0.08	9.6	0.1	9.62	0.08	9.63	0.07	9.7	
1.5	9.65	0.05	9.62	0.08	9.61	0.09	9.62	0.08	9.63	0.07	9.7	
2	9.65	0.05	9.62	0.08	9.6	0.1	9.62	0.08	9.63	0.07	9.7	
2.5	9.65	0.05	9.62	0.08	9.6	0.1	9.62	0.08	9.62	0.08	9.7	
3	9.65	0.05	9.62	0.08	9.6	0.1	9.62	0.08	9.62	0.08	9.7	
3.5	9.65	0.05	9.62	0.08	9.6	0.1	9.62	0.08	9.63	0.07	9.7	
4	9.65	0.05	9.62	0.08	9.6	0.1	9.62	0.08	9.62	0.08	9.7	
4.5	9.65	0.05	9.62	0.08	9.6	0.1	9.62	0.08	9.62	0.08	9.7	
5	9.65	0.05	9.61	0.09	9.59	0.11	9.61	0.09	9.62	0.08	9.7	
SD/*ave*	0.004045	*0.051818*	0.003015	*0.080909*	0.005394	*0.099091*	0.003015	*0.080909*	0.005222	*0.075455*		
uncert		0.055863		0.083924		0.104485		0.083924		0.080677		0.081775
20°C												
0	19.64	0.26	19.61	0.29	19.61	0.29	19.6	0.3	19.61	0.29	19.9	
0.5	19.65	0.25	19.61	0.29	19.61	0.29	19.6	0.3	19.61	0.29	19.9	
1	19.65	0.25	19.61	0.29	19.6	0.3	19.61	0.29	19.62	0.28	19.9	
1.5	19.65	0.25	19.62	0.28	19.6	0.3	19.61	0.29	19.62	0.28	19.9	
2	19.65	0.25	19.62	0.28	19.6	0.3	19.61	0.29	19.62	0.28	19.9	
2.5	19.65	0.25	19.62	0.28	19.61	0.29	19.61	0.29	19.62	0.28	19.9	
3	19.65	0.25	19.62	0.28	19.61	0.29	19.61	0.29	19.62	0.28	19.9	
3.5	19.65	0.25	19.62	0.28	19.61	0.29	19.61	0.29	19.62	0.28	19.9	
4	19.65	0.25	19.62	0.28	19.61	0.29	19.62	0.28	19.62	0.28	19.9	
4.5	19.65	0.25	19.62	0.28	19.61	0.29	19.62	0.28	19.62	0.28	19.9	
5	19.65	0.25	19.62	0.28	19.61	0.29	19.62	0.28	19.63	0.27	19.9	
SD/*ave*	0.003015	*0.250909*	0.004671	*0.282727*	0.004671	*0.292727*	0.007006	*0.289091*	0.005394	*0.280909*		
uncert		0.253924		0.287398		0.297398		0.296097		0.286303		0.284224
30°C												
0	29.57	0.13	29.54	0.16	29.53	0.17	29.53	0.17	29.54	0.16	29.7	
0.5	29.56	0.14	29.54	0.16	29.52	0.18	29.52	0.18	29.53	0.17	29.7	
1	29.56	0.14	29.54	0.16	29.52	0.18	29.52	0.18	29.53	0.17	29.7	
1.5	29.56	0.14	29.54	0.16	29.52	0.18	29.53	0.17	29.54	0.16	29.7	
2	29.56	0.14	29.54	0.16	29.52	0.18	29.53	0.17	29.54	0.16	29.7	
2.5	29.57	0.13	29.54	0.16	29.52	0.18	29.53	0.17	29.54	0.16	29.7	
3	29.57	0.13	29.55	0.15	29.52	0.18	29.53	0.17	29.54	0.16	29.7	
3.5	29.57	0.13	29.54	0.16	29.52	0.18	29.53	0.17	29.54	0.16	29.7	
4	29.56	0.14	29.54	0.16	29.52	0.18	29.53	0.17	29.54	0.16	29.7	

Table D2. continued.

4.5	29.56	0.14	29.54	0.16	29.52	0.18	29.53	0.17	29.54	0.16	29.7	
5	29.56	0.14	29.54	0.16	29.52	0.18	29.53	0.17	29.54	0.16	29.7	
SD/*ave*	0.005045	*0.136364*	0.003015	*0.159091*	0.003015	*0.179091*	0.004045	*0.171818*	0.004045	*0.161818*		
uncert		0.141409		0.162106		0.182106		0.175863		0.165863		0.16547
40°C												
0	39.51	0.21	39.51	0.21	39.46	0.16	39.48	0.18	39.51	0.21	39.3	
0.5	39.51	0.21	39.51	0.21	39.46	0.16	39.48	0.18	39.49	0.19	39.3	
1	39.52	0.22	39.51	0.21	39.47	0.17	39.48	0.18	39.49	0.19	39.3	
1.5	39.52	0.22	39.5	0.2	39.47	0.17	39.48	0.18	39.49	0.19	39.3	
2	39.52	0.22	39.5	0.2	39.47	0.17	39.48	0.18	39.48	0.18	39.3	
2.5	39.52	0.22	39.5	0.2	39.47	0.17	39.48	0.18	39.48	0.18	39.3	
3	39.52	0.22	39.5	0.2	39.47	0.17	39.48	0.18	39.48	0.18	39.3	
3.5	39.52	0.22	39.5	0.2	39.47	0.17	39.47	0.17	39.48	0.18	39.3	
4	39.52	0.22	39.5	0.2	39.47	0.17	39.47	0.17	39.48	0.18	39.3	
4.5	39.52	0.22	39.5	0.2	39.47	0.17	39.47	0.17	39.48	0.18	39.3	
5	39.52	0.22	39.5	0.2	39.47	0.17	39.47	0.17	39.47	0.17	39.3	
SD/*ave*	0.004045	*0.218182*	0.004671	*0.202727*	0.004045	*0.168182*	0.005045	*0.176364*	0.010357	*0.184545*		
uncert		0.222227		0.207398		0.172227		0.181409		0.194903		0.195633
Ave												
uncert		0.157306		0.163287		0.158028		0.163594		0.161503		**0.160744**

SiGT = Spirit in Glass Thermometer
IMTC = Interface Thermocouple (°C)
SD = Standard deviation of IFTC temps
ABSdif = Absolute difference from SiG Temperature at same Time
ave = Average of ABSdif
uncert = Uncertainty is SD + ave (°C)

Table D3. Participant Demographics.

Part#	Age (yrs)	Ht(cm)	Mass(kg)	Skinfold (mm)
1	23	168	93	26.7
2	20	178	80	20.3
3	21	186	86	28.7
4	23	178	82	29.1
5	22	175	76	21.2
6	20	186	81	27.0
7	26	200	110	21.5
8	22	192	91	20.3
9	22	186	83	22.2
10	22	180	80	23.0
11	20	192	112	21.7
12	21	178	75	21.0
Mean	21.8	183.3	87.4	23.6
SD	1.7	8.8	12.2	3.3

Table D4. Participant Baseline Temperatures (°C) and Time (min) to 10°C Below Baseline by Condition.

	Base Temp (°C)		Time to 10°C (min)	
Part #	Rest	Bike	Rest	Bike
1	36.2	36.3	123.5	36
2	36.9	36.5	51	32
3	36.9	37.2	97	33
4	36.1	36.2	103.5	16
5	36.5	36.1	36.5	30.5
6	36.6	36.5	117	43.5
7	36.6	36.8	51	20.5
8	36.5	36.4	52.5	16.5
9	36.6	36.1	68.5	52.5
10	36.2	36.1	80.5	43.5
11	35.9	36.4	61.5	33
12	37.1	36	38.5	10
Ave	36.5	36.4	73.4	30.6

Table D5. Interface No-Ice Temperatures (°C) by Time (min), Conditions, and Condition Differences. (n=12, mean ± SE)

Time	Bike	Rest	Δ
Imd	33.1 ± 0.4	31.7 ± 0.5	1.4
10	32.8 ± 0.3	31.6 ± 0.5	1.2
20	32.5 ± 0.3	31.5 ± 0.5	1.0
30	32.3 ± 0.3	31.4 ± 0.5	.9
40	32.2 ± 0.4	31.4 ± 0.5	.8
50	32.2 ± 0.4	31.3 ± 0.5	.9
60	32.0 ± 0.4	31.3 ± 0.5	.7
70	32.0 ± 0.4	31.2 ± 0.5	.8
80	31.8 ± 0.3	31.2 ± 0.5	.6
90	31.7 ± 0.3	31.2 ± 0.5	.5
100	31.6 ± 0.3	31.2 ± 0.5	.4
110	31.5 ± 0.3	31.2 ± 0.5	.3
120	31.3 ± 0.3	31.2 ± 0.5	.1

Table D6. Intramuscular No-Ice Temperatures (°C) by Time (min), Conditions, and Condition Differences. (n=12, mean ± SE)

Time	Bike	Rest	Δ
Imd	36.8 ± 0.1	35.6 ± 0.2	1.2
10	36.5 ± 0.1	35.5 ± 0.2	1.0
20	36.3 ± 0.1	35.5 ± 0.2	.8
30	36.2 ± 0.2	35.4 ± 0.3	.8
40	36.0 ± 0.2	35.4 ± 0.3	.6
50	36.0 ± 0.2	35.3 ± 0.3	.7
60	35.9 ± 0.2	35.1 ± 0.3	.8
70	35.8 ± 0.2	35.1 ± 0.3	.7
80	35.7 ± 0.2	35.0 ± 0.3	.7
90	35.6 ± 0.2	35.0 ± 0.3	.6
100	35.5 ± 0.2	35.0 ± 0.3	.5
110	35.4 ± 0.2	34.9 ± 0.4	.5
120	35.3 ± 0.2	34.9 ± 0.1	.4

Table D7. F-Statistic Results for Exercise Condition and Time on IF Rewarming Temperatures.

Source Term	DF	Sum of Squares	Mean Square	F-Ratio	Prob Level	Power (Alpha=0.05)
A: Subj	11	357.6601	32.51455			
B: Cond	1	428.8536	428.8536	18.31	0.001302*	0.972710
AB	11	257.6843	23.42585			
C: Time	12	12469.34	1039.112	837.55	0.000000*	1.000000
AC	132	163.7667	1.240657			
BC	12	47.22609	3.935507	4.78	0.000002*	0.999867
ABC	132	108.6432	0.8230547			
S	0					
Total (Adj)	311	13833.18				
Total	312					

* Term significant at alpha = 0.05

Table D8. F-Statistic Results for Time on Bike-Ice Condition on IF Rewarming Temperatures.

Source Term	DF	Sum of Squares	Mean Square	F-Ratio	Prob Level	Power (Alpha=0.05)
A: Subj	11	424.1151	38.55592			
B: Time	12	5987.192	498.9327	513.00	0.000000*	1.000000
AB	132	128.3815	0.9725874			
S	0					
Total (Adj)	155	6539.689				
Total	156					

* Term significant at alpha = 0.05

Table D9. Tukey-Kramer Multiple Comparison Test for Time on Bike-Ice Condition on IF Temperatures.

Time	Count	Mean	Different From Groups
0	12	5.2	10, 20, 30, 40, 50, 60, 70, 80, 90, 100, 110, 120
10	12	21.4	0, 20, 30, 40, 50, 60, 70, 80, 90, 100, 110, 120
20	12	23.9	0, 10, 30, 40, 50, 60, 70, 80, 90, 100, 110, 120
30	12	25.2	0, 10, 20, 50, 60, 70, 80, 90, 100, 110, 120
40	12	26.2	0, 10, 20, 70, 80, 90, 100, 110, 120
50	12	26.8	0, 10, 20, 30, 80, 90, 100, 110, 120
60	12	27.4	0, 10, 20, 30, 100, 110, 120
70	12	27.9	0, 10, 20, 30, 40, 120
80	12	28.3	0, 10, 20, 30, 40, 50
90	12	28.6	0, 10, 20, 30, 40, 50
100	12	28.9	0, 10, 20, 30, 40, 50, 60
110	12	29.1	0, 10, 20, 30, 40, 50, 60
120	12	29.4	0, 10, 20, 30, 40, 50, 60, 70

Alpha=0.050 Error Term=AB DF=132 MSE=0.9725874 Critical Value=4.7722

Table D10. F-Statistic Results for Time on Rest-Ice Condition on IF Rewarming Temperatures.

Source Term	DF	Sum of Squares	Mean Square	F-Ratio	Prob Level	Power (Alpha=0.05)
A: Subj	11	191.2293	17.38448			
B: Time	12	6529.378	544.1148	498.67	0.000000*	1.000000
AB	132	144.0284	1.091124			
S	0					
Total (Adj)	155	6864.635				
Total	156					

* Term significant at alpha = 0.05

Table D11. Tukey-Kramer Multiple Comparison Test for Time on Rest-Ice Condition on IF Rewarming Temperatures.

Time	Count	Mean	Different From Groups
0	12	3.0	10, 20, 30, 40, 50, 60, 70, 80, 90, 100, 110, 120
10	12	17.1	0, 20, 30, 40, 50, 60, 70, 80, 90, 100, 110, 120
20	12	20.7	0, 10, 30, 40, 50, 60, 70, 80, 90, 100, 110, 120
30	12	22.4	0, 10, 20, 50, 60, 70, 80, 90, 100, 110, 120
40	12	23.4	0, 10, 20, 60, 70, 80, 90, 100, 110, 120
50	12	24.2	0, 10, 20, 30, 80, 90, 100, 110, 120
60	12	25.0	0, 10, 20, 30, 40, 90, 100, 110, 120
70	12	25.6	0, 10, 20, 30, 40, 100, 110, 120
80	12	26.2	0, 10, 20, 30, 40, 50, 110, 120
90	12	26.8	0, 10, 20, 30, 40, 50, 60
100	12	27.3	0, 10, 20, 30, 40, 50, 60, 70
110	12	27.8	0, 10, 20, 30, 40, 50, 60, 70, 80
120	12	28.2	0, 10, 20, 30, 40, 50, 60, 70, 80

Alpha=0.050 Error Term=AB DF=132 MSE=1.091124 Critical Value=4.7722

Table D12. F-Statistic Results for Exercise Condition on IF Rewarming Imd Time Temperatures.

Source Term	DF	Sum of Squares	Mean Square	F-Ratio	Prob Level	Power (Alpha=0.05)
A: Subj	11	53.46655	4.860595			
B: Cond	1	29.062	29.062	16.44	0.001900*	0.957377
AB	11	19.44505	1.767731			
S	0					
Total (Adj)	23	101.9736				
Total	24					

* Term significant at alpha = 0.05

Table D13. Tukey-Kramer's Simultaneous CIs for MCs of All Pairs for Exercise Condition on IF Rewarming Imd Time Temperatures.

Comparison Groups	Count	Mean	Lower 95.0% Simult.C.I.	Mean Difference	Upper 95.0% Simult.C.I.	Test Result
bike	12	5.2				
- rest	12	3.0	1.0	2.2	3.4	U
rest	12	3.0				
- bike	12	5.2	-3.4	-2.2	-1.0	L

Alpha=0.050 Error Term=AB DF=11 MSE=1.767731 Critical Value=3.1127

Table D14. F-Statistic Results for Exercise Condition on IF Rewarming 10-min Time Temperatures.

Source Term	DF	Sum of Squares	Mean Square	F-Ratio	Prob Level	Power (Alpha=0.05)
A: Subj	11	119.2646	10.84223			
B: Cond	1	106.2604	106.2604	14.82	0.002699*	0.937863
AB	11	78.85458	7.168599			
S	0					
Total (Adj)	23	304.3796				
Total	24					

* Term significant at alpha = 0.05

Table D15. Tukey-Kramer's Simultaneous CIs for MCs of All Pairs for Exercise Condition on IF Rewarming 10-min Time Temperatures.

Comparison Groups	Count	Mean	Lower 95.0% Simult.C.I.	Mean Difference	Upper 95.0% Simult.C.I.	Test Result
bike	12	21.4				
- rest	12	17.1	1.8	4.2	6.6	U
rest	12	17.1				
- bike	12	21.4	-6.6	-4.2	-1.8	L

Alpha=0.050 Error Term=AB DF=11 MSE=7.168599 Critical Value=3.1127

Table D16. F-Statistic Results for Exercise Condition on IF Rewarming 20-min Time Temperatures.

Source Term	DF	Sum of Squares	Mean Square	F-Ratio	Prob Level	Power (Alpha=0.05)
A: Subj	11	53.18833	4.835303			
B: Cond	1	58.28167	58.28167	11.98	0.005326*	0.882297
AB	11	53.52833	4.866212			
S	0					
Total (Adj)	23	164.9983				
Total	24					

* Term significant at alpha = 0.05

Table D17. Tukey-Kramer's Simultaneous CIs for MCs of All Pairs for Exercise Condition on IF Rewarming 20-min Time Temperatures.

Comparison Groups	Count	Mean	Lower 95.0% Simult.C.I.	Mean Difference	Upper 95.0% Simult.C.I.	Test Result
bike	12	23.9				
- rest	12	20.7	1.1	3.1	5.1	U
rest	12	20.7				
- bike	12	23.9	-5.1	-3.1	-1.1	L

Alpha=0.050 Error Term=AB DF=11 MSE=4.866212 Critical Value=3.1127

Table D18 F-Statistic Results for Exercise Condition on IF Rewarming 30-min Time Temperatures.

Source Term	DF	Sum of Squares	Mean Square	F-Ratio	Prob Level	Power (Alpha=0.05)
A: Subj	11	36.34018	3.303653			
B: Cond	1	49.24935	49.24935	14.56	0.002862*	0.934034
AB	11	37.20085	3.381896			
S	0					
Total (Adj)	23	122.7904				
Total	24					

* Term significant at alpha = 0.05

Table D19. Tukey-Kramer's Simultaneous CIs for MCs of All Pairs for Exercise Condition on IF Rewarming 30-min Time Temperatures.

Comparison Groups	Count	Mean	Lower 95.0% Simult.C.I.	Mean Difference	Upper 95.0% Simult.C.I.	Test Result
bike	12	25.2				
- rest	12	22.4	1.2	2.9	4.5	U
rest	12	22.4				
- bike	12	25.2	-4.5	-2.9	-1.2	L

Alpha=0.050 Error Term=AB DF=11 MSE=3.381896 Critical Value=3.1127

Table D20. F-Statistic Results for Exercise Condition on IF Rewarming 40-min Time Temperatures.

Source Term	DF	Sum of Squares	Mean Square	F-Ratio	Prob Level	Power (Alpha=0.05)
A: Subj	11	29.81833	2.710757			
B: Cond	1	45.375	45.375	19.85	0.000970*	0.981270
AB	11	25.145	2.285909			
S	0					
Total (Adj)	23	100.3383				
Total	24					

* Term significant at alpha = 0.05

Table D21. Tukey-Kramer's Simultaneous CIs for MCs of All Pairs for Exercise Condition on IF Rewarming 40-min Time Temperatures.

Comparison Groups	Count	Mean	Lower 95.0% Simult.C.I.	Mean Difference	Upper 95.0% Simult.C.I.	Test Result
bike	12	26.2				
- rest	12	23.4	1.4	2.8	4.1	U
rest	12	23.4				
- bike	12	26.2	-4.1	-2.8	-1.4	L

Alpha=0.050 Error Term=AB DF=11 MSE=2.285909 Critical Value=3.1127

Table D22. F-Statistic Results for Exercise Condition on IF Rewarming 50-min Time Temperatures.

Source Term	DF	Sum of Squares	Mean Square	F-Ratio	Prob Level	Power (Alpha=0.05)
A: Subj	11	26.22125	2.38375			
B: Cond	1	40.30042	40.30042	23.29	0.000531*	0.992085
AB	11	19.03458	1.730417			
S	0					
Total (Adj)	23	85.55625				
Total	24					

* Term significant at alpha = 0.05

Table D23. Tukey-Kramer's Simultaneous CIs for MCs of All Pairs for Exercise Condition on IF Rewarming 50-min Time Temperatures.

Comparison Groups	Count	Mean	Lower 95.0% Simult.C.I.	Mean Difference	Upper 95.0% Simult.C.I.	Test Result
bike	12	26.8				
- rest	12	24.2	1.4	2.6	3.8	U
rest	12	24.2				
- bike	12	26.8	-3.8	-2.6	-1.4	L

Alpha=0.050 Error Term=AB DF=11 MSE=1.730417 Critical Value=3.1127

Table D24. F-Statistic Results for Exercise Condition on IF Rewarming 60-min Time Temperatures.

Source Term	DF	Sum of Squares	Mean Square	F-Ratio	Prob Level	Power (Alpha=0.05)
A: Subj	11	25.02458	2.274962			
B: Cond	1	35.77042	35.77042	25.46	0.000375*	0.995467
AB	11	15.45458	1.404962			
S	0					
Total (Adj)	23	76.24958				
Total	24					

* Term significant at alpha = 0.05

Table D25. Tukey-Kramer's Simultaneous CIs for MCs of All Pairs or Exercise Condition on IF Rewarming 60-min Time Temperatures.

Comparison Groups	Count	Mean	Lower 95.0% Simult.C.I.	Mean Difference	Upper 95.0% Simult.C.I.	Test Result
bike	12	27.4				
- rest	12	25.0	1.4	2.4	3.5	U
rest	12	25.0				
- bike	12	27.4	-3.5	-2.4	-1.4	L

Alpha=0.050 Error Term=AB DF=11 MSE=1.404962 Critical Value=3.1127

Table D26. F-Statistic Results for Exercise Condition on IF Rewarming 70-min Time Temperatures.

Source Term	DF	Sum of Squares	Mean Square	F-Ratio	Prob Level	Power (Alpha=0.05)
A: Subj	11	23.17458	2.10678			
B: Cond	1	31.97042	31.97042	23.13	0.000545*	0.991756
AB	11	15.20458	1.382235			
S	0					
Total (Adj)	23	70.34959				
Total	24					

* Term significant at alpha = 0.05

Table D27. Tukey-Kramer's Simultaneous CIs for MCs of All Pairs for Exercise Condition on IF Rewarming 70-min Time Temperatures.

Comparison Groups	Count	Mean	Lower 95.0% Simult.C.I.	Mean Difference	Upper 95.0% Simult.C.I.	Test Result
bike	12	27.9				
- rest	12	25.6	1.3	2.3	3.4	U
rest	12	25.6				
- bike	12	27.9	-3.4	-2.3	-1.3	L

Alpha=0.050 Error Term=AB DF=11 MSE=1.382235 Critical Value=3.1127

Table D28. F-Statistic Results for Exercise Condition on IF Rewarming 80-min Time Temperatures.

Source Term	DF	Sum of Squares	Mean Square	F-Ratio	Prob Level	Power (Alpha=0.05)
A: Subj	11	24.51458	2.228599			
B: Cond	1	26.25042	26.25042	16.15	0.002019*	0.954411
AB	11	17.87458	1.624962			
S	0					
Total (Adj)	23	68.63958				
Total	24					

* Term significant at alpha = 0.05

Table D29. Tukey-Kramer's Simultaneous CIs for MCs of All Pairs for Exercise Condition on IF Rewarming 80-min Time Temperatures.

Comparison Groups	Count	Mean	Lower 95.0% Simult.C.I.	Mean Difference	Upper 95.0% Simult.C.I.	Test Result
bike	12	28.3				
- rest	12	26.2	0.9	2.1	3.2	U
rest	12	26.2				
- bike	12	28.3	-3.2	-2.1	-0.9	L

Alpha=0.050 Error Term=AB DF=11 MSE=1.624962 Critical Value=3.1127

Table D30. F-Statistic Results for Exercise Condition on IF Rewarming 90-min Time Temperatures.

Source Term	DF	Sum of Squares	Mean Square	F-Ratio	Prob Level	Power (Alpha=0.05)
A: Subj	11	26.20458	2.382235			
B: Cond	1	19.26042	19.26042	10.24	0.008448*	0.829393
AB	11	20.68458	1.880417			
S	0					
Total (Adj)	23	66.14958				
Total	24					

* Term significant at alpha = 0.05

Table D31. Tukey-Kramer's Simultaneous CIs for MCs of All Pairs for Exercise Condition on IF Rewarming 90-min Time Temperatures.

Comparison Groups	Count	Mean	Lower 95.0% Simult.C.I.	Mean Difference	Upper 95.0% Simult.C.I.	Test Result
bike	12	28.6				
- rest	12	26.8	0.6	1.8	3.0	U
rest	12	26.8				
- bike	12	28.6	-3.0	-1.8	-0.6	L

Alpha=0.050 Error Term=AB DF=11 MSE=1.880417 Critical Value=3.1127

Table D32. F-Statistic Results for Exercise Condition on IF Rewarming 100-min Time Temperatures.

Source Term	DF	Sum of Squares	Mean Square	F-Ratio	Prob Level	Power (Alpha=0.05)
A: Subj	11	29.64125	2.694659			
B: Cond	1	14.88375	14.88375	7.41	0.019870*	0.698220
AB	11	22.10125	2.009205			
S	0					
Total (Adj)	23	66.62625				
Total	24					

* Term significant at alpha = 0.05

Table D33. Tukey-Kramer's Simultaneous CIs for MCs of All Pairs for Exercise Condition on IF Rewarming 100-min Time Temperatures.

Comparison Groups	Count	Mean	Lower 95.0% Simult.C.I.	Mean Difference	Upper 95.0% Simult.C.I.	Test Result
bike	12	28.9				
- rest	12	27.3	0.3	1.6	2.8	U
rest	12	27.3				
- bike	12	28.9	-2.8	-1.6	-0.3	L

Alpha=0.050 Error Term=AB DF=11 MSE=2.009205 Critical Value=3.1127

Table D34. F-Statistic Results for Exercise Condition on IF Rewarming 110-min Time Temperatures.

Source Term	DF	Sum of Squares	Mean Square	F-Ratio	Prob Level	Power (Alpha=0.05)
A: Subj	11	34.53458	3.139508			
B: Cond	1	10.53375	10.53375	5.32	0.041479*	0.557353
AB	11	21.76125	1.978295			
S	0					
Total (Adj)	23	66.82958				
Total	24					

* Term significant at alpha = 0.05

Table D35. Tukey-Kramer's Simultaneous CIs for MCs of All Pairs for Exercise Condition on IF Rewarming 110-min Time Temperatures.

Comparison Groups	Count	Mean	Lower 95.0% Simult.C.I.	Mean Difference	Upper 95.0% Simult.C.I.	Test Result
bike	12	29.1				
- rest	12	27.8	0.1	1.3	2.6	U
rest	12	27.8				
- bike	12	29.1	-2.6	-1.3	-0.1	L

Alpha=0.050 Error Term=AB DF=11 MSE=1.978295 Critical Value=3.1127

Table D36. F-Statistic Results for Exercise Condition on IF Rewarming 120-min Time Temperatures.

Source Term	DF	Sum of Squares	Mean Square	F-Ratio	Prob Level	Power (Alpha=0.05)
A: Subj	11	40.03333	3.639394			
B: Cond	1	8.881667	8.881667	4.88	0.049385*	0.521577
AB	11	20.03833	1.821667			
S	0					
Total (Adj)	23	68.95333				
Total	24					

* Term significant at alpha = 0.05

Table D37. Tukey-Kramer's Simultaneous CIs for MCs of All Pairs for Exercise Condition on IF Rewarming 120-min Time Temperatures.

Comparison Groups	Count	Mean	Lower 95.0% Simult.C.I.	Mean Difference	Upper 95.0% Simult.C.I.	Test Result
bike	12	29.4				
- rest	12	28.2	0.0	1.2	2.4	U
rest	12	28.2				
- bike	12	29.4	-2.4	-1.2	0.0	L

Alpha=0.050 Error Term=AB DF=11 MSE=1.821667 Critical Value=3.1127

Table D38. F-Statistic Results for Exercise Condition and Time on IM Rewarming Temperatures.

Source Term	DF	Sum of Squares	Mean Square	F-Ratio	Prob Level	Power (Alpha=0.05)
A: Subj	11	96.61612	8.783283			
B: Cond	1	156.9811	156.9811	12.61	0.004543*	0.897598
AB	11	136.9324	12.4484			
C: Time	12	1365.495	113.7913	178.91	0.000000*	1.000000
AC	132	83.95601	0.6360304			
BC	12	37.78961	3.149134	13.81	0.000000*	1.000000
ABC	132	30.10889	0.2280977			
S	0					
Total (Adj)	311	1907.879				
Total	312					

* Term significant at alpha = 0.05

Table D39. F-Statistic Results for Time on Bike-Ice Condition on IM Rewarming Temperatures.

Source Term	DF	Sum of Squares	Mean Square	F-Ratio	Prob Level	Power (Alpha=0.05)
A: Subj	11	80.47031	7.315483			
B: Time	12	733.947	61.16225	153.38	0.000000*	1.000000
AB	132	52.63644	0.3987609			
S	0					
Total (Adj)	155	867.0538				
Total	156					

* Term significant at alpha = 0.05

Table D40. Tukey-Kramer Multiple Comparison Test for Time on Bike-Ice Condition on IM Temperatures.

Time	Count	Mean	Different From Groups
0	12	26.1	20, 30, 40, 50, 60, 70, 80, 90, 100, 110, 120
10	12	25.9	20, 30, 40, 50, 60, 70, 80, 90, 100, 110, 120
20	12	27.1	10, 0, 30, 40, 50, 60, 70, 80, 90, 100, 110, 120
30	12	28.1	10, 0, 20, 50, 60, 70, 80, 90, 100, 110, 120
40	12	28.9	10, 0, 20, 60, 70, 80, 90, 100, 110, 120
50	12	29.6	10, 0, 20, 30, 70, 80, 90, 100, 110, 120
60	12	30.1	10, 0, 20, 30, 40, 80, 90, 100, 110, 120
70	12	30.6	10, 0, 20, 30, 40, 50, 100, 110, 120
80	12	31.1	10, 0, 20, 30, 40, 50, 60, 110, 120
90	12	31.4	10, 0, 20, 30, 40, 50, 60, 120
100	12	31.8	10, 0, 20, 30, 40, 50, 60, 70
110	12	32.2	10, 0, 20, 30, 40, 50, 60, 70, 80
120	12	32.5	10, 0, 20, 30, 40, 50, 60, 70, 80, 90

Alpha=0.050 Error Term=AB DF=132 MSE=0.3987609 Critical Value=4.7722

Table D41. F-Statistic Results for Time on Rest-Ice Condition on IM Rewarming Temperatures.

Source Term	DF	Sum of Squares	Mean Square	F-Ratio	Prob Level	Power (Alpha=0.05)
A: Subj	11	153.0782	13.9162			
B: Time	12	669.3377	55.77814	119.86	0.000000*	1.000000
AB	132	61.42846	0.4653671			
S	0					
Total (Adj)	155	883.8444				
Total	156					

* Term significant at alpha = 0.05

Table D42. Tukey-Kramer Multiple Comparison Test for Time on Rest-Ice Condition on IM Rewarming Temperatures.

Time	Count	Mean	Different From Groups
0	12	26.4	20, 50, 60, 70, 80, 90, 100, 110, 120
10	12	25.5	40, 50, 60, 70, 80, 90, 100, 110, 120
20	12	25.4	0, 40, 50, 60, 70, 80, 90, 100, 110, 120
30	12	26.0	50, 60, 70, 80, 90, 100, 110, 120
40	12	26.7	20, 10, 60, 70, 80, 90, 100, 110, 120
50	12	27.5	20, 10, 30, 0, 70, 80, 90, 100, 110, 120
60	12	28.2	20, 10, 30, 0, 40, 80, 90, 100, 110, 120
70	12	28.8	20, 10, 30, 0, 40, 50, 90, 100, 110, 120
80	12	29.4	20, 10, 30, 0, 40, 50, 60, 100, 110, 120
90	12	30.1	20, 10, 30, 0, 40, 50, 60, 70, 110, 120
100	12	30.6	20, 10, 30, 0, 40, 50, 60, 70, 80
110	12	31.0	20, 10, 30, 0, 40, 50, 60, 70, 80, 90
120	12	31.5	20, 10, 30, 0, 40, 50, 60, 70, 80, 90

Alpha=0.050 Error Term=AB DF=132 MSE=1.091124 Critical Value=4.7722

Table D43. F-Statistic Results for Exercise Condition on IM Rewarming Imd Time Temperatures.

Source Term	DF	Sum of Squares	Mean Square	F-Ratio	Prob Level	Power (Alpha=0.05)
A: Subj	11	2.53125	0.2301136			
B: Cond	1	0.5104167	0.5104167	2.38	0.150807	0.291832
AB	11	2.354583	0.214053			
S	0					
Total (Adj)	23	5.39625				
Total	24					

* Term significant at alpha = 0.05

Table D44. Tukey-Kramer's Simultaneous CIs for MCs of All Pairs for Exercise Condition on IM Rewarming Imd Time Temperatures.

Comparison Groups	Count	Mean	Lower 95.0% Simult.C.I.	Mean Difference	Upper 95.0% Simult.C.I.	Test Result
bike	12	26.1				
- rest	12	26.4	-0.7	-0.3	0.1	
rest	12	26.4				
- bike	12	26.1	-0.1	0.3	0.7	

Alpha=0.050 Error Term=AB DF=11 MSE=0.214053 Critical Value=3.1127

Table D45. F-Statistic Results for Exercise Condition on IM Rewarming 10-min Time Temperatures.

Source Term	DF	Sum of Squares	Mean Square	F-Ratio	Prob Level	Power (Alpha=0.05)
A: Subj	11	22.19125	2.017386			
B: Cond	1	1.260417	1.260417	1.04	0.330130	0.153916
AB	11	13.35458	1.214053			
S	0					
Total (Adj)	23	36.80625				
Total	24					

* Term significant at alpha = 0.05

Table D46. Tukey-Kramer's Simultaneous CIs for MCs of All Pairs for Exercise Condition on IM Rewarming 10-min Time Temperatures.

Comparison Groups	Count	Mean	Lower 95.0% Simult.C.I.	Mean Difference	Upper 95.0% Simult.C.I.	Test Result
bike	12	25.9				
- rest	12	25.5	-0.5	0.5	1.4	
rest	12	25.5				
- bike	12	25.9	-1.4	-0.5	0.5	

Alpha=0.050 Error Term=AB DF=11 MSE=1.214053 Critical Value=3.1127

Table D47. F-Statistic Results for Exercise Condition on IM Rewarming 20-min Time Temperatures.

Source Term	DF	Sum of Squares	Mean Square	F-Ratio	Prob Level	Power (Alpha=0.05)
A: Subj	11	16.61755	1.510686			
B: Cond	1	17.357	17.357	13.24	0.003897*	0.910991
AB	11	14.42005	1.310913			
S	0					
Total (Adj)	23	48.3946				
Total	24					

* Term significant at alpha = 0.05

Table D48. Tukey-Kramer's Simultaneous CIs for MCs of All Pairs for Exercise Condition on IM Rewarming 20-min Time Temperatures.

Comparison Groups	Count	Mean	Lower 95.0% Simult.C.I.	Mean Difference	Upper 95.0% Simult.C.I.	Test Result
bike	12	27.1				
- rest	12	25.4	0.7	1.7	2.7	U
rest	12	25.4				
- bike	12	27.1	-2.7	-1.7	-0.7	L

Alpha=0.050 Error Term=AB DF=11 MSE=1.310913 Critical Value=3.1127

Table D49. F-Statistic Results for Exercise Condition on IM Rewarming 30-min Time Temperatures.

Source Term	DF	Sum of Squares	Mean Square	F-Ratio	Prob Level	Power (Alpha=0.05)
A: Subj	11	14.12833	1.284394			
B: Cond	1	27.30667	27.30667	22.99	0.000558*	0.991467
AB	11	13.06333	1.187576			
S	0					
Total (Adj)	23	54.49833				
Total	24					

* Term significant at alpha = 0.05

Table D50. Tukey-Kramer's Simultaneous CIs for MCs of All Pairs for Exercise Condition on IM Rewarming 30-min Time Temperatures.

Comparison Groups	Count	Mean	Lower 95.0% Simult.C.I.	Mean Difference	Upper 95.0% Simult.C.I.	Test Result
bike	12	28.1				
- rest	12	26.0	1.2	2.1	3.1	U
rest	12	26.0				
- bike	12	28.1	-3.1	-2.1	-1.2	L

Alpha=0.050 Error Term=AB DF=11 MSE=1.187576 Critical Value=3.1127

Table D51. F-Statistic Results for Exercise Condition on IM Rewarming 40-min Time Temperatures.

Source Term	DF	Sum of Squares	Mean Square	F-Ratio	Prob Level	Power (Alpha=0.05)
A: Subj	11	12.99125	1.181023			
B: Cond	1	28.82042	28.82042	33.08	0.000128*	0.999401
AB	11	9.584583	0.8713257			
S	0					
Total (Adj	23	51.39625				
A: Subj	11	12.99125	1.181023			

* Term significant at alpha = 0.05

Table D52. Tukey-Kramer's Simultaneous CIs for MCs of All Pairs for Exercise Condition on IM Rewarming 40-min Time Temperatures.

Comparison Groups	Count	Mean	Lower 95.0% Simult.C.I.	Mean Difference	Upper 95.0% Simult.C.I.	Test Result
bike	12	28.9				
- rest	12	26.7	1.4	2.2	3.0	U
rest	12	26.7				
- bike	12	28.9	-3.0	-2.2	-1.4	L

Alpha=0.050 Error Term=AB DF=11 MSE=0.8713257 Critical Value=3.1127

Table D53. F-Statistic Results for Exercise Condition on IM Rewarming 50-min Time Temperatures.

Source Term	DF	Sum of Squares	Mean Square	F-Ratio	Prob Level	Power (Alpha=0.05)
A: Subj	11	9.908334	0.9007576			
B: Cond	1	26.04167	26.04167	27.31	0.000283*	0.997204
AB	11	10.48833	0.9534848			
S	0					
Total (Adj)	23	46.43833				
Total	24					

* Term significant at alpha = 0.05

Table D54. Tukey-Kramer's Simultaneous CIs for MCs of All Pairs for Exercise Condition on IM Rewarming 50-min Time Temperatures.

Comparison Groups	Count	Mean	Lower 95.0% Simult.C.I.	Mean Difference	Upper 95.0% Simult.C.I.	Test Result
bike	12	29.6				
- rest	12	27.5	1.2	2.1	3.0	U
rest	12	27.5				
- bike	12	29.6	-3.0	-2.1	-1.2	L

Alpha=0.050 Error Term=AB DF=11 MSE=0.9534848 Critical Value=3.1127

Table D55. F-Statistic Results for Exercise Condition on IM Rewarming 60-min Time Temperatures.

Source Term	DF	Sum of Squares	Mean Square	F-Ratio	Prob Level	Power (Alpha=0.05)
A: Subj	11	8.264584	0.7513258			
B: Cond	1	23.40375	23.40375	21.91	0.000671*	0.988774
AB	11	11.75125	1.068295			
S	0					
Total (Adj)	23	43.41958				
Total	24					

* Term significant at alpha = 0.05

Table D56. Tukey-Kramer's Simultaneous CIs for MCs of All Pairs for Exercise Condition on IM Rewarming 60-min Time Temperatures.

Comparison Groups	Count	Mean	Lower 95.0% Simult.C.I.	Mean Difference	Upper 95.0% Simult.C.I.	Test Result
bike	12	30.1				
- rest	12	28.2	1.0	2.0	2.9	U
rest	12	28.2				
- bike	12	30.1	-2.9	-2.0	-1.0	L

Alpha=0.050 Error Term=AB DF=11 MSE=1.068295 Critical Value=3.1127

Table D57. F-Statistic Results for Exercise Condition on IM Rewarming 70-min Time Temperatures.

Source Term	DF	Sum of Squares	Mean Square	F-Ratio	Prob Level	Power (Alpha=0.05)
A: Subj	11	10.00458	0.9095076			
B: Cond	1	19.98375	19.98375	17.40	0.001558*	0.966087
AB	11	12.63125	1.148295			
S	0					
Total (Adj)	23	42.61958				
Total	24					

* Term significant at alpha = 0.05

Table D58. Tukey-Kramer's Simultaneous CIs for MCs of All Pairs for Exercise Condition on IM Rewarming 70-min Time Temperatures.

Comparison Groups	Count	Mean	Lower 95.0% Simult.C.I.	Mean Difference	Upper 95.0% Simult.C.I.	Test Result
bike	12	30.6				
- rest	12	28.8	0.9	1.8	2.8	U
rest	12	28.8				
- bike	12	30.6	-2.8	-1.8	-0.9	L

Alpha=0.050 Error Term=AB DF=11 MSE=1.148295 Critical Value=3.1127

Table D59. F-Statistic Results for Exercise Condition on IM Rewarming 80-min Time Temperatures.

Source Term	DF	Sum of Squares	Mean Square	F-Ratio	Prob Level	Power (Alpha=0.05)
A: Subj	11	11.76125	1.069205			
B: Cond	1	15.84375	15.84375	11.70	0.005713*	0.875086
AB	11	14.89125	1.35375			
S	0					
Total (Adj)	23	42.49625				
Total	24					

* Term significant at alpha = 0.05

Table D60. Tukey-Kramer's Simultaneous CIs for MCs of All Pairs for Exercise Condition on IM Rewarming 80-min Time Temperatures.

Comparison Groups	Count	Mean	Lower 95.0% Simult.C.I.	Mean Difference	Upper 95.0% Simult.C.I.	Test Result
bike	12	31.1				
- rest	12	29.4	0.6	1.6	2.7	U
rest	12	29.4				
- bike	12	31.1	-2.7	-1.6	-0.6	L

Alpha=0.050 Error Term=AB DF=11 MSE=1.35375 Critical Value=3.1127

Table D61. F-Statistic Results for Exercise Condition on IM Rewarming 90-min Time Temperatures.

Source Term	DF	Sum of Squares	Mean Square	F-Ratio	Prob Level	Power (Alpha=0.05)
A: Subj	11	13.21125	1.201023			
B: Cond	1	11.34375	11.34375	7.82	0.017398*	0.721225
AB	11	15.96125	1.451023			
S	0					
Total (Adj)	23	40.51625				
Total	24					

* Term significant at alpha = 0.05

Table D62. Tukey-Kramer's Simultaneous CIs for MCs of All Pairs for Exercise Condition on IM Rewarming 90-min Time Temperatures.

Comparison Groups	Count	Mean	Lower 95.0% Simult.C.I.	Mean Difference	Upper 95.0% Simult.C.I.	Test Result
bike	12	31.4				
- rest	12	30.1	0.3	1.4	2.5	U
rest	12	30.1				
- bike	12	31.4	-2.5	-1.4	-0.3	L

Alpha=0.050 Error Term=AB DF=11 MSE=1.451023 Critical Value=3.1127

Table D63. F-Statistic Results for Exercise Condition on IM Rewarming 100-min Time Temperatures.

Source Term	DF	Sum of Squares	Mean Square	F-Ratio	Prob Level	Power (Alpha=0.05)
A: Subj	11	17.58333	1.598485			
B: Cond	1	9.375	9.375	6.58	0.026286*	0.647071
AB	11	15.675	1.425			
S	0					
Total (Adj)	23	42.63334				
Total	24					

* Term significant at alpha = 0.05

Table D64. Tukey-Kramer's Simultaneous CIs for MCs of All Pairs for Exercise Condition on IM Rewarming 100-min Time Temperatures.

Comparison Groups	Count	Mean	Lower 95.0% Simult.C.I.	Mean Difference	Upper 95.0% Simult.C.I.	Test Result
bike	12	31.8				
- rest	12	30.6	0.2	1.3	2.3	U
rest	12	30.6				
- bike	12	31.8	-2.3	-1.3	-0.2	L

Alpha=0.050 Error Term=AB DF=11 MSE=1.425 Critical Value=3.1127

Table D65. F-Statistic Results for Exercise Condition on IM Rewarming 110-min Time Temperatures.

Source Term	DF	Sum of Squares	Mean Square	F-Ratio	Prob Level	Power (Alpha=0.05)
A: Subj	11	19.36458	1.760417			
B: Cond	1	7.820416	7.820416	5.28	0.042256*	0.553577
AB	11	16.30458	1.482235			
S	0					
Total (Adj)	23	43.48958				
Total	24					

* Term significant at alpha = 0.05

Table D66. Tukey-Kramer's Simultaneous CIs for MCs of All Pairs for Exercise Condition on IM Rewarming 110-min Time Temperatures.

Comparison Groups	Count	Mean	Lower 95.0% Simult.C.I.	Mean Difference	Upper 95.0% Simult.C.I.	Test Result
bike	12	32.2				
- rest	12	31.0	0.0	1.1	2.2	U
rest	12	31.0				
- bike	12	32.2	-2.2	-1.1	0.0	L

Alpha=0.050 Error Term=AB DF=11 MSE=1.482235 Critical Value=3.1127

Table D67. F-Statistic Results for Exercise Condition on IM Rewarming 120-min Time Temperatures.

Source Term	DF	Sum of Squares	Mean Square	F-Ratio	Prob Level	Power (Alpha=0.05)
A: Subj	11	22.01458	2.001326			
B: Cond	1	5.70375	5.70375	3.79	0.077593	0.427308
AB	11	16.56125	1.505568			
S	0					
Total (Adj)	23	44.27958				
Total	24					

* Term significant at alpha = 0.05

Table D68. Tukey-Kramer's Simultaneous CIs for MCs of All Pairs for Exercise Condition on IM Rewarming 120-min Time Temperatures.

Comparison Groups	Count	Mean	Lower 95.0% Simult.C.I.	Mean Difference	Upper 95.0% Simult.C.I.	Test Result
bike	12	32.5				
- rest	12	31.5	-0.1	1.0	2.1	
rest	12	31.5				
- bike	12	32.5	-2.1	-1.0	0.1	

Alpha=0.050 Error Term=AB DF=11 MSE=1.505568 Critical Value=3.1127

BIBLIOGRAPHY

1. Washington LL, Gibson SJ, Helme RD. Age-related differences in the endogenous analgesic response to repeated cold water immersion in human volunteers. *Pain.* 2000;89:89-96.

2. Nadler SF, Weingand K, Kruse RJ. The physiologic basis and clinical applications of cryotherapy and thermotherapy for the pain practitioner. *Pain Physician.* 2004;7:395-399.

3. Knight KL. *Cryotherapy in sport injury management.* Champaign, IL: Human Kinetics; 1995.

4. Bugaj R. The cooling, analgesic, and rewarming effects of ice massage on localized skin. *Phys Ther.* 1975;55:11-19.

5. Thorsson O, Lilja B, Ahlgren L, Hemdal B, Westlin N. The effect of local cold application on intramuscular blood flow at rest and after running. *Med Sci Sports Exerc.* 1985;17:710-713.

6. Ho SSW, Illgen RL, Meyer RW, Torok PJ, Cooper MD, Reider B. Comparison of various icing times in decreasing bone metabolism and blood flow in the knee. *Am J Sports Med.* 1995;23:74-76.

7. Brooks GA, Fahey TD. *Exercise physiology : human bioenergetics and its applications.* New York: Wiley; 1984.

8. Merrick MA, Rankin JM, Andres FA, Hinman CL. A preliminary examination of cryotherapy and secondary injury in skeletal muscle. *Med Sci Sports Exerc.* 1999;31:1516-1521.

9. Nordstrom CH, Rehncrona S. Reduction of cerebral blood flow and oxygen consumption with a combination of barbiturate anaesthesia and induced hypothermia in the rat. *Acta Anaesthesiol Scand.* 1978;22:7-12.

10. Rao KS, Schutz RW, Feinberg H, Levitsky S. Metabolic evidence that regional hypothermia induced by cold saline protects the heart during ischemic arrest. *J Surg Res.* 1976;20:421-425.

11. Blair E. *Clinical hypothermia.* New York,: Blakiston Division; 1964.

12. Yanagisawa O, Niitsu M, Takahashi H, Goto K, Itai Y. Evaluations of cooling exercised muscle with MR imaging and P-31 MR spectroscopy. *Med Sci Sports Exerc.* 2003;35:1517-1523.

13. Sapega AA, Heppenstall RB, Sokolow DP, et al. The bioenergetics of preservation of limbs before replantation. The rationale for intermediate hypothermia. *J Bone Joint Surg*. 1988;70:1500-1513.

14. Long BC, Cordova ML, Brucker JB, Demchak TJ, Stone MB. Exercise and quadriceps muscle cooling time. *J Athl Train*. 2005;40:260-263.

15. Mars M, Hadebe B, Tufts M. The effect of ice pack cooling on skin and muscle temperature at rest and after exercise. *S African J Sports Med*. 2006;18:60-66.

16. Dykstra JH, Hill HM, Miller MG, Cheatham CC, Michael TJ, Baker RJ. Comparisons of cubed ice, crushed ice, and wetted ice on intramuscular and surface temperature changes. *J Athl Train*. 2009;44:136-141.

17. Jutte LS, Merrick MA, Ingersoll CD, Edwards JE. The relationship between intramuscular temperature, skin temperature, and adipose thickness during cryotherapy and rewarming. *Arch Phys Med Rehabil*. 2001;82:845-850.

18. Merrick MA, Knight KL, Ingersoll CD, Potteiger JA. The effects of ice and compression wraps on intramuscular temperatures at various depths. *J Athl Train*. 1993;28:236-245.

19. Petajan JH, Watts N. Effects of cooling on the triceps surae reflex. *Am J Phys Med Rehabil*. 1962;41:240-251.

20. Mancuso DL, Knight KL. Effects of prior physical activity on skin surface temperature response of the ankle during and after a 30-minute ice pack application. *J Athl Train*. 1992;27:242-249.

21. Palmer JE, Knight KL. Ankle and thigh skin surface temperature changes with repeated ice pack application. *J Athl Train*. 1996;31:319-323.

22. Housh TJ, Housh DJ, DeVries HA. *Applied exercise & sport physiology*. 2nd ed. Scottsdale, Ariz.: Holcomb Hathaway; 2006.

23. Belitsky RB, Odam SJ, Hubley-Kozey C. Evaluation of the effectiveness of wet ice, dry ice, and cryogenic packs in reducing skin temperature. *Phys Ther*. 1987;67:1080-1084.

24. Knight KL, Brucker JB, Stoneman PD, Rubley MD. Muscle injury management with cryotherapy. *Athl Ther Today*. 2000;5:26-30.

25. Casten CMS, Jordan P. *Aerobics today*. 2nd ed. Belmont, CA: Wadsworth/Thomson Learning; 2002.

26. Starkey C. *Therapeutic modalities*. 3rd ed. Philadelphia: F.A. Davis Co.; 2004.

27. Merrick MA, Jutte LS, Smith ME. Cold modalities with different thermodynamic properties produce different surface and intramuscular temperatures. *J Athl Train.* 2003;38:28-33.

28. Myrer JW, Myrer KA, Measom GJ, Fellingham GW, Evers SL. Muscle temperature is affected by overlying adipose when cryotherapy is administered. *J Athl Train.* 2001;36:32-36.

29. Otte JW, Merrick MA, Ingersoll CD, Cordova ML. Subcutaneous adipose tissue thickness alters cooling time during cryotherapy. *Arch Phys Med Rehabil.* 2002;83:1501-1505.

30. Myrer JW, Measom G, Fellingham GW. Temperature changes in the human leg during and after two methods of cryotherapy. *J Athl Train.* 1998;33:25-29.

31. Myrer JW, Measom GJ, Fellingham GW. Exercise after cryotherapy greatly enhances intramuscular rewarming. *J Athl Train.* 2000;35:412-416.

32. Hubbard TJ, Denegar CR. Does cryotherapy improve outcomes with soft tissue injury? *J Athl Train.* 2004;39:278-279.

33. Merrick MA. Secondary injury after musculoskeletal trauma: a review and update. *J Athl Train.* 2002;37:209-217.

34. Seiyama A, Shiga T, Maeda N. Temperature effect on oxygenation and metabolism of perfused rat hindlimb muscle. *Adv Exp Med Biol.* 1990;277:541-547.

35. Knight KL, Bryan KS, M. HJ. Circulatory changes in the forearm in 1, 5, 10, and 15 degree celsius water [abstruct] *Int J Sports Medicine.* 1981;4:281.

36. McMaster WC, Liddle S, Waugh TR. Laboratory evaluation of various cold therapy modalities. *Am J Sports Med.* 1978;6:291-294.

37. Knight KL, M. V, A. CJ, K. H. Comparison of Dura*kold compression ice wraps to crushed ice and refreezable flexible gel packs [abstruct]. *J Athl Train.* 1990;25:126.

38. Waylonis GW. The physiologic effects of ice massage. *Arch Phys Med Rehabil.* 1967;48:37-42.

39. Bocobo C, Fast A, Kingery W, Kaplan M. The effect of ice on intra-articular temperature in the knee of the dog. *Am J Phys Med Rehabil.* 1991;70:181-185.

40. McMaster WC. A literary review on ice therapy in injuries. *Am J Sports Med.* 1977;5:124-126.

41. Mlynarczyk JM. *Temperature changes during and after ice application of 10, 20, 30, 45, 60 minutes* [masters]. Terre Haute: Indiana State University; 1984.

42. Enwemeka CS, Allen C, Avila P, Bina J, Konrade J, Munns S. Soft tissue thermodynamics before, during, and after cold pack therapy. *Med Sci Sports Exerc*. 2002;34:45-50.

43. Myrer JW, Draper DO, Durrant E. Contrast therapy and intramuscular temperature in the human leg. *J Athl Train*. 1994;29:318-322.

44. Myrer JW, Measom G, Durrant E, Fellingham GW. Cold- and hot-pack contrast therapy: subcutaneous and intramuscular temperature change. *J Athl Train*. 1997;32:238-241.

45. Zemke JE, Andersen JC, Guion WK, McMillan J, Joyner AB. Intramuscular temperature responses in the human leg to two forms of cryotherapy: Ice massage and ice bag. *J Orthop Sports Phys Ther*. 1998;27:301-307.

46. Kennet J, Hardaker N, Hobbs S, Selfe J. Cooling efficiency of 4 common cryotherapeutic agents. *J Athl Train*. 2007;42:343-348.

47. Johnson DJ, Moore S, Moore J, Oliver RA. Effect of cold submersion on intramuscular temperature of the gastrocnemius muscle. *Phys Ther*. 1979;59:1238-1242.