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Effect of limb circumference on intramuscular cooling during and following an ice bag application after exercise

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EFFECT OF LIMB CIRCUMFERENCE ON INTRAMUSCULAR COOLING DURING AND FOLLOWING AN ICE BAG APPLICATION AFTER EXERCISE

An Abstract of a Thesis

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ABSTRACT

Context: Ice bags are commonly applied following exercise, but the effect of limb size on cooling duration and rewarming has not been documented. Objective: Investigate the effect of limb circumference on cooling duration to 10°C below resting baseline and examine the subsequent rewarming trends. Design: Two separate designs were used: a 1 X 2 cross-over design on limb circumference (large circumference [LC: 58-63.5cm] and small circumference [SC: 50-54cm]) and duration of treatment (time to 10°C below baseline) and a 2 X 7 cross-over design on the two limb circumference groups (LC and SC) and the rewarming trend at time Imd, 10-, 20-, 30-, 40-, 50-, and 60-minute. Setting: Laboratory Patients or Other Participants: Fourteen physically active, healthy, college-aged volunteers (20.8 ± 2.7y, ht: 174.6 ± 5.7cm, mass: 75.8 ± 11.9kg: skinfold: 17.9 ± 4.1mm). Interventions: Comparison of LC and SC limbs Main Outcome Measure(s): Duration to 10°C below baseline at 2-cm subadipose tissue depth of the midpoint of the quadriceps and temperature of rewarming at time Imd., 10-, 20-, 30-, 40-, 50-, and 60-minute. Two separate analyses were performed: a 1 X 2 crossover design for duration and a 2 X 7 crossover design for rewarming and Tukey-Kramer MC tests were used for the rewarming. Alpha was set *a priori* at 0.05. Results: The LC limbs took 6.5min. longer ($P = 0.02$) to cool than the SC limbs (45min) . There was an interaction of circumference and time on temperature ($P =.004$) with SC limbs being cooler at each time period except Imd. Conclusions: LC limbs took longer to cool to 10°C below baseline. LC limbs remained at the target temperature for 20 minutes while SC limbs continued to cool before warming past the target temperature at 40 minutes. Limb circumference influences treatment duration and rewarming trends.

Key Words: cold, cryotherapy, ice bag, limb circumference, rewarming

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APPROVAL PAGE

This Study by: Marcus A. Sojka

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INTRODUCTION

Cold applied directly to the skin is a common way to cool the skin surface and deeper tissues.[1] Cooling the skin surface reduces pain,[2,3] while in deeper tissues, cold decreases spasm and edema,[4] and limits secondary ischemic injury.[5] It is known that surface tissues are not dramatically affected by different cold modalities or protocols, meaning that if cold is applied to the skin, the skin will become cold quickly.[6-16] This is also evident during[10] and following[9,15,17] exercise, which means the most profound effects of different cooling protocols, occurs at deeper tissues.

Although we do not know how cold, cold enough is, we can assume that a 1°C difference has more physiological benefits.[1] Therefore, colder is better and treatments must be optimized to reduce temperatures as efficiently as possible. The Q_{10} effect describes theoretically how cellular metabolism is reduced by half when the system is cooled 10°C below baseline temperature.[4] A reduction in cellular metabolism could help to limit secondary ischemic injury and lead to quicker recovery times. For these reasons, the target tissue temperature for this study will be 26°C which is 10°C below the rested intramuscular temperature of the quadriceps.[13,14,17,18] Furthermore, focal intramuscular cooling is assisted by global cooling after exercise.[17] Since ice bags are commonly applied after physical activity, the effects of cooling after exercise need to be examined.

We know that surface contact area of an ice bag affects the cooling efficacy in that a larger ice bag can absorb more heat than a smaller ice bag. Investigators[13] have attempted to correlate surface cooling to deeper tissue cooling, which failed. While the possibility exists that surface cooling cannot be used a predictor of intramuscular temperature, one overlooked factor could be limb circumference.[19]

Increases in tissue mass lead to increases in surface area of a body part, which means a standard ice bag covers less surface contact area. Although larger muscles do not generate higher temperatures than smaller muscles, there is more to cool. This is especially important during and following exercise because active muscles generate heat. Hence, a limb with greater circumference due to increased muscle mass will cool differently than a limb with a smaller circumference. Therefore, the purpose of this study is to determine the effect limb circumference has on intramuscular cooling efficacy during ice bag application, as well as rewarming, following exercise.

METHODS

Design

This study was broken into two designs because two different dependent variables were needed.

During Treatment

A 1 X 2 cross-over design was used to detect the effect of circumference on cooling efficacy of the ice bag. The circumference levels were stratified into a small circumference (SC: 50-54 cm) and large circumference (LC: 58-63.5 cm). The dependent variable for this design was Duration to reach 26°C, which is 10°C below the consistently reported 2cm quadriceps tissue temperature.[13,14,17,18] Duration was measures to the nearest minute.

Rewarming

A 2 X 7 cross-over design was used to detect a difference in rewarming trends between the 2 circumference groups over 60 minutes after ice removal. The independent variables were Circumference (SC & LC) and Time [Imd (last During Tx measure before ice bag removal,) 10, 20, 30, 40, 50, and 60-minute]. The dependent variable was temperature measured to the nearest 0.1°C.

Participants

Fourteen healthy and physically active volunteers (21.3 ± 2.8y, ht: 176.7 ± 7.7cm, mass: 75.9 ± 12.1kg: skinfold: 18.1 ± 3.7mm, RHR: 71 ± 5.7) participated. Both quadriceps groups of the participants served as independent subjects. All participants were informed and consented to participate. They were familiarized, screened and completed a health history questionnaire. 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 10-30 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

A skin-fold caliper (Lange C-130, Beta Technology Inc. Cambridge, MD) was used to determine the vertical skinfold thickness of both the anterior thigh midpoints to the nearest mm. A flexible tape measure (Mabis DMI Flexible Tape Measure Waukegan, IL) was used to quantify thigh midpoint circumference to the nearest 0.5 cm.

Intramuscular temperatures were measured using custom made 36-gauge Type-T thermocouples. These thermocouples were connected to a 16-channel THERMES-ISO computer based thermometer temperature data acquisition system (Physitemp Instruments, Inc., Clifton, NJ). The data from this device was electronically transferred to a desktop computer, and then to a spreadsheet for statistical analysis.

Reliability and Validity of Temperature Acquisition System

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 intramuscular thermocouples built and tested. Having 6 thermocouples allowed participants to be tested without a sterilization delay and allowed for backup thermocouples.

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. The intramuscular thermocouple reliability was 0.0°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 intramuscular validity was 0.1°C.

Uncertainty of each thermocouple was the sum of the average reliability and average validity. The uncertainty for the intramuscular thermocouples did not range and had an average of 0.1°C. By averaging all of the thermocouple uncertainty values the system uncertainty was the same as the mentioned averages (0.1°C).

Procedures

Dressed in gym attire, participants reported to the Athletic Training Research Laboratory for 1 treatment session lasting approximately 2½ hours. The session consisted of obtaining informed consent, familiarizing and screening the subjects and data collection. Data collection involved having the participants ride a stationary cycle for 30 minutes before inserting thermocouples 2 cm plus ½ the skinfold thickness into the quadriceps musculature of both thighs, so the temperatures (to the nearest 0.1°C) can be measured until the limb reaches 10°C below baseline and then 60-minute rewarming following removal of the ice bag. The same investigator performed all procedures.

Before data collection began, the participants laid supine on a treatment table. A surgical pen mark on the anterior portion of the thigh mid-way between the ASIS and the proximal border of the patella identified the thermocouple insertion site. A mean of 3 consecutive vertical skinfold measurements using the skin-fold caliper quantified skinfold thickness. The average skinfold was divided by 2 to determine superficial tissue thickness, and then added to 2 cm to determine insertion depth. Thereafter, a 25 cm^2 area at the insertion site was shaved.

Once the area had been shaved each participant was fitted for a heart rate monitor and had their individual exercise target heart range calculated using the Karvoven equation:

$$THR = [(MHR - RHR) \times \%T] + RHR$$

The participant's age predicted maximum heart rate (MHR) is determined by taking 220 minus the participant's age. Resting heart rate was determined by the reading on the heart rate monitor. Because the participant has continued to lie quietly for a period of time greater than 5 minutes the reading at that time was considered accurate. The exercise target heart rate (THR) lower and upper range limits (%T) were set at 70% and 80%, respectively. Shortly thereafter, the participant was seated on a stationary bicycle. The subject performed a 5-minute warm-up on the stationary bicycle during which they worked up to the target zone of 70-80% Max Heart Rate (MHR). Even if the participant reached her/his range before the end of the 5 minutes, s/he completed the warm-up at that intensity. Cycling time began immediately following the 5-minute warm-up and lasted for 30 minutes.

At the end of the exercise, the participant was moved from the stationary bicycle back to the treatment table where s/he once again laid supine. After gently toweling the thighs and cleansing them with a chlorhexidine gluconate solution (Hibiclens, Regent Medical, Norcross, GA) for 3 minutes a 20-guage by 4.76 cm intravenous catheter measured and marked from the tip of the needle using the calculated target depth measure to ensure correct insertion depth was inserted at the site. Once the catheter was implanted a custom made 36-gauge Copper-Constantine Teflon coated Type-T intramuscular thermocouple was marked with the length of the catheter to ensure correct insertion depth of the thermocouple within the catheter. The 36-guage Type-T thermocouple was threaded into the catheter to the target depth. 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. The intramuscular thermocouple and catheter were secured to the skin with a 5.1 cm by 7.6 cm Bioclusive dressing (Johnson & Johnson MEDICAL, Gargrave, North Yorkshire, U.K.). Once the thermocouple was secured and connected to the computer, temperature data was recorded every 30 seconds for the duration of the session.

The first 2 minutes of temperature recordings served as the baseline for treatment. Treatment consisted of applying an ice bag to the right anterior thigh secured with a 15 cm × 3 m elastic wrap. Ice bag consisted of 2000mL of cubed ice and 300mL of room temperature water in 44 cm X 25.5 cm, 1-mil polyethylene bag, removing excess air and securing each bag with a knot. Left quadriceps muscle did not receive ice bag treatment. Duration was recorded when the limb had reached 10°C below baseline. Before removal of the ice bag, the last recorded temperature was labeled immediate, the ice bag was removed, and the rewarming phase began with the immediate, 10, 20, 30, 40, 50, and 60 minute temperatures used for the rewarming analysis.

After the last measures were recorded, the thermocouples were withdrawn, wiped and cleansed with saline solution. Once dry each intramuscular thermocouple was placed in its own self-sealable sterilization pouch, then steam sterilized in a Tuttnauer EZ9 Autoclave according to manufacturer instructions. The manufacturer protocol included 8 minutes of pressure and steam at 121°C (250°F) to 134°C (273°F) and 30 minutes of drying. To verify sterilization each pouch indicator was checked for appropriate color change. The insertion sites were cleansed with chlorhexidine gluconatte solution and an antibiotic ointment was applied and covered with adhesive bandage. Information listing signs and symptoms of infection and proper wound management were provided and discussed with each subject at the conclusion of each session.

Data and Statistical Analysis

Two different statistical analyses were performed. To detect the effect of Circumference on Duration a 1 X 2 ANOVA was utilized. To determine an interaction between Circumference and Temperature on Time a 2 X 7 ANOVA was used. As needed, subsequent testing for any interactions and main effects consist of post-hoc 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

After analyzing the data there was 3 data sets indicated as outliers, so this data was removed from further analyses. A summary of the Duration and Rewarming data used in the analyses is reported in Table 1 and Table 2, respectively. Additionally, the Duration trends and Rewarming trends are visually represented in Figure 2 and Figure 3, respectively.

Duration

There was a statistically detected difference indicating that the LC limbs took more than 6.5 minutes to cool ($F_{1,10} = 17.79$, $P = .002$, $1\text{-}\beta = .96$).

Rewarming

Circumference and Time statistically interacted on Temperature [(G-G) $F_{6,76} = 8.7$, $P = .004$, $1\text{-}\beta = .91$]. In order to detect the interaction specifics the *post hoc* analyses included two 1 X 7 repeated measures ANOVAs to detect the effect of Time within each Circumference on Temperature. Additionally, seven 1 X 2 ANOVAs were used to detect the effect of Circumference on Temperature at each Time.

Within both the LC and SC limbs, Temperature changed over Time [LC: $F_{6,34} = 62.85$, $P < .0001$, $1\text{-}\beta = 1.00$; SC: [(G-G) F6,41 = 56.56, $P = .0001$, $1\text{-}\beta = 1.00$]. Within the LC limb the Temperatures warmed with variable statistical differences between each Time (Tukey-Kramer Multiple Comparison: df = 24, MSE = .134, CV = 4.54, $P < .05$, Table 2). Likewise, within the SC limb Temperatures warmed with variable statistical differences between each Time (Tukey-Kramer Multiple Comparison: df = 30, MSE = .108, CV = 4.46, $P < .05$, Table 2).

At each Time, except at the Imd time, the LC temperature was greater than the SC (Tukey-Kramer Multiple Comparison: df = 9, range of MSE = .29 - .668, CV = 3.20, $P < .05$, Table 2).

DISCUSSION

Applying cold to the surface of the skin to cause an intramuscular therapeutic effect is well documented. Changes in the cooling modality,[7,8,16,18,20] application of a compression wrap,[6,14] skinfold thickness,[13,21,22] and exercise before treatment[9,15,17] can alter the results of the treatment. One study attempted to correlate the previously mentioned factors to predict intramuscular temperature, without success.[13] A potentially overlooked piece in that study may have been limb size.

The intent of this study was to determine if limb circumference has an effect on the duration of ice bag application to a specified temperature following exercise. Moreover, we investigated whether or not limb circumference affects rewarming trends following exercise. This interest was initiated by the fact that an ice bag that has a greater surface contact area will cool faster.[1] That is the reason it is common practice for an ice bag to be flattened and contoured to the shape of the body part that is being cool. It stands to reason that if the size of the limb under the ice bag was changed, cooling would be different, which raised the questions of interest.

Duration

Relative to our hypothesis that LC limbs will take longer to cool, we were correct. The LC limbs took 6.5 minutes longer to cool to 10°C below baseline than SC limbs. Not only was the difference statistically significant, but they have practical meaning as well.

We chose to cool to a predetermined temperature rather than cool for an amount of time, which is done clinically, to compare the two groups because we wanted to use a similar starting temperature for the rewarming data. Since duration was recorded when the temperature reached 26°C we could compare the temperatures of the LC and SC groups at subsequent time points after the ice bag was removed. Although previous research has shown rewarming data visually, without a common starting temperature, between-group comparisons are difficult. We chose our target temperature of 10°C below baseline because cell metabolism is reduced by half, and to be consistent with a previous study.[17] Although we used healthy participants, reducing cell metabolism can reduce secondary ischemic injury[5] which is important for clinicians.

Since we did choose to study time to 26°C, or duration, there was a lack of research to use as a comparison. One study[21] cooled tissue to 7°C below baseline but according to visual representation of our cooling trends, differences in the two groups did not manifest themselves until temperature was below 29°C which is only 7°C below baseline. Therefore, we can assume that limb circumference had little impact on the results of that study. Other studies applied cold for pre-determined times instead of to a temperature, which is more in line with clinical practice. Although we cannot argue with that procedure, we did not encounter enough research that suggested the standard treatment times were long enough to reach 10°C below baseline to slow the metabolic rate by half. Only one other study used our treatment parameters such as measurement site, depth, target temperature, and exercise before ice bag application and also cooled to our target treatment temperature.[17] Compared to that study, our durations for the SC and LC groups were much greater than their protocol lasted.

Many factors can influence the cooling of an ice bag, which is why the same investigator made and applied all of the treatments in the current study. In order to be consistent with the study most comparable we used a 1-kg crushed ice bag with a compression wrap to apply the modality to the limb. Because the same investigator created the ice bag and applied the compression wrap, we can be fairly certain that for each participant the ice bag and compression wrap were consistently secured to the limb.

Additionally, in order to compare to the other like study,[17] the exercise condition was the same. Long and the current study both used 70% to 80% Karvonen calculated exercise heart rate. The resting heart rate of our participants was 70 ± 4 bpm, whereas we are uncertain about the other study. Although the exercise intensity may have been a little different between the studies, knowing that the human body is very proficient at dissipating heat we do not suspect any exercise differences between the studies. Moreover, we do not suspect any exercise differences between our groups. Specifically, the LC group had and average resting heart rate of 71.6 bpm compared to the 70.5 bpm resting heart rate of the SC group. Meaning the physical conditioning of both the LC and SC groups was the same.

Moreover, skinfold thickness which also helps identify physical conditioning our LC and SC skinfolds were the same. The LC group had a thickness of 18.2 mm compared to the SC group of 17.7 mm. The similarity of thickness between the groups was suspected because participants were delimited to a range of 10 – 30 mm.

While we kept our skinfold thicknesses in line with other studies,[13,17,21] we did not know what range to set for our circumference measurements. After measuring a number of random quadriceps muscles, we decided that the SC group should be under 55cm and the LC group should be greater than that number. For our data, the SC group measured 50-54cm (mean=51.7±1.5cm) while the LC group measured 58-63.5 cm (mean=62.7±2.1cm). While our ranges were fairly close to each other, it was important to have a small gap between the two groups to avoid a situation where the two circumferences were separated by 1cm but had to be placed in different groups. Furthermore, our mean circumferences were almost 10cm different from each other thus we were confident that our two groups consisted of different sized legs.

In regards to cooling duration differences between the LC and SC groups, we suspected that relative mass being cooled compared to the ice bag contact surface area may have an effect. There is only one study that hinted this same effect.[19] Because all of our ice bags were created consistently and the larger mass limbs have a larger total surface area, we know that the ice bag covered less surface area on the larger limbs. Therefore, the ratio of total contact area of the limb to ice bag contact area could be the factor that affected the duration. A future study should look into applying ice bags to limbs based on limb size to ice bag ratio.

Although the duration difference may be considered small when already cooling for nearly an hour, there is still a practical importance to the results. If a treatment is to be effective, proper goals need to be met, in this case intramuscular tissue temperature to slow metabolism to one half of baseline temperature[5]. Although we know most clinicians do not measure intramuscular temperature, it remains important to understand how long a treatment should be to reach the therapeutic benefit of having metabolism reduced by half. In the current study, both treatment groups cooled for over 45 minutes which is longer than previously reported.[17] Since all factors that affect cooling, except limb circumference which was not reported, were similar between the two studies, the differences in cooling duration could be attributed to environmental factors. Even though we cannot be sure of the differences in limb circumference between the two studies, with skinfold measurements being similar we have to assume that circumferences in the previous study would have been similar to the circumference range of the current study. Regardless of the cooling duration differences between studies, we propose that a 1-kg ice bag treatment applied the quadriceps group following exercise be at least 45 minutes in duration.

Rewarming

In regards to tissue rewarming we hesitated to hypothesize because there is no research to directly compare to and there are 3 ways to consider how limb circumference would affect exercised tissue rewarming following an ice bag application. There was a possibility that both groups would rewarm similarly to each other. We did not think this very likely because we were expecting that the two groups had substantial mass differences, so they would behave differently. The next possibility we considered was that the LC limbs would have cooler temperatures at all times beside Imd. than the SC limbs. Because we expected that the ice bag would be applied for a greater amount of time to the LC limbs, it stood to reason that the rewarming would be more gradual even though it started from the same temperature. Our last possible hypothesis was that the

LC limbs would have warmer temperatures because of the ratio of surface contact area to limb size as previously mentioned in the Duration section.

After visually comparing our rewarming trends to others, our SC trends are similar.[7-9,12,14-16] Specially, as with those studies, our SC limbs continued to cool for an additional 10 minutes before rewarming began. On the other hand, the LC limbs did not act in this fashion as they maintained initial ice bag near the removal temperature for 20 minutes before practical rewarming began. Even though the SC limbs began to rewarm sooner than the LC limbs, the SC rewarming began at a lower temperature. However, the SC limbs were still near 26°C at 40 minutes after ice bag removal, whereas the LC limbs were at 26°C at 20 minutes. Regardless of the when the rewarming began the rewarming slope looks similar. Therefore, the residual cooling following ice removal in the SC limbs accounted for the difference. This is interesting because the LC limbs had longer treatment durations.

Practically speaking, and assuming that having the tissues at 10°C for a longer period of time is more beneficial, then the longer the tissues stay at this temperature the better. In order for LC limbs to maintain target temperature of 10°C below baseline for the same 40 minute period witnessed in SC limbs, the LC limbs would need an additional 20 minutes of cooling. Of course, ice bags will not stop cooling at specific temperatures during application, so the additional duration of application may further change rewarming trends in the LC limbs. This new question needs investigation, and may be accomplished by using a predetermined ice bag treatment duration on both limbs. The results from a study that cools for a specific duration might be more practical for the clinician because that is how they treat patients. Additionally, if the ratio of limb size to ice bag size is similar between the LC and SC limbs the rewarming trends maybe similar. This also needs to be investigated.

In summary, the relative thigh mass compared to the ice bag mass has an impact on cooling and rewarming trends. This is not based on larger muscle being hotter, but the fact that there is more mass to cool. Additionally, larger limb masses have more total heat to be removed therefore do not remain as cold as long as smaller limb masses. This is most likely due to larger limb masses having also larger surface areas needing more coverage to get the same residual cooling seen in smaller mass limbs.

CONCLUSION

Large circumference limbs will cool to 10°C below baseline slower than SC limbs after exercise. Furthermore, LC limbs will not continue to cool following ice bag removal, which accounts for the warmer temperatures at each time point during rewarming. These conclusions are practically important because they highlight the fact that larger limbs take longer to cool and rewarm faster.

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Table 1. Treatment Duration (min) To 10°C Below Baseline By Circumference. (mean ± SE)

Circumference	Duration
Large (n=5)	53.5 ± 1.5[*]
Small (n=6)	46.8 ± 0.7[*]
AVE (n=11)	49.9 ± 1.3

[*] = Large > Small

Table 2. Rewarming Temperatures (°C) and Temperature Differences by Circumference and Time. (n=11, mean ± SE)

Time	Large Circ (n=5)	Small Circ (n=6)	Δ
Imd	26.0 ± 0.0[b]	26.0 ± 0.0[g]	0.0
10[a]	26.1 ± 0.5[b]	24.8 ± 0.3[h]	1.3
20[a]	26.4 ± 0.4[c]	25.0 ± 0.3[i]	1.4
30[a]	27.1 ± 0.3[d]	25.4 ± 0.3[j]	1.7
40[a]	27.8 ± 0.2[e]	26.2 ± 0.3[k]	1.6
50[a]	28.6 ± 0.2[f]	26.8 ± 0.3[l]	1.8
60[a]	29.3 ± 0.1[f]	27.6 ± 0.3[m]	1.7

[a] = Large Circ > Small Circ
[b] = Imd, 10, 20 < 30, 40, 50, 60
[c] = Imd, 10, 20, 30 < 40, 50, 60
[d] = Imd, 10 < 20, 30, 40 < 50, 60
[e] = Imd, 10, 20 < 30, 40 < 50, 60
[f] = Imd, 10, 20, 30, 40 < 50, 60
[g] = 10, 20 < Imd, 30, 40 < 50, 60
[h] = 10, 20 < Imd, 30, 40, 50, 60
[i] = 10, 20, 30 < Imd, 40, 50, 60
[j] = 10 < Imd, 20, 30 < 40, 50, 60
[k] = 10, 20, 30 < Imd, 40, 50 < 60
[l] = Imd, 10, 20, 30 < 40, 50 < 60
[m] = Imd, 10, 20, 30, 40, 50 < 60

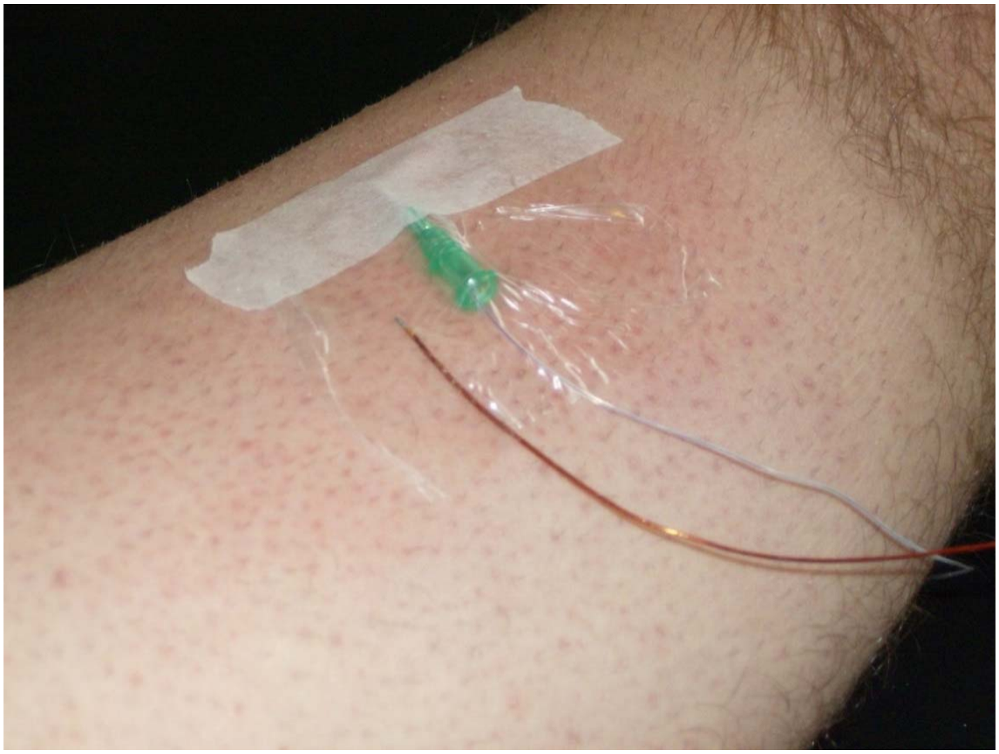

Figure 1. Secured Intramusucular Thermocouple With Flexible Catheter. *(Copper interface thermocouple was not used.)*

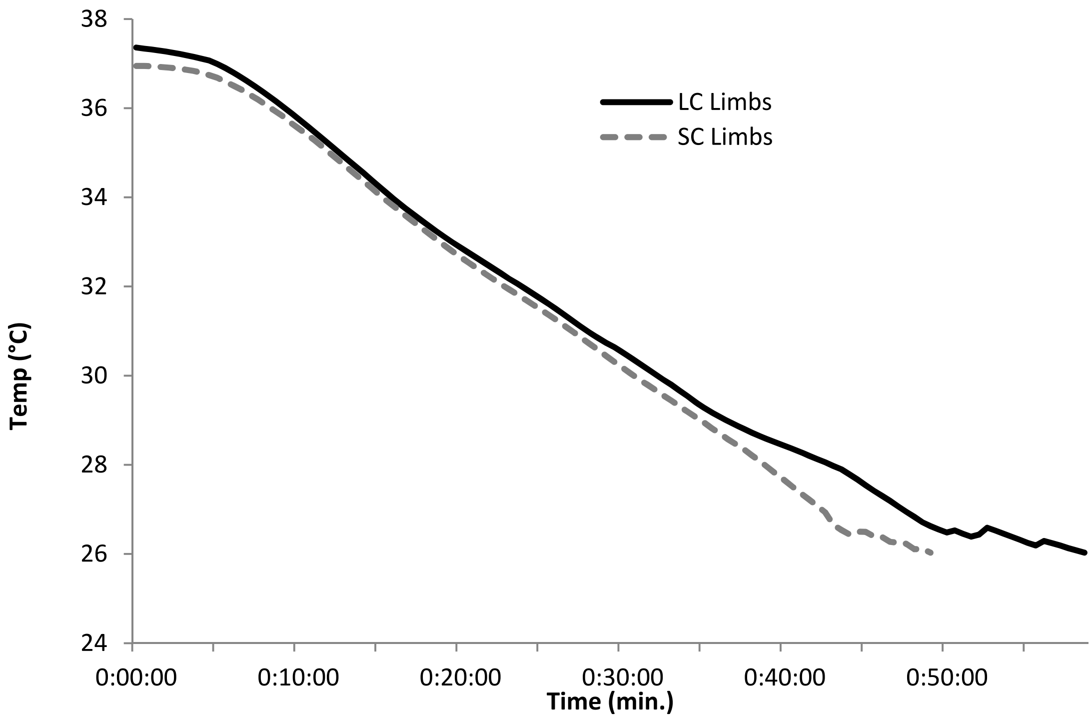

Figure 2. Temperature During Cooling By Circumference

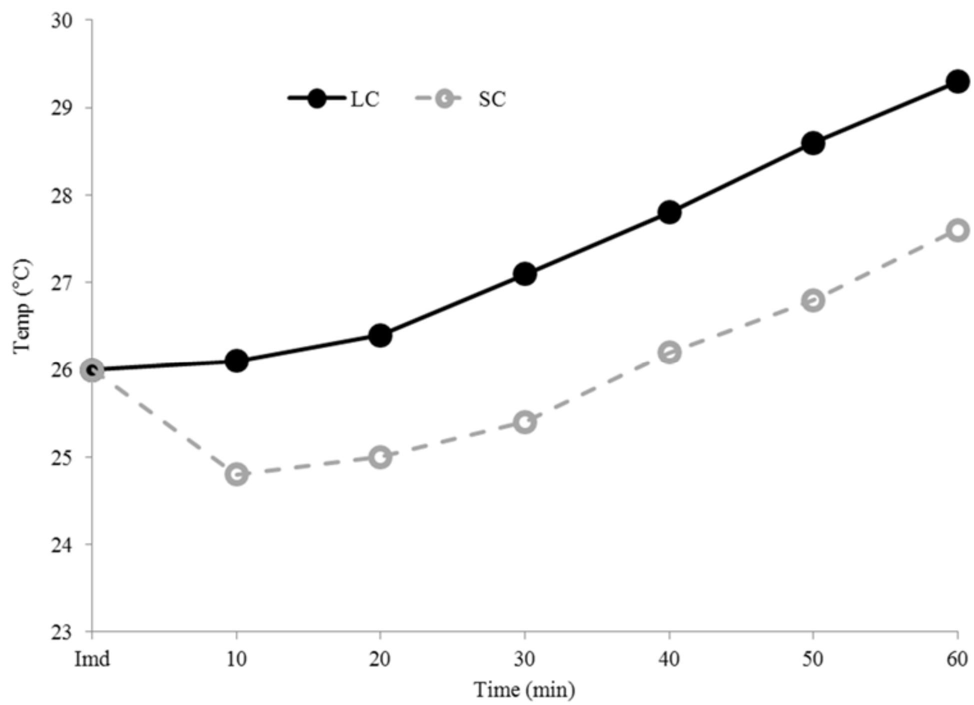

Figure 3. Rewarming Trends By Circumference.

APPENDIX A

EXTENDED RATIONALE AND PURPOSE

The Problem

Statement of the Problem

There are many ways to apply cold to body parts. Factors that influence cooling efficacy include the type of cold modality, use of a compression wrap, time of application, site of application, exercise before and during application, and adipose tissue thickness affect cooling. Although we do not know how cold, cold enough is, we assume that a 1°C decrease has more physiological benefits; therefore, the cooler the better.

In order to help clinicians make sure they get the correct amount of heat removal, there have been attempts to correlate treatment time to tissue temperature. These attempts were unsuccessful. One possible reason for the lack of success is that the effect of limb size on focal cooling is not understood. For example, a 1-kg ice bag applied to a small diameter limb may have a different cooling effect versus applying the same ice bag to a larger limb when both limbs have the same amount of subcutaneous thicknesses.

Moreover, it is likely that ice bags are applied following activity, which speeds cooling. However, this may be relative to amount of muscle mass present in the limb. Since a limb with more muscle mass may be generating more heat, the effects of activity before cooling need to also be addressed. Therefore, the purpose of this study is to determine the effect limb circumference has on intramuscular cooling efficacy during ice bag application, as well as rewarming, following exercise.

Research Questions

This study will attempt to answer the following:

1. Does Tx duration to 10°C below baseline after an exercise bout change because of limb circumference?
2. Does limb circumference effect intramuscular rewarming following a post-exercise ice bag application?

Experimental Hypotheses

The following hypotheses will guide this study:

1. Limb circumference has an effect on the time of intramuscular cooling to reach 10°C below baseline.
2. Limb circumference has an effect on intramuscular rewarming after ice bag application.

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.
3. Thermocouple depths will be consistent between subjects.
4. Participants will have a baseline body temperature of 36°C.

Delimitations

This study will be delimited to the following:

1. Physically active college-aged participants.
2. Quadriceps muscle group.
3. Interface and Intramuscular tissue temperature.
4. Skinfold thickness between 15-30 mm

5. Intramuscular temperatures must reach 10°C below baseline
6. 60 minute post-application period beginning immediately after ice bag removal.

Limitations

Limitation for this study will include:

1. Duration measurement to the nearest full minute
2. 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. Circumference – Average of three measurements of the halfway point between the proximal patellar border and the anterior superior iliac spine.
4. Quadriceps – Midpoint of the quadriceps at the halfway point between the proximal patellar border and the anterior superior iliac spine.
5. Healthy – Individual who has not been taking any prescription medication, not diagnosed with an illness or illnesses or has no allergy to ice.
6. Uninjured – No injury to the lower extremities for the past 3 months.

7. 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.
8. Intramuscular Depth – 2 cm plus ½ skinfold thickness.
9. Baseline Temperature – Average of the temperature that measured for 5 minutes before the ice bag application.
10. Post-Application Time – 60 minutes from the end of application time.

Significance of the Study

Intramuscular cooling is dependent on many factors including type of cold modality, treatment time, compression wrap, exercise before application, and adipose tissue thickness. Missing from this list is limb circumference, which has not been studied. Since a muscle with a larger mass has more volume to generate heat, limbs with a greater muscle mass may need more time to cool to the same temperature as muscles with less mass. After removal of the ice bag, limbs of different sizes may behave differently as they rewarm back to baseline. Furthermore, few studies have been able to compare intramuscular rewarming from the same starting temperature.

APPENDIX B

EXTENDED LITERATURE REVIEW

Review of Literature

The following literature review will discuss the search strategies used, the purposes of cooling, evidence related to the use of cold, factors that affect tissue cooling, rewarming, and temperatures during application

Search Strategies Used

The PUBMed, CIHNAL, and SportDISCUS databases were searched to obtain information using the following keywords, singularly or combined: adipose tissue thickness, cooling, cryokinetics, cryotherapy, efficacy, ice immersion, immersion temperature, intramuscular temperature, and interface temperature. Additional information was obtained from references cited and course textbooks.

Purposes of Cooling

Cold applied directly to the skin removes heat from the body thereby decreasing local tissue temperature.[1] Decreasing skin and tissue temperature decreases pain,[2,3] reduces muscle spasm,[4] decreases edema,[5] and reduces secondary ischemic injury,[6] hence cold is oftentimes applied prophylactically after practices and competitions and immediately following acute injury.

Practically important to this study is the concept of secondary ischemic injury. Secondary ischemic injury refers to phenomenon whereas after primary injury, surrounding undamaged tissues are restricted by lack of oxygen, fuel, and waste removal.[7] Without these necessary components to normal cellular activity, the undamaged cells around the primary injury site begin to die. It is proposed that in order delay death to the undamaged cells, the metabolic rate of those cells needs to be delayed.[6] Although more research is needed, application of cold does help to reduce oxidative enzymes associated with secondary ischemic injury[6] and to reduce the total injury area.[8] Moreover, even though this study will not involve injured participants, the theoretically basis for our target temperature is important to understand.

Evidence Related to the Use of Cold

Researchers have examined the effectiveness of cold treatments following acute injury and surgery. Although this study does not use injured participants, support that a cold treatment can cause a therapeutic benefit is important. While the results of many studies do support that a cold treatment does reduce pain after injury[2] and surgery,[3] and minimizes time to return to play,[9] more randomized controlled studies of better quality need to be performed to reach a conclusion on the direct benefits of cold therapy.

Factors That Affect Tissue Cooling

Despite the widespread use of cold, controversy does exist on the proper parameters for the cold treatments. Although we do not know how cold, cold enough is, we can assume that a 1°C difference has more physiological benefits. Local analgesia requires a surface temperature of 13.6°C[10] while intramuscular decreases of 10°C can reduce metabolic activity[11] by half. Therefore, it is assumed that colder is better and treatments must be optimized to reduce temperatures as efficiently as possible. The type of cold modality, use of a compression wrap, duration of application, exercise before and during application, and adipose tissue thickness are all factors that can affect the efficiency of the treatment.

The type of cold modality directly affects how much heat can be absorbed from the tissues. Cold modalities that undergo a phase change absorb more heat than those modalities that merely warm.[12] Ice bags are inexpensive and easy to make while also cooling tissues similarly or more efficiently than cold whirlpool immersion[13,14] commercially sold cold packs,[15] and gel packs.[16,17] Furthermore, adding water to an ice bag cools to lower temperatures than using ice alone.[18]

Along with the type of modality, the size of the modality matters.[12] A bigger ice bag will cool more efficiently than a smaller ice bag because of the amount of latent heat of fusion potential contained in the ice bag. More importantly, the total surface area that the ice bag covers is more essential to the ability of the ice bag to cool than the overall volume of the ice bag. For this reason, it is common practice for an ice bag to have all air removed and to be contoured to the shape of body part being cooled. Therefore, in this study a 1-kg ice bag consisting of 2000mL of cubed ice and 300mL of room temperature water.

The use of a compression wrap is more effective at cooling tissue than no compression wrap.[19,20] Since the type of compression wrap does not affect cooling, in this study, an elastic compression wrap will be utilized. Although I have no way of determining the exact pressure of the compression wrap, after 5 years of applying ice bags with compression, I can assume that my applications are consistent.

Duration of application is a complicated factor that depends on the goals of the ice bag treatment. Treatment durations have ranged from 8-59 minutes[21] with a majority of researchers using 15-30 minutes. Other studies have examined the duration of ice bag application until a certain temperature is reached in concordance with treatment goals. A treatment to decrease temperature by 7°C takes 8-58.6 minutes depending on adipose tissue thickness.[21] At rest, treatment durations for the quadriceps to reach 10°C below baseline lasted between 45 and 53.6 minutes while after exercise, these treatment durations decreased to 32-40 minutes depending on tissue depth.[22] In the current study, treatment duration will be measured as the time until intramuscular temperate at baseline reaches 26°C, which is consistent with another study.[22]

Adipose tissue just below the skin surface helps insulate the body from changes in temperature. Therefore, it makes sense that adipose tissue would affect cooling efficacy of an ice bag. Since a temperature taken on the surface of the skin will not be affected by adipose tissue thickness below the skin, interface temperatures are not considered. Intramuscular temperatures are inversely related to adipose tissue thickness whereas more adipose tissue results in higher intramuscular temperatures after a specific treatment time.[23] In a comparison of different adipose tissue thicknesses on cooling duration to 7°C,the limbs with more adipose tissue required 50 minutes more cooling than the small thickness limbs.[21] Since adipose tissue thickness may affect our cooling and rewarming data, we will set a range of skinfold thicknesses between 10-30 mm which is consistent with a similar study.[22]

We have already discussed how cold is commonly applied following injury or used as a prophylactic modality after practice or competitions. These two situations both include a pre-application bout of exercise. To date, research has primarily focused on the effects of cold on rested muscles while few studies have examined how exercise effects focal cooling.[22,24-26] While interface cooling trends remained fairly consistent between post-exercise and rest, intramuscular cooling rate was more rapid after exercise compared to rest.[22] Furthermore, during exercise interface cooling remained consistent with previous studies in that the skin cooled with the application of the ice bag while intramuscular temperature did not decrease in temperature at all.[27]

One factor that has been rarely discussed in previous literature is limb circumference. Although one group of researchers determined a correlation between limb size and cooling in the biceps brachii, his findings have been largely overlooked.[28] Furthermore, we found only one study that listed circumference as a demographic statistic.[18] Although research for the most part has ignored limb circumference, we believe it may effect intramuscular cooling after exercise. Limbs with larger circumferences but similar skin fold thicknesses will have larger masses than smaller circumference limbs. After exercise, the larger muscle has more heat generating capacity, although the overall temperature may not be warmer than a smaller muscle. Furthermore, if an ice bag is applied, the ratio of total surface contact area of the muscle to ice bag surface contact area will be much less in a larger limb. Therefore limbs of different sizes may affect intramuscular cooling and rewarming. Since only one study has listed circumference as a demographic, the effect of limb size needs to be explored.

Rewarming

Comparing rewarming temperatures across studies is difficult because of the inconsistency between tissue depth, measurement location, and starting temperature. On the other hand, visually we can study the behavior of the rewarming trends in other studies. Interface and subcutaneous temperatures rewarm shortly after removal of the ice bag.[13,15-16,18-19,24-26,29] Since, in most cases, the thermocouple is placed directly underneath the ice bag, these results are expected.

After removal of an ice bag, intramuscular temperatures of varying depths and locations seem to cool for a small amount of time before gradually rewarming.[13,15,18-19,24-25,29] To our knowledge, previous studies, with the exception of one[24] have examined rewarming data on rested muscles subjected to an ice bag treatment. Since we know that exercised muscle requires one hour to return to baseline temperatures[22] and most treatments durations are under one hour, exercise before ice bag application may also effect rewarming. In the one study that did look at rewarming following exercise, continued cooling did not occur for the exercise group, but data is difficult to compare based on the fact that between the exercise and no-exercise group the rewarming started at different temperatures.

In this study, we will begin rewarming once intramuscular temperatures reach 26°C so that our initial rewarming temperature is the same between both groups. This will allow us to compare temperature at different time points throughout the post-application period. We assume that visually our trends will be consistent with previous research. Comparisons between temperatures could react in three different ways. Both groups could rewarm with no differences between the groups, the large circumference group could rewarm faster, or the small circumference could rewarm faster. However, since research is lacking, we cannot hypothesize on how temperature may differ between the two groups.

Temperatures During Application

The following summary details the effects of focal cooling, using a variety of cold modalities, on interface (Table B1 and B2) and intramuscular (Table B3 and B4) tissue temperatures at rest (Tables B1 and B3) and during and after exercise (Tables B2 and B4). While the two depths of tissues react differently to cold, it is apparent how the aforementioned factors can affect cooling efficacy. Furthermore, this summary will serve to predict the duration and temperatures expected in this study.

Interface. As shown in Table B1, interface temperatures cooled in a range of 3.5°C to 22.1°C depending on the modality, duration of application, and use of a compression wrap. The table does not illustrate how interface temperatures rapidly dropped in temperature within the first ten minutes of application followed by a gradual plateau until the end of treatment.

As discussed earlier, interface cooling trends seem to be unaffected by exercise. During exercise, interface temperatures stayed consistent between the treadmill walking group and the rested group for the entire 30 minute treatment. In fact, at the 30 minute time period, the walking group (10.28°C) was cooler than the resting group (16.87°C).[27] After exercise, the interface cooling trends showed similar results with the rested group and exercise group cooling to the same temperature.[24]

With the work of these previous researchers, it is obvious that interface temperatures are unaffected by rest, exercise before treatment, or exercise during treatment. We are confident that interface temperatures will react similarly to previous research and do not need to be examined. Furthermore, since the premise of our study deals with limb size, examining the surface of the skin does not seem to deliver any insight. Therefore, interface temperatures will not be examined in this study.

Intramuscular. As shown in Table B2, intramuscular temperatures cooled in a range of 22.2°C to 33.94°C depending on type of modality, duration of application, use of a compression wrap, site of application, depth of measurement, adipose tissue thickness, duration of treatment, and exercise before and during application. Intramuscular cooling trends tend to be gradual with tissues at rest continuing to cool after the ice bag has been removed.

Application of an ice bag during exercise did not affect the intramuscular temperature, as tissues cooled only 0.5°C from baseline during the 30 minute treatment.[27] Exercise before treatment has a much more pronounced effect. Although one group of researchers did not notice a difference between an exercise and rest condition before application of an ice bag, they only cooled for 15 minutes which may not be long enough to see an observable difference.[24] Long et al.[22] on the other hand, examined duration of treatment to 10°C below baseline at 1 cm and 2 cm depths. The exercise group cooled to the desired temperature 13 minutes faster than the rest group at 1 cm and 14 minutes at the 2 cm depth. Furthermore, the differences between rest and exercise groups was elicited at the 20 minute mark at both depths which could explain the lack of differences in previous studies.[24]

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[18]	-2000 ml crushed ice bag	20	Calf	15.9	120	26.6
	-2000ml cubed ice bag			16.3		26.1
	-2000ml ice w/300ml H_2O bag			13.3		25.6
Kennet, 2007[13]	-1L crushed ice bag,	20	Ankle	9.24	30	20.5
	-Gel pack			16.01		24
	-Frozen peas			14.61		23
	-Immersion(6L H_2O/1L ice)			13.01		20.5 (Estimated from graph)
Mars, 2006[24]	Crushed ice in a wet towel	15	Thigh	8.1	45	25.6
Merrick, 2003[17]	-1 kg crushed ice bag	30	Thigh	6.47	NA	NA
	-Wet-ice			6.24		
	-Flex-i-cold			9.86		

(table continues)

1st Author, Yr	Modality	Tx Dur (Min.)	Body Part	Post-Tx Temp. (°C)	Re-Warm Dur (Min.)	Final Rewarming Temp. (°C)
Jutte, 2001[30]	500g cubed ice bag	30	Thigh	27 decrease from the baseline	120	30 (Estimated from graph)
Myrer, 1998[14]	-1.8 kg crushed ice bag, -Cold whirlpool (10°C)	20	Calf	13.8 19.0	30	26.1 26.4
Merrick, 1993[19]	1 kg crushed ice bag	30	Thigh	7.24	20	26 (Estimated from graph)
Belitsky, 1987[15]	-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[31]	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 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[24]	Treadmill VO2 max	A pack of crushed ice in a wet towel	15	Thigh	7.0	45	26.4
Palmer, 1996[26]	15min of stationary cycle ergometer at 60-80% maximum heart rate same	Ice pack same	20 30 40 same	Ankle Thigh	5.9 5.2 4.4 4.8 4.2 3.5	20min simulated showering & 40min lying: same	29.2 29.0 26.9 31.1 30.2 29.2
Mancuso, 1992[25]	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 B3. Summary of Reports Regarding Cooling Effects on Rested Intramuscular Temperatures.*

1st Author, Year	Modality	Tx Dur (Min.)	Body Part & Depth Treated	Limb Circum.	Post-Tx Temp. (°C)	Re-Warm Dur (Min.)	Final Rewarming Temp. (°C)
Tomchuk, 2010[20]	-1.58 kg ice bag no compression	30	Calf; 2cm	NA	29.52	60	29.57
	-1.58 kg ice bag elastic wrap				25.53		27.82
	-1.58 kg ice bag Flex-i-Wrap				27.17		27.41
Dykstra, 2009[18]	-2000 ml crushed ice bag	20	Calf; 2 cm + ½ skinfold (12.8 mm)	42.4cm	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[24]	A pack of crushed ice in a wet towel	15	Thigh; 1 cm + adipose thickness (0.43 cm)	NA	26.2	45	29.4
Long, 2005[22]	1-kg ice bag	45.0	•Thigh; 1 cm + ½ skinfold (25.4mm)	NA	27 (Estimated from graph)	NA	NA
		53.6	•Thigh; 2 cm + ½ skinfold (25.4mm)		27.8 (Estimated from graph)		
Merrick, 2003[17]	1-kg crushed ice bag	30	•Thigh; 1 cm + ½ skinfold (19.3 mm)	NA	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[21]	750g crushed ice bag	58.6	Thigh; 1 cm + ½ Skinfold (31-40mm)	NA	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)				

(table continues)

1st Author, Year	Modality	Tx Dur (Min.)	Body Part & Depth Treated	Limb Circum.	Post-Tx Temp. (°C)	Re-Warm Dur (Min.)	Final Rewarming Temp. (°C)
Myrer, 2001[23]	1.8-kg crushed-ice pack	20	•Calf ; 1 cm + ½ skinfold (6.5 mm)	NA	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
Myrer, 2000[32]	1.8-kg crushed-ice pack		•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, 1998[14]	-1.8-kg crushed-ice pack -Cold whirlpool (10°C)	20	Calf; 1 cm + ½ skinfold (16.6 mm)	NA	29.67	30	28.91
Zemke, 1998[33]	-2 cups ice bag -Ice cup	20	Calf; 1 cm + ½ skinfold (not reported)	NA	27.8 28.2	30	29.8 26.4
Merrick, 1993[19]	1-kg crushed ice bag	15	•Calf; 1 cm + subcutaneous thickness (0.78 cm)		29.67	NA	NA
			•Calf; 1 cm + subcutaneous thickness (0.59 cm)		29.67		
Johnson, 1979[34]	10°C water bath	30	•Thigh; 1 cm + ½ skinfold (15.8 mm)	NA	26.58	20	28.5 (Estimated from graph)
			•Thigh; 2 cm + ½ skinfold		28.21		29.5 (Estimated from graph)
Petajan, 1962[31]	Immersion (12.5-13°C H_2O)	30	Calf ; 25.3mm		22.2	240	~ 32.5° (estimated from graph)
		30	Calf (N/A)		29.3	220	28 (Estimated from graph)

* 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[24]	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[22]	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.

APPENDIX C

EXTENDED METHODS

Table C1. Consent Form

CONSENT TO PARTICIPATE IN RESEARCH
University of Northern Iowa

RESEARCH TITLE: Effect of limb circumference on intramuscular cooling during and following an ice bag application after exercise

NAME OF INVESTIGATORS: Marcus Sojka, and Dr. Jody B. Brucker

INVITATION TO PARTICIPATE:
You have been asked to participate in a research study conducted by Marcus Sojka, 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 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 the 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 (skin thickness) measurements of either thigh are less or greater than 10 to 30 mm thickness, you will be excluded due to the limitations of our equipment**.**

NATURE AND PURPOSE:
The purpose of this study is to determine the effect limb size has on muscle cooling during ice bag application, as well as rewarming, following exercise.

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 one 2 ½ hour session.

During the 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 instruments, testing procedures, the risks, and methods in this study. At this time, 3 distance measurements around the leg and 3 skin pinch thickness measures will be taken and averaged.

The location of the thigh temperature collection sites will be identified using a tape measure and marked with a non-permanent pen at the midpoint of the front of the thigh, which will be used for muscle temperature measurement. Data collection will include insertion of a thin wire thermometer into the muscle, application of an ice bag until temperatures reach 10 C below your starting temperature, and temperature measurements before application of the ice bag, during application of the ice bag, and 60 minutes after removal of the ice bag.

Sterile techniques will be used during all procedures. A 5 cm by 5 cm area around the insertion site on your thigh will be shaved and cleansed with a sterilization solution for 3 minutes. The insertion depth will be 2 cm below superficial tissue thickness. A hollow needle will be inserted into your thigh deep enough to enter your muscle, and then removed, leaving a tube in which the thin wire thermometer will be inserted. The thin wire thermometer and the catheter will then be secured to the skin with dressing tape. After the thermometer is connected to the computer, temperature recording will begin.

Following the 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 thin wire 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 techniques will be used during instrument and tissue handling for the needle and thin wire insertion. Any soreness from the needle and thin wire insertion should be minimal, and not affect your daily activities. Since ice will be applied to the site, this may help to reduce muscle soreness caused by instrument insertion. These methods have been consistently used in our research laboratory over the past three years, particularly for cryotherapy research. In addition to the PI, there will be at least one additional CPR/First AID certified individual in the laboratory during data collection.

QUALIFICATIONS OF INVESTIGATORS:
The primary investigator has been properly trained and practiced sterile techniques, correct thin wire 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:
This study may be of no direct benefit to you.

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.

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 Marcus Sojka, LAT ATC University of Northern Iowa (815)222-9559 sojkam@uni.edu	Faculty Sponsor Jody Brucker, PhD, LAT, ATC 003E HPC University of Northern Iowa (319)273-6477 jody.brucker@uni.edu

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 at anita.gordon@uni.edu 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

Study Title: *Effect of limb circumference on intramuscular cooling during and following an ice bag application after exercise.*

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. If there are any words that you do not understand, please ask the investigator and he will explain.

Height: _________ in Weight: ________ lbs Age: __________ yrs

Please answer the following questions to the best of your knowledge:

1.	Do you regularly exercise for at least 30 minutes 2 times a week?	Yes	No
2.	Have you ever applied a cold pack or ice pack directly to your skin?	Yes	No
3.	Did you have any adverse reactions to the cold application?	Yes	No
4.	Are you presently under the care of a Physician, or on any prescription medication?	Yes	No
5.	Do you have a pacemaker?	Yes	No
6.	Do you have, or suspect you have, a blood clotting disorder such as hemophilia?	Yes	No
7.	Do you have, or suspect that you have any circulatory problems, condition, disorders or diseases?	Yes	No
8.	Have you ever been rejected for giving blood?	Yes	No
9.	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
10.	Have you ever had an allergic reaction to adhesives, latex, antibiotic creams or disinfectants (chlorhexidine, rubbing alcohol, etc.)?	Yes	No
11.	Do you have, or suspect that you have, mitral valve prolapse, or any other disease, condition, or disorder that may be aggravated by participating in this study?	Yes	No
12.	Do you experience numbness, tingling, or decreased sensation in extremities, or have other neurological problems, conditions, disorders, or diseases?	Yes	No
13.	Have you injured either one of your legs in the last 3 months?	Yes	No
14.	Have you taken any prescription medication in the last 14 days? (Coumadin, Heparin, antidepressants, sinus medicine, etc.)	Yes	No
15.	Have you taken any over-the-counter medications or dietary supplements in the last 14 days? (Aspirin, Ticlopidine (Ticlid), tissue plasminogen factor, dicumarol, or nonsteroidal anti-inflammatory drugs (NSAIDs), ibuprofen (e.g. Motrin, Advil, Nuprin, etc.), ketop (e.g. Orudis, Orudis KT, Oruvail), naproxen (e.g. Naprosyn, Aleve, Anaprox). Herbal supplements include ginkgo biloba, vitamin E, vitamin K, curcumin (tumeric), N-Acetyl-L-Cysteine, onion juice, garlic capsules, green tea, and/or protein supplements.	Yes	No

If you answered "YES", to any questions, EXCEPT #1 & #2, 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. The questions and responses will be recorded on the back of this page.

I certify that the information provided is correct.

____ ________

Participant Signature Date
Participant #

I certify that the information verbally provided was accurately recorded.

____ ________

Investigator Signature Date

Table C3. 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:
Marcus Sojka (815) 222-9559

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

APPENDIX D

ADDITIONAL RESULTS

Table D1. Uncertainty Data and Analysis. (°C)

WBS Temp.	Time (min.)	SiG	IM 1	ABS Diff	IM2	ABS Diff	IM 3	ABS Diff	IM 4	ABS Diff	IM 5	ABS Diff
1.0	0:30	1.1	1.1	0	1.1	0	1.1	0	1.1	0	1.2	0.1
	1:00	1.1	1.1	0	1.1	0	1.1	0	1.1	0	1.1	0
	1:30	1.1	1.1	0	1.1	0	1.1	0	1.1	0	1.1	0
	2:00	1.1	1.1	0	1.0	0.1	1.0	0.1	1.0	0.1	1.1	0
	2:30	1.1	1.1	0	1.0	0.1	1.0	0.1	1.0	0.1	1.1	0
	3:00	1.1	1.0	0.1	1.0	0.1	1.0	0.1	1.0	0.1	1.1	0
	3:30	1.1	1.0	0.1	1.0	0.1	1.0	0.1	1.0	0.1	1.1	0
	4:00	1.1	1.0	0.1	1.0	0.1	1.0	0.1	1.0	0.1	1.0	0.1
	4:30	1.1	1.0	0.1	1.0	0.1	1.0	0.1	1.0	0.1	1.0	0.1
	5:00	1.1	1.0	0.1	1.0	0.1	1.0	0.1	1.0	0.1	1.0	0.1
Column - (SD) or AVE		***(0.1)***	***0.05***	***(0.0)***	***0.07***	***(0.0)***	***0.07***	***(0.0)***	***0.07***	***(0.1)***	***0.04***	
10.0	0:30	9.4	9.5	0.1	9.4	0	9.4	0	9.4	0	9.7	0.3
	1:00	9.4	9.5	0.1	9.4	0	9.4	0	9.4	0	9.7	0.3
	1:30	9.4	9.5	0.1	9.5	0.1	9.4	0	9.4	0	9.7	0.3
	2:00	9.4	9.5	0.1	9.5	0.1	9.5	0.1	9.5	0.1	9.7	0.3
	2:30	9.4	9.5	0.1	9.5	0.1	9.5	0.1	9.5	0.1	9.7	0.3
	3:00	9.4	9.5	0.1	9.5	0.1	9.5	0.1	9.5	0.1	9.7	0.3
	3:30	9.4	9.5	0.1	9.5	0.1	9.5	0.1	9.5	0.1	9.7	0.3
	4:00	9.4	9.5	0.1	9.5	0.1	9.5	0.1	9.5	0.1	9.7	0.3
	4:30	9.4	9.5	0.1	9.5	0.1	9.5	0.1	9.5	0.1	9.7	0.3
	5:00	9.4	9.5	0.1	9.5	0.1	9.5	0.1	9.5	0.1	9.7	0.3
Column - (SD) or AVE		***(0.0)***	***0.1***	***(0.0)***	***0.08***	***(0.0)***	***0.07***	***(0.0)***	***0.07***	***(0.0)***	***0.3***	
20.0	0:30	19.7	19.6	0.1	19.6	0.1	19.5	0.2	19.6	0.1	19.8	0.1
	1:00	19.7	19.6	0.1	19.6	0.1	19.5	0.2	19.6	0.1	19.8	0.1
	1:30	19.7	19.6	0.1	19.6	0.1	19.6	0.1	19.6	0.1	19.8	0.1
	2:00	19.7	19.6	0.1	19.6	0.1	19.6	0.1	19.6	0.1	19.8	0.1
	2:30	19.7	19.6	0.1	19.6	0.1	19.6	0.1	19.6	0.1	19.8	0.1
	3:00	19.7	19.6	0.1	19.6	0.1	19.6	0.1	19.6	0.1	19.8	0.1
	3:30	19.7	19.6	0.1	19.6	0.1	19.6	0.1	19.6	0.1	19.8	0.1
	4:00	19.7	19.6	0.1	19.6	0.1	19.6	0.1	19.6	0.1	19.8	0.1
	4:30	19.7	19.6	0.1	19.6	0.1	19.6	0.1	19.6	0.1	19.8	0.1
	5:00	19.7	19.6	0.1	19.6	0.1	19.6	0.1	19.6	0.1	19.8	0.1
Column - (SD) or AVE		***(0.0)***	***0.1***	***(0.0)***	***0.1***	***(0.0)***	***0.12***	***(0.0)***	***0.1***	***(0.0)***	***0.1***	
30.0	0:30	29.4	29.5	0.1	29.5	0.1	29.5	0.1	29.5	0.1	29.7	0.3
	1:00	29.4	29.5	0.1	29.5	0.1	29.5	0.1	29.5	0.1	29.7	0.3
	1:30	29.4	29.5	0.1	29.5	0.1	29.5	0.1	29.5	0.1	29.7	0.3
	2:00	29.4	29.5	0.1	29.5	0.1	29.5	0.1	29.5	0.1	29.7	0.3
	2:30	29.4	29.5	0.1	29.5	0.1	29.5	0.1	29.5	0.1	29.7	0.3

(table continues)

WBS Temp.	Time (min.)	SiG	IM 1	ABS Diff	IM2	ABS Diff	IM 3	ABS Diff	IM 4	ABS Diff	IM 5	ABS Diff
	3:00	29.4	29.5	0.1	29.5	0.1	29.5	0.1	29.5	0.1	29.7	0.3
	3:30	29.4	29.5	0.1	29.5	0.1	29.5	0.1	29.5	0.1	29.7	0.3
	4:00	29.4	29.5	0.1	29.5	0.1	29.5	0.1	29.5	0.1	29.7	0.3
	4:30	29.4	29.5	0.1	29.5	0.1	29.5	0.1	29.5	0.1	29.7	0.3
	5:00	29.4	29.5	0.1	29.5	0.1	29.5	0.1	29.5	0.1	29.7	0.3
Column - (SD) or AVE			***(0.0)***	***0.1***	***(0.0)***	***0.1***	***(0.0)***	***0.1***	***(0.0)***	***0.1***	***(0.0)***	***0.3***
40.0	0:30	39.7	39.6	0.1	39.5	0.2	39.5	0.2	39.5	0.2	39.4	0.3
	1:00	39.7	39.6	0.1	39.5	0.2	39.5	0.2	39.5	0.2	39.4	0.3
	1:30	39.7	39.6	0.1	39.5	0.2	39.5	0.2	39.5	0.2	39.4	0.3
	2:00	39.7	39.6	0.1	39.5	0.2	39.5	0.2	39.5	0.2	39.4	0.3
	2:30	39.7	39.6	0.1	39.5	0.2	39.5	0.2	39.5	0.2	39.4	0.3
	3:00	39.7	39.6	0.1	39.5	0.2	39.5	0.2	39.5	0.2	39.4	0.3
	3:30	39.7	39.6	0.1	39.5	0.2	39.5	0.2	39.5	0.2	39.4	0.3
	4:00	39.7	39.6	0.1	39.5	0.2	39.5	0.2	39.5	0.2	39.4	0.3
	4:30	39.7	39.6	0.1	39.5	0.2	39.5	0.2	39.5	0.2	39.4	0.3
	5:00	39.7	39.6	0.1	39.5	0.2	39.5	0.2	39.5	0.2	39.4	0.3
Column - (SD) or AVE			***(0.0)***	***0.1***	***(0.0)***	***0.2***	***(0.0)***	***0.2***	***(0.0)***	***0.2***	***(0.0)***	***0.3***
Reliability*		**0.0**										
Validity†		**0.1**										
Uncertainty‡		**0.1**										

Water Bath Setting (WBS), Spirit in Glass Thermometer Temperature (SiG), Intramuscular Thermocouple (IM), Absolute difference from SiG Temperature at same Time (ABS Diff).

* = average of all (SD) numbers
† = average of all AVE numbers
‡ = sum of Reliability and Validity

Table D2. Subject Demographics.

Subject#	Sex	Age (yrs)	Ht (cm)	Mass (kg)	Skinfold (mm)	Circumference (cm)	Resting Heart Rate (bpm)
1	m	21	172.7	90.7	14	62.5	72
2	m	21	182.9	86.2	22	63.5	78
3	m	21	177.8	81.7	14	61.5	71
6	m	23	175.3	84.8	24	63.5	72
7	m	26	182.9	83.9	17	58	65
11	m	21	177.8	81.7	12	53	70
12	f	24	170.2	61.2	24	54	69
14	m	18	172.7	74.8	18	51	67
15	m	18	175.3	72.6	20	50	78
16	f	18	167.6	56.7	15	50	71
17	f	18	165.1	59.0	17	52	68
Mean		20.8	174.6	75.8	17.9	56.3	71
SD		2.7	5.7	11.9	4.1	5.6	4.1

Table D3. F-Statistic Results For Circumference Effect On Cooling Duration.

Source Term	DF	Sum of Squares	Mean Square	F-Ratio	Prob Level	Power (Alpha=0.05)
A: Circ	1	121.2121	121.2121	17.79	0.002248*	0.962180
B(A): Subj	9	61.33333	6.814815			
S	0					
Total (Adj)	10	182.5455				
Total	11					

* Term significant at alpha = 0.05

Table D4. Tukey-Kramer's CIs for MCs of Circumference Effect on Cooling Duration.

Comparison Groups	Count	Mean	Lower 95.0% Simult.C.I.	Mean Difference	Upper 95.0% Simult.C.I.	Test Result
Lg	5	53.5				
- Sm	6	46.8	3.1	6.7	10.2	U
Sm	6	46.8				
- Lg	5	53.5	-10.2	-6.7	-3.1	L

Alpha=0.050 Error Term=B(A) DF=9 MSE=6.814815 Critical Value=3.1992

Table D5. F-Statistic Results For Circumference and Time Effects On Rewarming Temperature.

Source Term	DF	Sum of Squares	Mean Square	F-Ratio	Prob Level	Power (Alpha=0.05)
A: Circ	1	35.08588	35.08588	14.40	0.004252*	0.920334
B(A): Subj	9	21.92865	2.436517			
C: Time	6	82.09573	13.68262	114.64	0.000000*(G-G)	1.000000(G-G)
AC	6	6.231854	1.038642	8.70	0.003805*(G-G)	0.908986(G-G)
BC(A)	54	6.445171	0.119355			
S	0					
Total (Adj)	76	150.5161				
Total	77					

* Term significant at alpha = 0.05

Table D6. F-Statistic Results For Time Effects On Small Circumference Rewarming Temperature.

Source Term	DF	Sum of Squares	Mean Square	F-Ratio	Prob Level	Power (Alpha=0.05)
A: Subj	5	14.78667	2.957334			
B: Time	6	36.53632	6.089386	56.56	0.000132*(G-G)	0.999999(G-G)
AB	30	3.229914	0.1076638			
S	0					
Total (Adj)	41	54.5529				
Total	42					

* Term significant at alpha = 0.05

Table D7. Tukey-Kramer's CIs for MCs of All Time Pairs On SC Temperatures by Time.

Comparison Groups	Count	Mean	Lower 95.0% Simult.C.I.	Mean Difference	Upper 95.0% Simult.C.I.	Test Result
Imd	6	26.0				
- 10	6	24.8	0.6	1.2	1.8	U
- 20	6	25.0	0.4	1.0	1.6	U
- 30	6	25.4	0.0	0.6	1.2	
- 40	6	26.2	-0.8	-0.2	0.4	
- 50	6	26.8	-1.4	-0.8	-0.2	L
- 60	6	27.6	-2.2	-1.6	-1.0	L
10	6	24.8				
-Imd	6	26.0	-1.8	-1.2	-0.6	L
- 20	6	25.0	-0.8	-0.2	0.4	
- 30	6	25.4	-1.2	-0.6	0.0	L
- 40	6	26.2	-2.0	-1.4	-0.8	L
- 50	6	26.8	-2.6	-2.0	-1.4	L
- 60	6	27.6	-3.4	-2.8	-2.2	L
20	6	25.0				

(table continues)

Comparison Groups	Count	Mean	Lower 95.0% Simult.C.I.	Mean Difference	Upper 95.0% Simult.C.I.	Test Result
-Imd	6	26.0	-1.6	-1.0	-0.4	L
- 10	6	24.8	-0.4	0.2	0.8	
- 30	6	25.4	-1.0	-0.4	0.2	
- 40	6	26.2	-1.8	-1.3	-0.7	L
- 50	6	26.8	-2.4	-1.8	-1.2	L
- 60	6	27.6	-3.2	-2.6	-2.0	L
30	6	25.4				
-Imd	6	26.0	-1.2	-0.6	0.0	
- 10	6	24.8	0.0	0.6	1.2	U
- 20	6	25.0	-0.2	0.4	1.0	
- 40	6	26.2	-1.4	-0.8	-0.2	L
- 50	6	26.8	-2.0	-1.4	-0.8	L
- 60	6	27.6	-2.8	-2.2	-1.6	L
40	6	26.2				
-Imd	6	26.0	-0.4	0.2	0.8	
- 10	6	24.8	0.8	1.4	2.0	U
- 20	6	25.0	0.7	1.3	1.8	U
- 30	6	25.4	0.2	0.8	1.4	U
- 50	6	26.8	-1.2	-0.6	0.0	
- 60	6	27.6	-2.0	-1.4	-0.8	L
50	6	26.8				
-Imd	6	26.0	0.2	0.8	1.4	U
- 10	6	24.8	1.4	2.0	2.6	U
- 20	6	25.0	1.2	1.8	2.4	U
- 30	6	25.4	0.8	1.4	2.0	U
- 40	6	26.2	0.0	0.6	1.2	
- 60	6	27.6	-1.4	-0.8	-0.2	L
60	6	27.6				
-Imd	6	26.0	1.0	1.6	2.2	U
- 10	6	24.8	2.2	2.8	3.4	U
- 20	6	25.0	2.0	2.6	3.2	U
- 30	6	25.4	1.6	2.2	2.8	U
- 40	6	26.2	0.8	1.4	2.0	U
- 50	6	26.8	0.2	0.8	1.4	U

Alpha=0.050 Error Term=AB DF=30 MSE=0.1076638 Critical Value=4.4642

Table D8. F-Statistic Results For Time Effects On Large Circumference Rewarming Temperature.

Source Term	DF	Sum of Squares	Mean Square	F-Ratio	Prob Level	Power (Alpha=0.05)
A: Subj	4	7.141983	1.785496			
B: Time	6	50.52003	8.420005	62.85	0.000000*	1.000000
AB	24	3.215257	0.1339691			
S	0					
Total (Adj)	34	60.87727				
Total	35					

* Term significant at alpha = 0.05

Table D9. Tukey-Kramer's CIs for MCs of All Time Pairs On LC Temperatures by Time

Comparison Groups	Count	Mean	Lower 95.0% Simult.C.I.	Mean Difference	Upper 95.0% Simult.C.I.	Test Result
Imd	5	26.0				
- 10	5	26.1	-0.8	-0.1	0.6	
- 20	5	26.4	-1.1	-0.3	0.4	
- 30	5	27.1	-1.8	-1.1	-0.3	L
- 40	5	27.8	-2.5	-1.8	-1.0	L
- 50	5	28.6	-3.3	-2.6	-1.8	L
- 60	5	29.3	-4.1	-3.3	-2.6	L
10	5	26.1				
-Imd	5	26.0	-0.6	0.1	0.8	
- 20	5	26.4	-1.0	-0.2	0.5	
- 30	5	27.1	-1.7	-1.0	-0.2	L
- 40	5	27.8	-2.4	-1.7	-1.0	L
- 50	5	28.6	-3.2	-2.5	-1.7	L
- 60	5	29.3	-4.0	-3.2	-2.5	L
20	5	26.4				
-Imd	5	26.0	-0.4	0.3	1.1	
- 10	5	26.1	-0.5	0.2	1.0	
- 30	5	27.1	-1.5	-0.7	0.0	
- 40	5	27.8	-2.2	-1.4	-0.7	L
- 50	5	28.6	-3.0	-2.2	-1.5	L
- 60	5	29.3	-3.7	-3.0	-2.2	L
30	5	27.1				
-Imd	5	26.0	0.3	1.1	1.8	U
- 10	5	26.1	0.2	1.0	1.7	U
- 20	5	26.4	0.0	0.7	1.5	
- 40	5	27.8	-1.5	-0.7	0.0	
- 50	5	28.6	-2.3	-1.5	-0.8	L
- 60	5	29.3	-3.0	-2.3	-1.5	L
40	5	27.8				
-Imd	5	26.0	1.0	1.8	2.5	U
- 10	5	26.1	1.0	1.7	2.4	U
- 20	5	26.4	0.7	1.4	2.2	U
- 30	5	27.1	0.0	0.7	1.5	
- 50	5	28.6	-1.5	-0.8	-0.1	L
- 60	5	29.3	-2.3	-1.5	-0.8	L
50	5	28.6				
-Imd	5	26.0	1.8	2.6	3.3	U
- 10	5	26.1	1.7	2.5	3.2	U
- 20	5	26.4	1.5	2.2	3.0	U
- 30	5	27.1	0.8	1.5	2.3	U
- 40	5	27.8	0.1	0.8	1.5	U
- 60	5	29.3	-1.5	-0.7	0.0	
60	5	29.3				
-Imd	5	26.0	2.6	3.3	4.1	U
- 10	5	26.1	2.5	3.2	4.0	U
- 20	5	26.4	2.2	3.0	3.7	U
- 30	5	27.1	1.5	2.3	3.0	U
- 40	5	27.8	0.8	1.5	2.3	U
- 50	5	28.6	0.0	0.7	1.5	

Alpha=0.050 Error Term=AB DF=24 MSE=0.1339691 Critical Value=4.5413

Table D10. F-Statistic Results For Circumference Effects At The Imd Time Rewarming Temperature.

Imd Analysis of Variance Table

Source Term	DF	Sum of Squares	Mean Square	F-Ratio	Prob Level	Power (Alpha=0.05)
A: Circ	1	6.136363E-04	6.136363E-04	0.27	0.618356	0.074917
B(A): Subj	9	0.02075	2.305556E-03			
S	0					
Total (Adj)	10	2.136364E-02				
Total	11					

* Term significant at alpha = 0.05

Table D11. Tukey-Kramer's CIs for MCs of Circumference Pairs On Imd Time Temperatures.

Comparison Groups	Count	Mean	Lower 95.0% Simult.C.I.	Mean Difference	Upper 95.0% Simult.C.I.	Test Result
Lg	5	26.0				
- Sm	6	26.0	-0.1	0.0	0.1	
Sm	6	26.0				
- Lg	5	26.0	-0.1	0.0	0.1	

Alpha=0.050 Error Term=B(A) DF=9 MSE=2.305556E-03 Critical Value=3.1992

Table D12. F-Statistic Results For Circumference Effects At The 10-Minute Time Rewarming Temperature.

Source Term	DF	Sum of Squares	Mean Square	F-Ratio	Prob Level	Power (Alpha=0.05)
A: Circ	1	4.685038	4.685038	7.14	0.025561*	0.662973
B(A): Subj	9	5.908253	0.6564726			
S	0					
Total (Adj	10	10.59329				
Total	11					

* Term significant at alpha = 0.05

Table D13. Tukey-Kramer's CIs for MCs of Circumference Pairs On 10-Minute Time Temperatures.

Comparison Groups	Count	Mean	Lower 95.0% Simult.C.I.	Mean Difference	Upper 95.0% Simult.C.I.	Test Result
Lg	5	26.1				
- Sm	6	24.8	0.2	1.3	2.4	U
Sm	6	24.8				
- Lg	5	26.1	-2.4	-1.3	-0.2	L

Alpha=0.050 Error Term=B(A) DF=9 MSE=0.6564726 Critical Value=3.1992

Table D14. F-Statistic Results For Circumference Effects At The 20-Minute Time Rewarming Temperature.

Source Term	DF	Sum of Squares	Mean Square	F-Ratio	Prob Level	Power (Alpha=0.05)
A: Circ	1	5.246643	5.246643	7.86	0.020605*	0.704272
B(A): Subj	9	6.00923	0.6676922			
S	0					
Total (Adj)	10	11.25587				
Total	11					

* Term significant at alpha = 0.05

Table D15. Tukey-Kramer's CIs for MCs of Circumference Pairs On 20-Minute Time Temperatures.

Comparison Groups	Count	Mean	Lower 95.0% Simult.C.I.	Mean Difference	Upper 95.0% Simult.C.I.	Test Result
Lg	5	26.4				
- Sm	6	25.0	0.3	1.4	2.5	U
Sm	6	25.0				
- Lg	5	26.4	-2.5	-1.4	-0.3	L

Alpha=0.050 Error Term=B(A) DF=9 MSE=0.6676922 Critical Value=3.1992

Table D16. F-Statistic Results For Circumference Effects At The 30-Minute Time Rewarming Temperature.

Source Term	DF	Sum of Squares	Mean Square	F-Ratio	Prob Level	Power (Alpha=0.05)
A: Circ	1	7.509238	7.509238	11.99	0.007131*	0.867883
B(A): Subj	9	5.636653	0.6262948			
S	0					
Total (Adjusted)	10	13.14589				
Total	11					

* Term significant at alpha = 0.05

Table D17. Tukey-Kramer's CIs for MCs of Circumference Pairs On 30-Minute Time Temperatures.

Comparison Groups	Count	Mean	Lower 95.0% Simult.C.I.	Mean Difference	Upper 95.0% Simult.C.I.	Test Result
Lg	5	27.1				
- Sm	6	25.4	0.6	1.7	2.7	U
Sm	6	25.4				
- Lg	5	27.1	-2.7	-1.7	-0.6	L

Table D18. F-Statistic Results For Circumference Effects At The 40-Minute Time Rewarming Temperature.

40 Analysis of Variance Table						
Source Term	DF	Sum of Squares	Mean Square	F-Ratio	Prob Level	Power (Alpha=0.05)
A: Circ	1	6.81986	6.81986	12.85	0.005893*	0.889311
B(A): Subj	9	4.778214	0.5309126			
S	0					
Total (Adjusted)	10	11.59807				
Total	11					

* Term significant at alpha = 0.05

Table D19. Tukey-Kramer's CIs for MCs of Circumference Pairs On 40-Minute Time Temperatures.

Comparison Groups	Count	Mean	Lower 95.0% Simult.C.I.	Mean Difference	Upper 95.0% Simult.C.I.	Test Result
Lg	5	27.8				
- Sm	6	26.2	0.6	1.6	2.6	U
Sm	6	26.2				
- Lg	5	27.8	-2.6	-1.6	-0.6	L

Alpha=0.050 Error Term=B(A) DF=9 MSE=0.5309126 Critical Value=3.1992

Table D20. F-Statistic Results For Circumference Effects At The 50-Minute Time Rewarming Temperature.

Source Term	DF	Sum of Squares	Mean Square	F-Ratio	Prob Level	Power (Alpha=0.05)
A: Circ	1	8.761251	8.761251	23.09	0.000967*	0.988938
B(A): Subj	9	3.415003	0.3794448			
S	0					
Total (Adjusted)	10	12.17625				
Total	11					

* Term significant at alpha = 0.05

Table D21. Tukey-Kramer's CIs for MCs of Circumference Pairs On 50-Minute Time Temperatures.

Comparison Groups	Count	Mean	Lower 95.0% Simult.C.I.	Mean Difference	Upper 95.0% Simult.C.I.	Test Result
Lg	5	28.6				
- Sm	6	26.8	0.9	1.8	2.6	U
Sm	6	26.8				
- Lg	5	28.6	-2.6	-1.8	-0.9	L

Alpha=0.050 Error Term=B(A) DF=9 MSE=0.3794448 Critical Value=3.1992

Table D22. F-Statistic Results For Circumference Effects At The 60-Minute Time Rewarming Temperature.

Source Term	DF	Sum of Squares	Mean Square	F-Ratio	Prob Level	Power (Alpha=0.05)
A: Circ	1	8.295098	8.295098	28.65	0.000461*	0.997136
B(A): Subj	9	2.60572	0.2895244			
S	0					
Total (Adjusted)	10	10.90082				
Total	11					

* Term significant at alpha = 0.05

Table D23. Tukey-Kramer's CIs for MCs of Circumference Pairs On 60-Minute Time Temperatures.

Comparison Groups	Count	Mean	Lower 95.0% Simult.C.I.	Mean Difference	Upper 95.0% Simult.C.I.	Test Result
Lg	5	29.3				
- Sm	6	27.6	1.0	1.7	2.5	U
Sm	6	27.6				
- Lg	5	29.3	-2.5	-1.7	-1.0	L

Alpha=0.050 Error Term=B(A) DF=9 MSE=0.2895244 Critical Value=3.1992

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