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The Effects of Three Different Ice Bath Immersion Times on Numbness (Sensation of Pressure), Surface Temperature, and Perceived Pain

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THE EFFECTS OF THREE DIFFERENT ICE BATH IMMERSION TIMES ON NUMBNESS (SENSATION OF PRESSURE), SURFACE TEMPERATURE, AND PERCEIVED PAIN

by

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GRADUATE COMMITTEE APPROVAL

of a thesis submitted by

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

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BRIGHAM YOUNG UNIVERSITY

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

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ABSTRACT

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Norma E. Johnson

Department of Exercise Sciences

Master of Science

Objectives: Determine if numbness differs in magnitude and duration between 10-, 15-, and 20-min ice bath immersions, when temperature was held constant. **Design:** Dependant variables; sensation of pressure (g), perceived pain (cm), and skin temperature (º C). A repeated measures 3 X 19 factorial guided this study. Conditions were 10-, 15-, and 20-min ice bath immersions. Measurement times were before immersion, 1, 3, 5, 7, 9, 10, 11, 13, 15, 17, 19, and 20 min immersion, and 1.5, 3, 5, 7, 9 and 11 min postimmersion. **Subjects:** Eighteen college-aged volunteers. **Measurements:** Subjects participated in three ice bath immersions (10, 15, and 20 min). Sensation of pressure was tested over the anterior talofibular ligament prior to immersion, and 1.5, 3, 5, 7, 9, and 11 min postimmersion. Cold induced pain was recorded at baseline (prior to treatment),

every 2 min during immersion (beginning with 1 min), immediately following foot removal (10, 15, and 20 min), and directly following each monofilament reading (1.5, 3, 5, 7, 9, and 11 min posttreatment). Water bath and skin temperature were recorded every min (baseline to 11 min postimmersion). ANOVA's and Tukey-Kramer multiple range tests were used to determine significance. **Results:** Water bath temperature was held constant at 1° C. Loss of sensation was greater following 20 min of immersion than 10 min of immersion at all postimmersion measurement times. The greatest loss of sensation was at 1.5 min following the 20-min immersion. Cold induced pain was greatest, in all conditions, during the first 5 min of immersion. Pain peaked at 1 min of immersion and declined sharply until 9 min after immersion. Postimmersion pain was significantly greater following 20 min of immersion than 10 or 15 min of immersion. Skin temperature did not differ among conditions at baseline or during immersion. **Conclusions:** Our research supports clinical recommendations of 12-20 min initial immersion during cryokinetics. There was no difference in water or skin temperature between groups; therefore, the increased magnitude and duration of numbness following 20-min immersion was due to the increased length of immersion. Prolonging immersion past the point of perceived numbness may be beneficial. **Key words:** numbness, cryokinetics, cold water bath, cryotherapy, rehabilitation

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The Effects of Three Different Ice Bath Immersion Times on Numbness (Sensation of Pressure), Surface Temperature, and Perceived Pain

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Abstract

Objectives: Determine if numbness differs in magnitude and duration between 10-, 15-, and 20-min ice bath immersions, when temperature was held constant. **Design:** Dependant variables; sensation of pressure (g), perceived pain (cm), and skin temperature (º C). A repeated measures 3 X 19 factorial guided this study. Conditions were 10-, 15-, and 20-min ice bath immersions. Measurement times were before immersion, 1, 3, 5, 7, 9, 10, 11, 13, 15, 17, 19, and 20 min immersion, and 1.5, 3, 5, 7, 9 and 11 min postimmersion. **Subjects:** Eighteen college-aged volunteers. **Measurements:** Subjects participated in three ice bath immersions (10, 15, and 20 min). Sensation of pressure was tested over the anterior talofibular ligament prior to immersion, and 1.5, 3, 5, 7, 9, and 11 min postimmersion. Cold induced pain was recorded at baseline (prior to treatment), every 2 min during immersion (beginning with 1 min), immediately following foot removal (10, 15, and 20 min), and directly following each monofilament reading (1.5, 3, 5, 7, 9, and 11 min posttreatment). Water bath and skin temperature were recorded every min (baseline to 11 min postimmersion). ANOVA's and Tukey-Kramer multiple range tests were used to determine significance. **Results:** Water bath temperature was held constant at 1° C. Loss of sensation was greater following 20 min of immersion than 10 min of immersion at all postimmersion measurement times. The greatest loss of sensation was at 1.5 min following the 20-min immersion. Cold induced pain was greatest, in all conditions, during the first 5 min of immersion. Pain peaked at 1 min of immersion and declined sharply until 9 min after immersion. Postimmersion pain was significantly greater following 20 min of immersion than 10 or 15 min of immersion.

Skin temperature did not differ among conditions at baseline or during immersion. **Conclusions:** Our research supports clinical recommendations of 12-20 min initial immersion during cryokinetics. There was no difference in water or skin temperature between groups; therefore, the increased magnitude and duration of numbness following 20-min immersion was due to the increased length of immersion. Prolonging immersion past the point of perceived numbness may be beneficial. **Key words:** numbness, cryokinetics, cold water bath, cryotherapy, rehabilitation

Introduction

Cryotherapy is effective in both immediate care and rehabilitation of injuries. One rehabilitative technique, cryokinetics,[1,2] uses ice to reduce pain so that the patient can begin exercise soon after injury. With injury, pain reduces range of motion and inhibits normal gait, leading to restricted and/or incorrect motor patterns. By inducing numbness, the healing effects of motion can take place with minimal restriction. Ice is merely a means of inducing localized analgesia, thus allowing movement to occur earlier.[1-3]

Many types of cold application can be used in cryokinetics, however, ice bath immersion is preferred when treating the extremities.[1,3,4] Immersion in 1º C water appears to be more effective than 4º C, and 10º C water in inducing numbness and decreasing skin surface temperature.[5] Cryokinetic immersion times have not been studied, but clinical experience indicates that 12-20 min of initial immersion allows approximately 3-5 min of pain free rehabilitation.[3] This research was conducted to answer the following. *Research Question:* Does numbness differ in magnitude and duration between three different ice bath immersion times, when temperature is held constant?

Methods

The design for this study was a repeated measures 3 X 19 factorial. The independent variables were immersion time (10, 15, and 20 min) and measurement time (before immersion, 1, 3, 5, 7, 9, 10, 11, 13, 15, 17, 19, and 20 min during immersion, and 1.5, 3, 5, 7, 9 and 11 min postimmersion). Dependant variables were sensation of pressure (g), perceived pain (cm), and skin temperature (ºC). Water bath temperature

was recorded as a control variable. Subjects were randomly assigned to one of six treatment orders established by two 3 x 3 Balanced Latin Squares.

Subjects

Nine male (height 70.22 ± 1.72 in; weight 172.11 ± 18.81 lbs) and nine female (height 65.78 ± 2.73 in; weight 145 ± 14.58 lbs) college-aged (age 23.89 ± 2.42) volunteers participated in this study. Subjects reported via a medical history questionnaire, no past frostbite, adverse reactions to cold, neurological disorders, cardiovascular disorders, or ankle injuries within six months. The study was approved by the Institutional Review Board, and all subjects gave written informed consent.

Measurements

Numbness was quantified using 48 Semmes-Weinstein monofilaments (Connecticut Bioinstruments, CT), which exerted 0.0082 to 196.69 grams of force when applied. The Semmes-Weinstein monofilaments are reliable when manufactured and calibrated correctly.[6] We calibrated each monofilament by taking the average force of 10 measurements on a 1/10000th of a gram sensitive scale (XA Fisher Scientific, Denver). We then laid the monofilaments out in order from smallest to the most pressure production. Forces reported in these data are consistent with our calibration results.

When a monofilament is applied, the calibrated pressure occurs when the monofilament bends. Variability in application force is absorbed in the bend of the monofilament. Variablility is also minimized by having only one monofilament tester who uses consistent application speed.[7,8] Consistent application speed was practiced by the tester prior to data collection using a metronome.

Monofilaments were applied perpendicular to the skin until it bowed, held approximately 1.5 sec and released. Each filament was applied 2-3 times, with two out of three correct responses (those in which a monofilament was applied and the subject responded with a "yes") indicating the subject felt the monofilament.[8]

Skin temperature was measured with type-T thermocouples (TX-31; Columbus Instruments, Colombus, Ohio) via a 16-channel Isothermex (Columbus Instruments, Colombus, Ohio) interfaced with a personal computer. The thermocouples were applied with 2 X ¼ in Leukotape P (Beiersdorf, Bangkok, Thailand), over the right anterior talofibular (ATF) ligament. This location was marked with a permanent marker to insure consistent placement of the thermocouple. The tape was placed proximal to the tip of the thermocouple to insure it remained in contact with the skin, but did not cover the thermocouple tip, or the ATF ligament. Additional tape was applied at four locations proximal to the immersion site, stabilizing the thermocouple from the ankle to the knee.

Pain, induced by the ice bath, was measured with a visual analog scale and reported in cm.[9] Subjects marked the visual analog scale at baseline (prior to treatment), every 2 min during immersion (beginning with 1 min), immediately following foot removal (10, 15, and 20 min), and directly following each monofilament reading (1.5, 3, 5, 7, 9, and 11 min posttreatment). Subjects were allowed to see their previously marked scale as a means of providing a reference point because most individuals think in terms of change, rather than in absolute terms.[9] Additionally, we asked the subjects to indicate the location of greatest pain at each time point. No standardized anatomical chart or descriptors were given.

A 7 gallon cooler of ice water (1º C) was placed on the floor in front of the seated subject, and filled with water to cover approximately 5 cm above the lateral malleolus. This location was marked with a permanent marker to insure consistent water depth. To insure that the water stayed as close to 1º C as possible, a thermocouple (TX-31) was placed in the water and temperature readings were taken every min. To inhibit thermal gradients, an air pump (Breg, Vista, California) was placed in the water to insure constant water movement.[3] We also stirred the water vigorously every min. Ice was added and removed as needed to keep the temperature consistent.

Procedures

Subjects participated in three days of testing. Testing sessions were at the same time of day, and at least 24 hours apart. Females were scheduled to avoid menstruation. Upon agreeing to participate in the study, the subjects were advised to get a typical night's sleep, fast three hours prior to participation, and avoid activities that would significantly increase circulation. Subjects were asked, prior to each day's testing, if any of the above recommendations had been violated (if the recommendations for activities prior to participation had been violated, they would have been rescheduled). There were no violations of the prior activity protocol.

On the first day of testing, subjects arrived 10 min early in order to learn about testing procedure, fill out the medical history questionnaire, learn how to use the visual analog scale, undergo a 3-min cold sensitivity test (including monofilament practice), and sign the written informed consent. The cold sensitivity test consisted of a 3-min ice

massage applied to the left gastrocnemius. This was performed in order to rule out any allergic reaction to cold.[3] Pilot work also indicated that monofilament detection was especially difficult immediately after cold application. Accuracy of monofilament responses increased following the first trial. Therefore, following the ice massage, the monofilaments were applied to the numb gastrocnemius in order to expose the subject to the unfamiliar sensations.

Each day of testing began with the subjects seated for 10 min while the thermocouple was attached and a baseline skin temperature was reached. Just before their foot was immersed into the bath, a monofilament measurement was taken, and then a toe cap (McDavid) was pulled over the toes. Previous studies have shown greater compliance when verbal distractions were allowed.[10,11] Therefore, we talked to, and encouraged the subjects through the cold induced pain.

Following immersion, the foot was lifted from the ice bath and the toe cap was removed. The cooler was then moved to the side, and the foot was lowered onto a towel on the floor. Very little ankle motion took place. The ankle was gently dried to avoid any water drops from running down the ankle during sensation measurements. The first sensation measurement began immediately.

During session one, the first monofilament used following immersion was the monofilament that indicated the greatest numbness during the cold sensitivity test. During sessions two and three, we began with the monofilament that indicated the greatest numbness during session one. Monofilament measurements were completed by 1.5, 3, 5, 7, 9, and 11 min postimmersion.

The subjects remained seated for the entire testing session. Monofilament readings were taken by the same individual. Each subject was prevented from seeing when monofilaments were applied by drawing a curtain across his or her lap just as the ankle was removed from the ice bath.

Sensation Testing Procedures

Numbness (decrease in skin sensation) was noted as an increase in sensation of pressure as measured by the monofilaments.[7] As skin sensation decreased, a larger diameter monofilament (more grams of force) was used in order to stimulate sensory nerves. When two out of three monofilaments applications were felt, smaller filaments were applied and if not felt, the test was over and the larger monofilament was noted as the force felt. False-positive responses (those in which there was a "yes" response and no monofilament was applied) were ignored. If the subjects did not respond two out of three times correctly, a larger monofilament was applied. To speed the process, a "leap-frog" technique was used. Three or more monofilaments were skipped when the previous monofilament was not felt by the subject. When two out of three responses were correct, smaller filaments were applied and if not felt, the test was over and the larger monofilament was recorded. Monofilament testing sessions were ended at 1.5, 3, 5, 7, 9, and 11 min postimmersion in order to compare sensation at standardized time points.

Statistical Analysis

Means and standard deviations were calculated for all four dependant variables, by condition, and time. A two-way 3 x 7 ANOVA with repeated measures was used to

determine overall sensation of pressure differences between condition (10, 15, and 20 min immersion), and time (baseline, 1.5, 3, 5, 7, 9, and 11 min postimmersion). Skin and water bath temperatures were analyzed with a 3 x 4 two-way repeated measures ANOVA for condition (10, 15, 20 min immersion), and time (baseline, at 10 min immersion, last immersion time and 11 min postimmersion time). Perceived pain was analyzed using a 3 X 7 two-way repeated measures ANOVA during immersion (times: baseline, 1, 3, 5, 7, 9, and last immersion time), and a 3 x 6 two-way repeated measures ANOVA postimmersion (times: 1.5, 3, 5, 7, 9, and 11). If an interaction was found following the two-way ANOVAs, one-way ANOVAs were then performed. If at any point in the statistical analysis, significance was found without an interaction between dependant variables, Tukey-Kramer multiple range tests were performed. All tests were evaluated with an alpha of 0.05.

Results

There was no difference in water bath temperatures between conditions ($F_{2,32}$ = 0.87, p = 0.73), or time ($F_{3,48}$ = 2.21, p = 0.10).

Loss of sensation was greater following 20 min of immersion than 10 min of immersion at all postimmersion measurement times ($F_{2,34}$ > 7.67, p < 0.002; Table 1, Figure 1). The greatest loss of sensation was at 1.5 min pos-immersion ($F_{6,102}$ < 36.96, p = 0.000001). Following 1.5 min postimmersion, sensation of pressure declined rapidly until 5 min postimmersion, and more gradually thereafter.

Cold induced pain was greatest, in all conditions, during the first five minutes of immersion ($F_{6,102}$ < 47.81, p = 0.000001). Pain peaked at 1 min of immersion and

declined sharply through 9 min immersion (Table 2, Figure 2), then dropped minimally (with the exception of a small jump at 20 min immersion) until immersion ceased. During 11 min postimmersion, pain dropped sharply, while still remaining slightly above baseline. Pain during the 11 minutes following immersion was significantly greater following 20 min of immersion than following 10 or 15 min of immersion ($F_{2,34} = 8.17$, $p = 0.001$). For all three conditions, pain was significantly different at 1.5, 3, 5, and 7 min postimmersion than at any time point 3.5-4 minutes away ($F_{5,85} = 37.26$, $p = 0.000001$). For example, pain at 5 min was significantly less than at 1.5 min and significantly greater than 9 and 11 min postimmersion.

Patients reported that during 10 min of immersion the greatest pain was felt in the ankle and the heel. The frequency of reported ankle pain then decreased while heel pain and forefoot pain increased nearing 15 min of immersion. Nearing 20 min immersion, the frequency of reported toe pain increased.

Skin temperature did not differ among condition at baseline or during immersion, but the 11 min postimmersion temperature was significantly lower ($F_{2,34} = 9.53$, $p < 0.005$) following 20 min of immersion (20.24 ± 1.3^{o} C) than following 10 min of immersion (18.98 ± 1.2^{o} C; Table 3, Figure 3).

Discussion

Our research supports the clinical recommendations that cryokinetic treatments include 12-20 minutes initial immersion and 3-5 minutes of therapy before reimmersion.[3] Following 10, 15 and 20 min immersions, the greatest loss of sensation was in the first 5 minutes. Also, 20 min of immersion produced the greatest loss in sensation.

Clinical application of cryokinetics involves ice immersion until the area is numb. Any immersion past that point is thought to be a waste of time.[12] Our research indicates that the duration of immersion may be important. Water temperature remained consistent throughout immersion, and there was no difference in skin temperature between groups, therefore, the significant difference in numbness was due to the length of immersion. Although an individual's ankle may feel numb after 10 min, a greater degree of numbness is gained after 20 min of immersion.

Sensation of Pressure as a Measure of Numbness

This study was based upon the assumption that sensation of pressure is a measurement of numbness. Numbness is an "indefinite term for abnormal sensation, including absent or reduced sensory perception."[13] Sensory perception was reduced following cryotherapy as indicated by the need to use monofilaments of greater force to elicit sensation of pressure. Further justification for the assumption comes from an analysis of the tracts by which pressure and pain are transmitted.

Pain and temperature sensations are conducted along the lateral spinothalamic tract; light touch, and pressure sensations are conducted along the anterior spinothalamic tract.[14,15] Lesions on the lateral spinothalamic tract eliminate pain and temperature sensations below the point of the lesion on the opposite side of the body, while lesions on one side of the anterior spinothalamic tract will not eliminate all light-touch and pressure sensations on the opposite side of the body due to the large number of collateral branches that cross the cord at various levels. If these two tracts are the only tracts involved, then a correlation between changes in pressure and changes in pain is false. But they are not.

The dorsal column-medial lemniscal system transmits proprioception, two-point discrimination, pressure and vibration.[15,16] Its origin is in the cutaneous receptors and joints. Tactile and mechanoreceptors are often activated by the same stimuli that affect pain receptors. Superficial pain is localized due to the activation of mechanoreceptors as well as pain receptors in the skin, while deep pain tends to be more diffuse and not highly localized, because of the absence of numerous mechanoreceptors.[14]

The gate-control theory ties pain and the dorsal column-medial lemniscal system together as a pain relief technique.[17] Primary neurons of the dorsal column-lemniscal system send out collateral branches that synapse with association neurons in the posterior horn of the spinal cord. These association neurons have an inhibitory effect on the secondary neurons in the lateral spinothalamic tract. Thus, pain action potentials from the lateral spinothalamic tract can be suppressed by action potentials that originate in the dorsal column-medial lemniscal system, and the pain "gate" is shut. Acupuncture, TENS, massage, exercise, and vigorous rubbing tend to reduce the amount of pain felt by the individual indicating a cross-over effect between the lateral spinothalamic tract and the dorsal column-medial lemniscal system.[14] In this instance, the assumption that pressure can be used as an indicator of pain is feasible.

Temperature

Skin temperatures responded as expected during and after ice bath immersion.[3,18-21] Temperature dropped rapidly for the first few minutes of immersion and continued to drop slowly until a temperature a few degrees higher than the water was reached. After immersion, temperature increased rapidly in the first few minutes, after

which skin temperature continued to climb gradually, still remaining significantly lower than preimmersion temperatures. Since water temperature was the same between conditions, and was consistent throughout the immersion, the difference in skin temperature at 11 min postimmersion was due to the length of immersion.

Length of cold application is related to the depth of target tissue. The deeper the tissue, the less effect the cold modality will have on temperature.[20,22,23] Therefore, the length of treatment should increase if deep cooling is desired. For this study, sensation was measured on the skin, but clinically, ankle injuries involve deeper tissues as well. Twenty minutes of immersion produced greater losses in sensation, and would be expected to have cooled deeper than 10, or 15 min of immersion.

Perceived Pain

The pattern of perceived pain during[3] and after[5] ice-bath immersion was consistent with prior research. Pain was most intense in the first three minutes of immersion, dropping sharply till 7 to 9 minutes of immersion and then leveling off for the remainder of the immersion. Pain then dropped to near baseline measurements following 11 minutes postimmersion.

Our observation that the most pain was at one min immersion, and the greatest loss of sensation was at 1.5 min postimmersion is misleading. These were our first measurements; subjects' comments during data collection lead us to believe that the greatest pain occurred prior to our first pain measurement. Similarly, the greatest numbness may have been prior to our measurement at 1.5 min postimmersion. Earlier

sensation measurements were difficult to obtain due to the length of time needed to obtain a monofilament reading.

Clinicians must look toward the goal of a rapid, full recovery and return to sport, that is possible with increased mobility. Intensity of pain during immersion is directly related to water bath temperature.[3,5] Yet cold induced pain is short lived and gets easier to endure with each subsequent immersion.[10,24,25] Also, the severity of the pain can be minimized by the use of a toe cap,[18] and by talking with, informing, and encouraging the athlete through the initial intense cold induced pain.[11,24]

Future Research

- Investigate the relationship between level of numbness and duration of therapeutic exercise possible by an injured subject.
- Investigate the relationship between subject's perception of numbness and sensation of pressure.
- Investigate the effect of therapeutic exercise on return of sensation following cryotherapy.
- Compare the effects ice bag application, ice bag massage, and ice bath immersion on numbness and perceived pain during and following application.

References

1. Grant AE. Massage with ice (cryokinetics) in the treatment of painful conditions of the musculoskeletal system. *Archives of Physical Medicine & Rehabilitation.* 1964;44:233-238.
2. Hayden CA. Cryokinetics in an early treatment program. *Journal of American Physical Therapy Association.* 1964;44:990-993.
3. Knight KL, Aquino J, Johannes SM, Urban CD. A re-examination of Lewis'cold-induced vasodilation in the finger and the ankle. *Journal of Athletic Training.* 1980;15:248-250.
4. Halvorson GA. Therapeutic heat and cold for athletic injuries. *The Physician and Sportsmedicine.* 1990;18(5):87-94.
5. Jutte L, Suzie K, Reynolds S, Knight KL. The effects of cold bath temperatures on perceived pain and numbness [abstract]. *Journal of Athletic Training.* 2003;38(2):S-44.
6. Bell-Krotoski J, Tomancik E. The repeatability of testing with Semmes-Weinstein monofilaments. *Journal of Hand Surgery.* 1987;12A;1;155-161.
7. Bell-Krotoski J, Weinstein S, Weinstein C. Testing sensibility including touch-pressure, two-point discrimination, point localization, and vibration. *Journal of Hand Therapy.* 1993;6:114-123.
8. Mielke K, Novak CB, Mackinnon SE, Feely CA. Hand sensibility measures use by therapists. *Annuals of Plastic Surgery.* 1996;36:292-296.

9. Huskisson EC. Visual analogue scales. In: Melzack R, ed. *Pain Measurement and Assessment*. New York: Raven Press; 1983;33-40.
10. Streator S. The role of sensory information on affective pain. [Abstract] *Journal of Athletic Training.* 1994; 29:166.
11. Streator S, Ingersoll CD, Knight KL. Sensory information can decrease cold-induced pain perception. *Journal of Athletic Training.* 1995;30(4):293-296
12. Knight KL. Cryokinetics in rehabilitation of joint sprains. *C.A.T.A. Journal*. Fall 1981;17-18.
13. Spraycar M. *Steadman's Medical Dictionary for the Health Professions.* 26th ed. Baltimore: Williams & Wilkins; 1995.
14. Seeley RR, Stephens TD, Tate P. *Anatomy and Physiology* (3rd ed.). St. Louis: Mosby-Year Book; 1995.
15. Van De Graff K. . *Human Anatomy* (updated 5th ed.). Tennessee: McGraw-Hill; (2000).
16. deGroot J, Chusid JG. *Correlative Neuroanatomy* (21st ed.). New Jersey: Appleton & Lange; (1991).
17. Melzack R, Wall P. Pain mechanisms: a new theory. *Science*. 1965; 150:971-979.
18. Nimchick PSR, Knight KL. Effects of wearing a toe cap or a sock on temperature and perceived pain during ice water immersion. *Journal of Athletic Training.* 1983;18:144-147.
19. Palmer JC, Knight KL. Ankle and thigh skin temperature changes with repeated ice pack application. *Journal of Athletic Training.* 1996;31(4):319-323.

20. Merrick MA, Knight KL, Ingersol CD, Potteiger JA. The effects of ice and compression wraps on intramuscular temperatures at various depths. *Journal of Athletic Training.* 1993;28(3):236-245.

21. Myrer JW, Measom G, Fellingham GW. Temperature changes in the human leg during and after two methods of cryotherapy. *Journal of Athletic Training.* 1998;33:25-29.

22. Waylonis GW. The physiologic effects of ice massage. *Archives of Physical Medicine and Rehabilitation.* January 1967; 37-42.

23. Petajan JH, Watts N. Effects of cooling on the triceps surae reflex. *Journal of American Physical Medicine.* 1962;41:240-251.

24. Carman KW, Knight KL. Habituation to cold-pain during repeated cryokinetic sessions. *Journal of Athletic Training.* 1992;27(3):223-230.

25. Ingersoll CD, Mangus BC. Habituation to the perception of the qualities of cold-induced pain. *Journal of Athletic Training.* 1992;27(3):218-222.

Table 1. Sensation of Pressure (Grams; Mean ± SD, Statistical Summaries)

Time	10 min	15 min	20 min	Statistical Differences*
baseline	0.72 ± 1.2	0.71 ± 1.0	0.73 ± 1.2	
postimmersion				
1.5	4.03 ± 2.7	6.28 ± 3.8	9.25 ± 9.3	cond20>cond10
3	2.75 ± 2.4	4.58 ± 3.7	6.35 ± 6.7	cond20>cond10
5	1.46 ± 1.1	2.90 ± 2.7	4.04 ± 3.7	cond15&20>cond10
7	1.10 ± 1.1	1.62 ± 1.1	2.80 ± 2.8	cond20>cond10&15
9	0.96 ± 1.1	1.07 ± 0.7	2.10 ± 2.0	cond20>cond10&15
11	0.87 ± 1.1	0.92 ± 0.6	1.54 ± 1.5	cond20>cond10&15
Statistical Differences*	1.5>3>5,7,9,11&0	1.5>3>5,9,11&0 1.5&3>7	1.5&3>7,9,11&0 1.5>5>0	

* Tukey-Kramer $p < .05$

Table 2. Visual Analog Pain Scale (CM; Mean ± SD)

Time	10 min	15 min	20 min*
baseline	0.00 ± 0.00	0.00 ±0.00	0.00 ±0.00
during immersion			
1	5.41 ± 2.6	5.63 ± 2.6	5.55 ± 2.6
3	4.52 ± 2.1	5.11 ± 2.3	5.09 ± 2.4
5	3.63 ± 1.8	4.24 ± 1.9	4.08 ± 2.0
7	3.00 ± 1.7	3.42 ± 1.8	3.48 ± 1.9
9	2.58 ± 1.4	3.19 ± 1.7	3.24 ± 1.8
10	2.37 ± 1.6		
11		3.06 ± 1.9	2.96 ± 1.9
13		2.90 ± 1.9	2.83 ± 1.6
15		2.73 ± 2.2	2.87 ± 1.9
17			2.76 ± 1.7
19			2.78 ± 1.9
20			2.81 ± 1.9
postimmersion			
1.5†	2.02 ± 1.3	2.22 ± 1.7	3.14 ± 2.0
3†	1.71 ± 1.4	1.82 ± 1.6	2.67 ± 1.9
5†	1.11 ± 1.1	1.28 ± 1.3	2.13 ± 1.7
7†	0.60 ± 0.7	0.76 ± 0.9	1.50 ± 1.6
9	0.33 ± 0.5	0.43 ± 0.5	1.04 ± 1.3
11	0.22 ± 0.4	0.21 ± 0.2	0.73 ± 1.1

* Postimmersion: cond20 > cond10 & cond15

† Postimmersion: 1.5, 3, 5 & 7 are > and < every time point at least two away.

Table 3. Skin Temperature (°C; Mean ± SD)

Time	10 min*	15 min*	20 min*
baseline	31.41 ± 1.0	31.73 ± 1.2	31.26 ± 1.1
during immersion			
1	7.65 ± 2.5	8.41 ± 2.2	8.30 ± 3.1
3	5.13 ± 1.5	5.45 ± 1.5	5.23 ± 1.9
5	4.59 ± 1.2	4.77 ± 1.5	4.36 ± 1.1
7	3.90 ± 0.9	4.19 ± 1.2	4.30 ± 1.0
9	3.93 ± 0.9	3.77 ± 1.1	3.85 ± 1.0
10	3.77 ± 0.7	3.62 ± .91	3.87 ± 1.1
11		3.41 ± 1.0	3.59 ± 1.0
13		3.63 ± 0.6	3.37 ± 1.0
15		3.69 ± 1.5	3.42 ± 0.7
17			3.20 ± 0.7
19			3.05 ± 1.0
20			3.13 ± 0.7
postimmersion			
1.5	11.32 ± 1.0	10.45 ± 1.1	9.53 ± 1.0
3	14.47 ± 1.2	13.51 ± 1.2	12.45 ± 1.4
5	17.23 ± 1.4	16.43 ± 1.3	15.40 ± 1.6
7	18.91 ± 1.4	18.25 ± 1.4	17.38 ± 1.6
9	19.76 ± 1.3	19.21 ± 1.3	18.45 ± 1.4
11[†]	20.24 ± 1.3	19.68 ± 1.3	18.98 ± 1.2

***** Time (Tukey-Kramer): baseline > 11 min post > at 10 min & last immersion (for all three conditions)

[†] Condition (Tukey-Kramer): Skin temp 11 min postimmersion was higher after 10-min immersion than skin temp 11 min postimmersion after 20-min immersion.

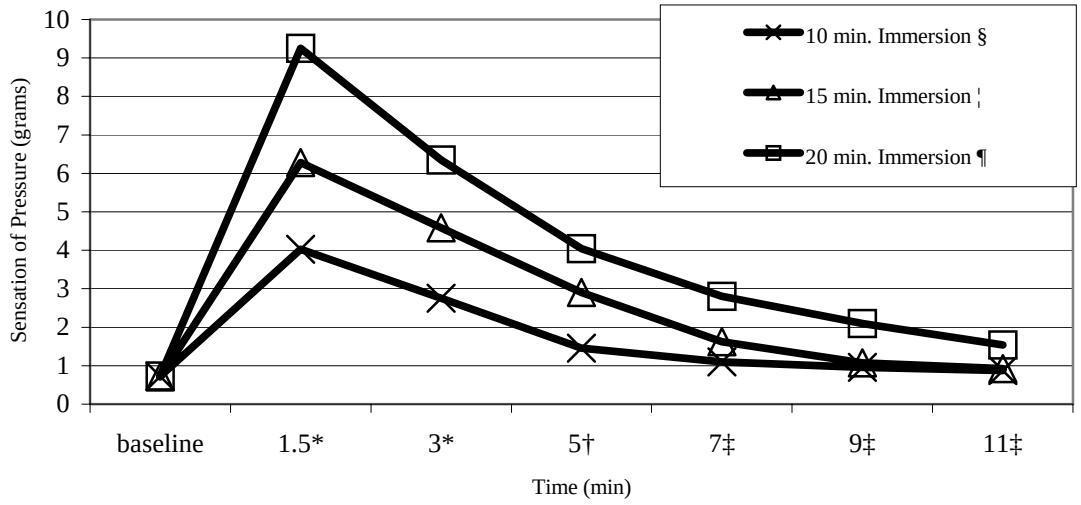

Figure 1. Sensation of pressure at baseline and following 10, 15, & 20 min immersions (* Cond20 > Cond10; † Cond20 & Cond15 > Cond10; ‡ Cond20 > Cond10 & Cond15; § 1.5 > 3 > 5, 7, 9, 11 & 0; ¦ 1.5 > 3 > 5 & 7 > 9, 11 & 0; ¶ 1.5 & 3 > 7, 9, 11 & 0; 1.5 > 5 > 0).

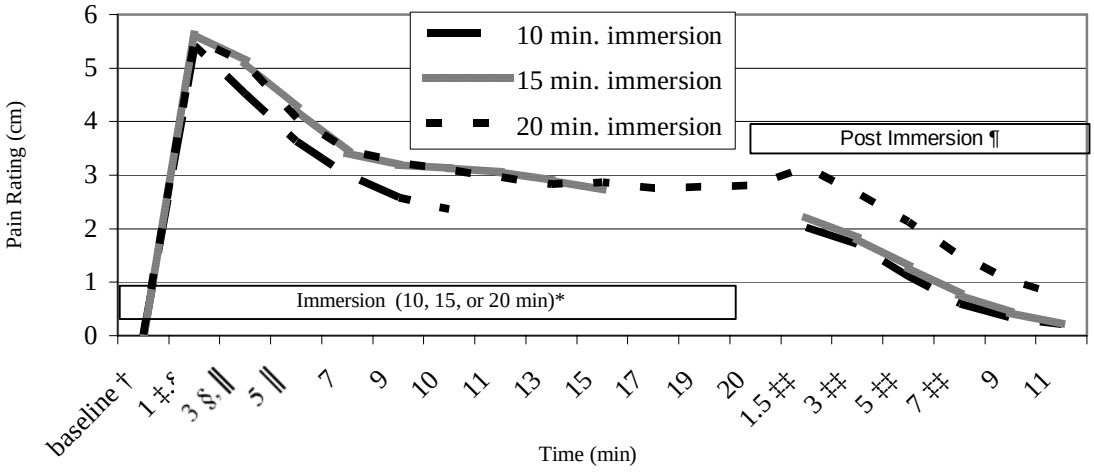

Figure 2. Visual analog pain scale during 10, 15, & 20 min immersions, and for 11 min postimmersion (<u>During Immersion</u>: * no difference in condition (time<12); † baseline < all ; ‡ 1 > 5 & greater; § 1 & 3 > 7 & greater; ? 3 & 5 > all but < 1 <u>Postimmersion</u>: ¶ Cond20 > Cond10 & Cond15; ‡‡ 1.5, 3, 5 & 7 are > and < any measurement two times away).

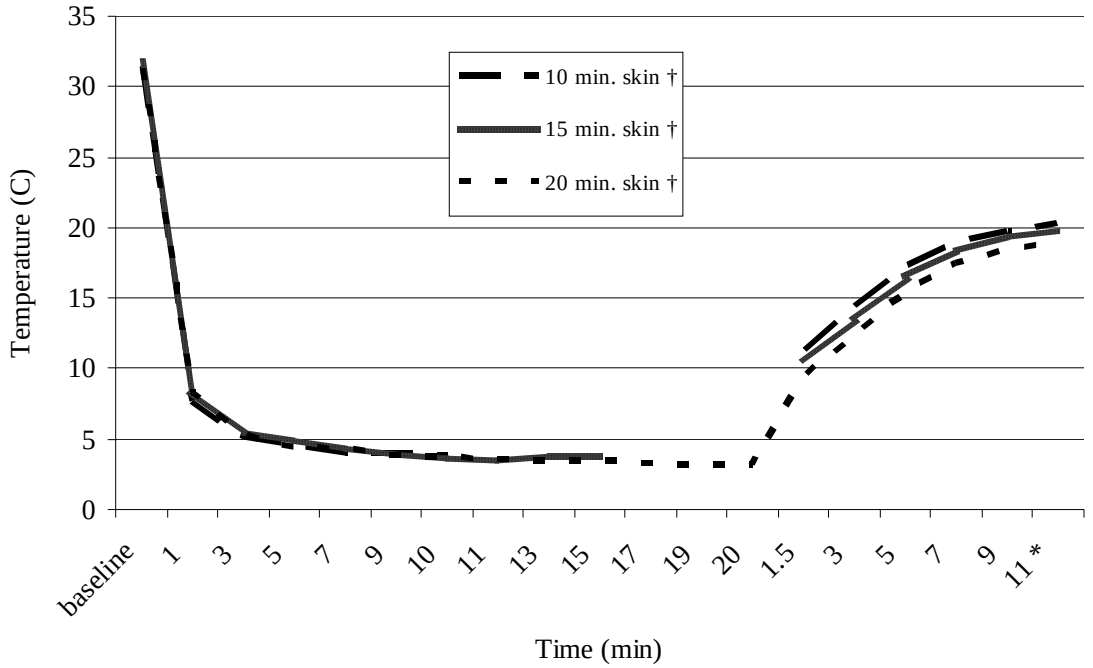

Figure 3. Skin temperatures during 10, 15, & 20 min immersions, and for 11 min postimmersion (* Cond10 > Cond20; † baseline > 11 min post > at 10 min immersion & last immersion time)

Appendix A

Prospectus

Chapter 1

Introduction

Cryotherapy has long been used for the treatment of injury (McMaster, 1982; Grant, 1964; Hayden, 1964). Ice application decreases blood flow (Knight & Londeree, 1980; Sherwin, Illgen, Meyer, Torok, Cooper & Reider, 1995; Karanakara, Lephart & Pincivero, 1999), slows cellular metabolism (Knight, 1976; Knight, 1995; Merrick, 2002), reduces secondary hypoxic injury (Knight, 1976; Merrick, 2002), and decreases muscle spasm and pain (Everall, 1976; Lehmann, Warren, & Scham, 1974).

Cryotherapy is effective in both immediate care and rehabilitation of injuries. One rehabilitative technique, cryokinetics (Grant, 1964; Hayden, 1964), uses ice to reduce pain so that the patient can begin earlier exercise. The goal is to restore proper motion as soon as possible. With injury, pain reduces range of motion and inhibits normal gait, leading to restricted and/or incorrect motor patterns. By inducing numbness, the healing effects of motion can take place without restriction. Ice is merely a means of inducing localized analgesia, thus allowing movement to occur (Grant, 1964; Hayden, 1964; Knight, 1995).

Many types of cold application can be used in cryokinetics. When treating the extremities, ice bath immersion is the most efficient modality of choice (Halvorson, 1990; Grant, 1964; Knight, 1995). Immersion in 1º C water appears to be more effective than 4º C, and 10º C water in inducing numbness and decreasing skin surface temperature (Jutte, Konz, Reynolds, & Knight, 2003). Cryokinetic immersion times have not been studied, but clinical experience indicates that 12-20 minutes of initial immersion, will

allow approximately 3-5 minutes of pain free rehabilitation (Knight, 1995; Prentice, 2003). This research was conducted in order to indicate the most efficient immersion times to induce numbness, and the time available for rehabilitation while analgesia of the body part is present.

Research Questions

1. What effect would length of ice bath immersion have on numbness (sensation of pressure)?
2. What effect would length of ice bath immersion have on time of analgesia available for rehabilitation?

Hypothesis

Two Null Hypothesis will be studied.

1. There would be no difference in ankle sensation of pressure following immersion in a 1° C ice bath for 10, 15, and 20 minutes.
2. There would be no difference in ankle sensation of pressure during 11 minutes of sitting preceded by 10, 15, and 20 minutes of immersion in 1º C water.

This study was delimited to:

1. The effect of 1º C water bath immersion on sensation of pressure following 10, 15, and 20 minutes of treatment.
2. The effects of sitting upon rate of sensation of pressure return following 10,15, and 20 minutes immersion.
3. Skin surface temperature was recorded throughout the study.
4. Healthy, college aged volunteers were the subjects for this study.

Definitions

1. Sensation of Pressure - An individuals ability to detect superficial stimulation imposed by the Semmes-Weinstein Monofilaments (Spraycar, 1995; Rogers, 2001; Jutte et al., 2003).
2. Numbness - Abnormal sensation including absent or reduced sensory perception (Spraycar, 1995). An increase in sensation of pressure, as measured by the Semmes-Weinstein Monofilaments, indicates reduced sensory perception.
3. Surface Temperature - Skin interface temperature (between skin and water bath, or skin and atmosphere) as measured by type-T thermocouples (Columbus Instruments, Colombus, Ohio) interfaced with a 16-channel Isothermex (Columbus Instruments, Colombus, Ohio).
4. Perceived Pain - Subjective description of pain felt by the subject, and expressed on a visual analog scale.

Assumptions

1. Changes in skin sensation of pressure would correlate with changes in numbness.

Chapter 2

Review of Literature

This chapter is organized as follows:
1) Cryokinetics
2) Cold induced pain
3) Use of toe caps
4) Contraindications
5) Effect of cryotherapy on temperature of superficial and deep tissues
6) Rate of tissue warming after cryotherapy
7) Effect of cold on nerve conduction
8) Sensation of pressure
9) The sensation of pressure-pain conflict
10) Summary

Table 1. Search Topics and Databases Used (# of applicable articles)

Keyword	Sport Discus (1975-)	Medline (1966-)	CINAHL (1982-)
1) cryokinetics	9 (9)	1 (1)	2 (1)
2) ice bath	7 (6)	94	4 (3)
3) #2 and cold		19 (2)	
4) water bath	25 (2)	1659	23 (3)
5) #4 and ankle	0	0	0
6) #4 and musculoskeletal	0	3 (0)	0
7) #4 and joint pain	0	0	0
8) #4 and rehabilitation	1 (1)	6 (1)	4 (1)
9) #4 and pain	0	17 (2)	0
10) #4 and joint	0	12 (1)	1 (0)
11) cryotherapy	463	3727	123
12) #11 and sports medicine	83	12 (7)	12 (6)
13) #11 and submersion	2 (2)	1 (0)	0
14) monofilaments	1 (1)	198	31 (10)
15) #14 and ice	1 (1)	1 (0)	0
16) #14 and cold	1 (1)	12 (2)	3 (0)
17) submersion	39 (2)	470	34 (0)
18) submersion and ankle	2 (1)	1 (0)	1 (0)
19) immersion	693	8210	237
20) #19 and cryotherapy	32 (18)	36 (4)	7 (6)
21) #19 and ankle	13 (10)	20 (6)	9 (6)
22) spinothalamic tract	0	387	2 (0)
23) #22 and sensation		50	
24) #23 and pain		38 (16)	
25) #24 and temperature		16 (5)	
26) nerve conduction velocity	28 (5)	2074	55
27) #26 and cryotherapy	3 (3)	3 (2)	1 (1)
28) #26 and cold	2 (2)	28 (6)	3 (1)
29) #28 and pain	1 (1)	7 (2)	1 (0)
30) #29 and temperature	3 1 (1)	3 (1)	0

Cryokinetics

Cryotherapy, the use of ice in the treatment of injury, has been a method for the treatment of injuries for thousands of years. It was even used by Hippocrates in 300 or 400 BC (McMaster, 1982). Grant (1964), and Hayden (1964), of Brooke army hospital, developed a technique they called cryokinetics, which used cold to numb an acute injury and therefore allow pain free motion. They noticed marked improvements in soldiers who were treated immediately after physician consultation with cryokinetics. They were influenced, no doubt, by Dehn who was an advocate of early mobilization in rehabilitation of injuries and also had worked at Brooke army hospital (Knight, 1995). Since that time, ice has been used more to induce numbness, and promote movement. Athletic trainers, in particular, are advocates of the use of ice in the treatment of athletic injuries.

Tissue cooling can be accomplished in a number of ways including vapocoolant sprays, ice bags, ice massages, and ice baths (Knight, 1995; Prentice 2003; Torg, Vegso & Torg, 1987). Depending upon the desired result, and the area of the body to be treated, one treatment may be more appropriate than the others. Ice baths are most favorable when treating post-acute, highly contoured areas of the body such as the feet, ankle, hand, or elbows (Knight, 1995). Ice bath temperatures in the past have ranged from 0° C to 18° C. While the warmer temperatures may reduce the painful stimuli of the cold, they do not seem to induce numbness as well as colder temperatures (Provins & Morton, 1960; Bugaj 1975; Waylonis, 1967). Recently, ice immersion at 1° C has been found as an optimal temperature for decreasing sensation of pressure (increased numbness), which

is key when used for cryokinetics (Jutte et al., 2003). Clinicians have reported that numbing typically takes 12-20 minutes with the initial immersion, and 3-5 minutes upon reimmersion (Knight, 1995; Prentice, 2003). However, there has been no literature to date indicating the most effective immersion time with regards to numbness.

Cold Induced Pain

Cryotherapy causes varying degrees of discomfort depending on the modality of choice, the temperature, and the length of application (Knight, 1995). While descriptions of this cold-induced pain cycle differ, the basic concepts still apply. One description states that if ice is applied (or another technique that has equal or lesser temperatures is used), there are typically three stages of sensation that the skin undergoes (Hocutt, 1981; Hocutt, Jaffe, Rylander & Beebe, 1982). The first three minutes yield a painful cold sensation followed by a burning/aching feeling at 2-7 minutes application. Numbness is induced within 5-12 minutes of the application. At this point, pain and reflex impulses are thought to be interrupted.

Knight (1995) describes the cold induced sensations as a progression from feelings of cold to a deep, aching pain. That pain then plateaus, or decreases, and is replaced with “pins and needles” sensations. Those sensations abate and the area then becomes numb with possible pain sensations occurring at irregular and unpredictable intervals between 3 and 18 minutes treatment. The difference in descriptions may be due to the modality of choice. Hocutt (1981) described sensations felt during cryotherapy treatments in general, while Knight (1995) reported sensations felt during ice bath immersion.

Clinicians have noted individuals habituating (getting used to, or accustomed to) to the cold-induced pain associated with cryotherapy. In an attempt to substantiate these claims, Ingersol & Mangus (1992) used five consecutive days of 2º C ice bath immersion for 21 minutes. Subjects were not allowed to converse with anyone and all outside distractions were minimized. A McGill Pain Questionnaire was used every three minutes to measure pain during immersion and 21 minutes following immersion. Despite clinicians claims that individuals habituate to the cold-induced pain, there was no significant different in the qualities of pain described over the five day period.

Another similar, yet more applicable study to clinicians was performed by Carman & Knight (1992). Immersion in 1º C water was done five times a day (in a cryokinetic manner) for eight days. Instead of subjects being isolated, they encouraged their subjects to interact and distract each other from the cold-induced pain (Streator, 1994; Streator, Ingersoll & Knight, 1995). Also, subjects were not asked to focus on the pain, and exercise was done in between immersion bouts. What ever the differences between these studies were, they were enough to cause differing results, as Carman & Knight (1992), did report that pain was significantly greater on day one than days two through eight. Also, perceived pain decreased between bouts on the same day of immersion. Although more research is needed in this area, it appears that individuals who are made aware of the sensations they will experience (Streator et al., 1995) and who are encouraged and coached through the cold-induced pain (Carman et al., 1992; Streator, 1994), will habituate to that pain, and subsequent treatments will become more tolerable.

Toe Caps

Water bath immersion can be a painful experience. Ice bath temperatures of 1º C cause a greater change in skin surface temperature, and numbness is greater at 1º C than 10º C (Jutte et al., 2003). Yet, the colder the ice bath, the greater the cold induced pain and discomfort (Knight, 1995; Carman et al., 1992). This discomfort tends to be localized to a large degree in the toes (Tovell, 1980). By using a toe cap, the patient may be saved much undue pain (Misasi, Morin, Kemler, Olmstead & Pryzgocki, 1995). Nimchick and Knight (1983) tested skin surface temperature at six sites on the foot and ankle. Two sites were located within the toe cap, and four were located outside the toe cap. A sock, a toe cap, and no external barrier were used to determine temperature differences and perceived pain. There was no difference between groups regarding temperature at the four sites outside the toe cap. All three conditions were significantly different ($p<.01$) at the toe during immersion and after immersion, with the toe cap temperatures remaining highest, and sock temperatures remaining significantly higher than the control. Only one subject reported feeling pain in the big toe while using the toe cap. This pain was reported in the last few minutes of immersion (17-20 minutes), whereas many subjects wearing the sock reported feeling pain between 1-3 minutes immersion, and all subjects reported extreme pain with no external barrier within the first minute of immersion.

Toe caps can be very beneficial in cryokinetic treatments. The skin surface temperatures are not effected in the ankle, and the severity of pain in the toes is significantly decreased (Nimchick et al., 1983).

Contraindications

While treatment with ice is low cost, effective, and convenient, there are some maladies that can be triggered by cryotherapy (Harvey, 1992). Frostbite has long been noted as a concern with exposure to cold (Knight, 1995; Washburn, 1962; Harvey, 1962). The direct, prolonged exposure of skin to cold can increase the likelihood of frostbite. Wet extremities in direct contact with great thermal conductors such as metal are especially susceptible. The length of exposure and the temperature needed to induce frostbite are highly variable due to many other compounding variables. As a rule though, temperature and time of exposure are related. As the temperature goes down, the length of exposure needed to get frostbite also decreases (Knight, 1995). Signs of frostbite may include white, waxy looking skin, the development of blisters after rewarming, as well as stinging, swelling and burning sensations (Washburn, 1962). Once an individual has been frostbitten, the area is particularly susceptible to recurring frostbite upon treatment (Washburn, 1962).

No published cases of frostbite, as a result of ice bath immersion used during cryotherapy, have been found, but caution must be used when deciding upon treatment application times. Edholm, Fox, Lewis and Macpherson (1957) reported redness and swelling in an arm that had been immersed in -1º C - 9º C water for an hour with restricted circulation (due to a plesmograph). The redness and swelling lasted days, but did not cause symptoms sever enough to be determined frostbite.

There are many forms of cold hypersensitivity. The most common is cold urticaria, an allergic reaction to cold. An individual may consistently respond to cold

with an outbreak of hives caused by the release of histamine during rewarming (Knight, 1995). With the excessive release of histamine, mast cells are degranulated. Swelling in the mucous membranes and viscera will lead to increased heart rate and decreased blood pressure (Keahey, Indrisano, & Kaliner, 1988). Symptoms of cold urticaria include red skin that develops a rash or wheal, itchy eyes, and respiratory changes. As with other allergic reactions, most cases can be treated with antihistamines such as Benadryl™ (Knight, 1995; Michlovitz, 1996). Individuals with no previous reaction to cold may sporadically show signs of urticaria as well.

Nerve palsy, insult to typically superficial nerves through the inappropriate application of ice, can be debilitating, but is fairly uncommon (Malone, Engelhardt, Kirkpatrick, & Bassett, 1992). Knight (1995) calculated the cases reported to date and determined that there was less than a .001% incident rate among those treated with cryotherapy. It is not known conclusively what causes nerve palsy. Many suggest it is the use of a compression wrap commonly used to secure the ice to the body. Collins, Storey & Peterson, (1986), reported nerve palsy in a 26-year-old athlete who fell asleep with ice applied to the anterior and posterior aspects of the knee. No wrap was used to secure the ice to the knee, and peroneal nerve palsy still occurred. Direct contact with the skin has been criticized as well. However, Green, Zachzewski, and Jordan (1989), reported a case of peroneal nerve palsy when ice was applied over a towel for only 20 minutes. Surely prudence should be used when applying ice, especially in areas containing superficial nerves.

Raynaud's Phenomenon is an excessive vasoconstriction of arteries and arterioles in response to sympathetic nervous stimulation (Knight, 1995). It is most typically seen in women under the age of 45, and is also quite uncommon. During treatment, the skin may turn blue and then red with burning, prolonged numbness, and tingling associated with the phenomenon (Coffman, 1989).

Effects of Cryotherapy on Temperature of Superficial and Deep Tissues

Many studies have been conducted over the years to determine surface temperatures during cyotherapy (see Table 2). Skin temperature drops dramatically in the first few minutes of modality application, then continues to drop until a temperature a few degrees above the temperature of the modality is reached. Upon removal of the cold modality, the skin temperature increases at a rapid rate similar to the initial rate of cooling, but in a smaller magnitude. Temperature then plateaus and slowly returns to pre-application temperatures (Knight, 1995; Knight, Aquino, Johannes & Urban, 1980; Palmer & Knight, 1992; Petajan & Watts, 1962; Bugaj, 1975; Post & Knight 1992).

Temperature patterns of the subcutaneous tissues are similar to the skin during treatment, but cooling occurs a few minutes later, and to a lesser magnitude (Knight, 1995; Waylonis, 1967). The deeper the tissue, the less effect the cold modality will have on temperature (Waylonis, 1967; Merrick, Knight, Ingersol & Potteiger, 1993; Petajan et al. 1962). Therefore, the length of treatment should increase if deep cooling is desired. As the cold modality is removed, deep tissues continue to drop slightly over the following 10-15 minutes (Petajan et al., 1962; Knight 1995). The duration of the

temperature drop is dependant upon the depth and type of the tissue being cooled (Waylonis, 1967; Lehmann et al., 1974).

Subcutaneous fat acts as an insulator to the tissue beneath. McMaster (1982) suggested that a cold treatment of at least 20-30 minutes be applied if deep cooling is desired. Since fat is a low thermal conductor, the exchange of internal heat and surface cooling is slow. Therefore, deep tissue temperatures will be reached more slowly, and skin surface temperatures will return to normal at a faster rate (Lehmann et al., 1974; Lowdon & Moore, 1975). Myrer, Myrer, Measom, Fellingham & Evers (2001) indicated that when examined over a wide range of skin fold thicknesses (3.8-35.3 mm), subcutaneous fat has a significant effect upon the magnitude and rate of intramuscular cooling during and after ice treatment. Body fat percentage as a whole has even been shown to effect cooling of the lower leg (Johnson, Moore, Moore & Oliver, 1979), and rectal temperatures during full body immersion in 15º C water for 30 minutes were higher in individuals with higher body fat percentage (Keatinge, 1960).

Rate of Tissue Warming Following Cryotherapy

The time needed to warm the tissue following cryotherapy is dependant upon the amount of heat removed from the tissue (this depends on the temperature and duration of the cold modality), versus the amount of heat available to reheat the tissues (Knight, 1995). The fingers reheat much more rapidly than the arm or the ankle (Knight & Elam, 1981). While the mass of the fingers is substantially less than the other two areas, the increased rate of rewarming is probably due to greater circulation in the hands (Knight, 1995).

Table 2. Tissue Temperature Change Due to Cryotherapy

Modality	Treatment Area	Temp. Change (º C)	Depth	Time	Authors
Ice Bag	Ant. Thigh	28.5	Surface	40 min	Palmer, ‘96
Ice Bag & Comp	Ant. Thigh	27.85	Surface	30 min	Merrick, ’93
Ice Bag	Ant. Thigh	27.8	Surface	30 min	Palmer, ‘96
Ice Bag	Ant. Thigh	26.8	Surface	20 min	Palmer, ‘96
Ice Bag	Lateral Ankle	25.5	Surface	40 min	Palmer, ‘96
Ice Bag	Ant. Thigh	25.26	Surface	30 min	Merrick, ’93
Ice Bag	Lateral Ankle	24.9	Surface	30 min	Palmer, ‘96
Ice Bag	Lateral Ankle	23.7	Surface	20 min	Palmer, ‘96
Ice Bag	Lateral Ankle	21.8	Surface	30 min	Mancuso, ‘92
Frozen Peas	Ant. Thigh	20.20	Surface	20 min	Chesterton, ‘02
Ice Bag	Gastroc.	17.0	Under Skin	20 min	Myrer, ‘98
Ice Gel Pack	Ant. Thigh	16.5	Surface	20 min	Chesterton, ‘02
Ice Bag	Gastroc.	14.43	Little Fat + 1 cm	20 min	Myrer, ‘01
Ice Bag & Comp	Ant. Thigh	12.59	Fat + 1 cm	30 min	Merrick, ’93
Ice Bag & Comp	Ant. Thigh	9.92	Fat + 2 cm	30 min	Merrick, ’93
Ice Bag	Ant. Thigh	9.7	Fat + 1 cm	30 min	Merrick, ’93
Ice Bag	Gastroc.	9.06	Med. Fat + 1 cm	20 min	Myrer, ‘01
Ice Bag	Ant. Thigh	8.38	Fat + 2 cm	30 min	Merrick, ’93
Ice Gels Deep	Thigh (dog)	8	Deep (?)	60 min	McMaster, ‘82
Ice Bag	Gastroc.	7.1	1 cm	20 min	Myrer, ‘98
Ice Bag	Gastroc.	6.62	Little Fat + 3 cm	20 min	Myrer, ‘01
Ice Bag	Gastroc.	5.0	Much Fat + 1 cm	20 min	Myrer, ‘01
Ice Bag	Gastroc.	3.86	Med. Fat + 3 cm	20 min	Myrer, ‘01
Gel Pack	Ant. Thigh	3.78	Surface	20 min	Enwemeka, ‘02
Gel Pack	Ant. Thigh	2.49	1 cm	20 min	Enwemeka, ‘02
Ice Bag	Gastroc.	2.42	Much Fat + 3 cm	20 min	Myrer, ‘01
Ice Bag	Gastroc.	.5	5 cm	5 min	Draper, ‘95
Ice Massage	Gastroc	26.6	Surface	10 min	Bugaj, ‘75
Ice Massage	Biceps Brachii	20.36	2 cm	15 min	Lowdon, ‘75
Ice Massage	Post. Thigh	19.2	Surface	5 min	Waylonis, ‘67
Ice Massage	Biceps Brachii	18.36	2 cm	10 min	Lowdon, ‘75
Ice Massage	Post. Thigh	18.2	Surface	10 min	Waylonis, ‘67
Ice Massage	Gastroc.	17.2	Surface	5 min	Waylonis, ‘67
Ice Massage	Biceps Brachii	15.9	2 cm	5 min	Lowdon, ‘75
Ice Massage	Gastroc.	13.2	.5 cm	5 min	Waylonis, ‘67
Ice Massage	Post. Thigh	12.4	.5 cm	5 min	Waylonis, ‘67
Ice Massage	Post. Thigh	12.4	.5 cm	10 min	Waylonis, ‘67
Ice Massage	Post. Thigh	11.0	1 cm	10 min	Waylonis, ‘67
Ice Massage	Post. Thigh	8.8	1 cm	5 min	Waylonis, ‘67
Ice Massage	Gastroc.	6.2	1 cm	5 min	Waylonis, ‘67
Ice Massage	Post. Thigh	5.2	2 cm	10 min	Waylonis, ‘67
Ice Massage	Post. Thigh	4.4	2 cm	5 min	Waylonis, ‘67
Ice Massage	Post. Thigh	1.4	3 cm	10 min	Waylonis, ‘67
Ice Massage	Post. Thigh	1.1	3 cm	5 min	Waylonis, ‘67
Ice Massage	Gastroc.	1.1	2 cm	5 min	Waylonis, ‘67
Ice Massage	Post. Thigh	.4	4 cm	5 min	Waylonis, ‘67
Ice Massage	Gastroc.	.2	3 cm	5 min	Waylonis, ‘67

Table 2. Tissue Temperature Change Due to Cryotherapy Continued

Modality	Treatment Area	Temp. Change (º C)	Depth	Time	Authors
Ice Massage	Post. Thigh	.1	4 cm	10 min	Waylonis, ‘67
Ice Massage	Gastroc.	0.0	4 cm	5 min	Waylonis, ‘67
Immersion					
1º C	Lat. Ankle	24.7	Surface	20 min	Nimchick, ‘80
Immersion					
1.4º C	Lat. Ankle	26.1	Surface	25 min	Knight, ’80
1.4º C	Lat. Ankle	25.7	Surface	20 min	Knight, ’80
1.4º C	Lat. Ankle	25.1	Surface	15 min	Knight, ’80
1.4º C	Lat. Ankle	24.6	Surface	10 min	Knight, ’80
1.4º C	Lat. Ankle	23.3	Surface	5 min	Knight, ’80
Immersion					
10º C	Gastroc.	12	2.5 cm	30 min	Johnson, ‘79
Immersion					
1º C	Lat. Ankle	19.9	Surface	15 min	Jutte, ‘03
4º C	Lat. Ankle	18.82	Surface	15 min	Jutte, ‘03
10º C	Lat. Ankle	15.95	Surface	15 min	Jutte, ‘03
Immersion					
13º C	Gastroc.	16.6	Surface	30 min	Petajan, ‘62
13º C	Gastroc.	6.0	Deep (?)	30 min	Petajan, ‘62
Immersion					
1º C	Forearm	28.5 (approx.)	Surface	45 min	Knight, ‘81
5º C	Forearm	25 (approx.)	Surface	45 min	Knight, ‘81
10º C	Forearm	20 (approx.)	Surface	45 min	Knight, ‘81
15º C	Forearm	15 (approx.)	Surface	45 min	Knight, ‘81
Immersion					
10º-42ºC	Forearm	Skin temps approach the water temps.	Surface	30 min @ each temp.	Fox, ‘62
Immersion					
10º C	Lower Leg	13.8	Under Skin	20 min	Myrer, ‘98
10º C	Lower Leg	5.1	1 cm	20 min	Myrer, ‘98

Petajan et al. (1962) reported skin and intermuscular temperatures of the posterior calf to be less than pre-immersion temperatures even after 6 hours of rewarming. The lower leg was immersed in 13º C water for 30 minutes. Skin rewarming occurred rapidly in the first 10-15 minutes post-immersion with 5-6º C being gained. The rate of rewarming, however, then slowed to .2-.3º C per hour. In the muscle, the temperature

dropped 2º C more, ten minutes following immersion and then rewarmed at the same rate as the skin. Myrer, Measom & Fellingham (1998) noted that 1 cm below subcutaneous fat, the temperature continues to drop for 30 minutes post-immersion. Just under the skin, the tissue temperature approached baseline temperatures, although not reaching those temperatures even after 30 minutes post-immersion.

Activity prior to cryotherapy will not slow the rate at which cooling occurs, but a longer application time may be needed due to the elevated initial temperature (Palmer et al., 1996; Mancuso & Knight, 1992). Activity such as walking, showering, and dressing causes an accelerated rate of rewarming (Palmer et al., 1996). Cryokinetics could cause a faster rate of temperature return than other cryotherapy modalities due to the added movement involved.

The Effects of Cold on Nerve Conduction

There has been much research conducted regarding the effect of cold on nerve conduction. The effect of cold on nerve fibers, action potentials, different fiber sizes, and on golgi tendon organs and muscle spindles will be discussed here.

Conduction Along Nerve Fibers

Cold has a somewhat linear relationship with nerve conduction. The cooler the nerve becomes, the slower the nerve conducts until transmission is ceased altogether (Murphy, 1960; Bugaj, 1975; Weeks, 1957; Waylonis, 1967). Weeks (1957), chilled the skin of humans and subjected them to a painful pin prick. When the skin was 12-15º C, 53% of the subjects had analgesia. Between 11-11.9º C, 62% of the subjects had analgesia, and below 10º C, 100% of the subjects did not feel the pin prick. Transmission

rates, however, have been seen to slow at 27º C or lower (Bugaj, 1975). Buchtal and Rosenfalck (1966) reported a 2.0 m/sec decrease in sensory nerve conduction from 36-21º C in transcutaneous measurement of the human median nerve.

Halar, DeLisa and Brozovich (1980) immersed the lower leg in 18.3º C water and measured tibial motor nerve conduction, sural sensory nerve conduction and temperature at three depths (intermuscular, subcutaneous, and surface). The tibial motor nerve conduction slowed 1.4 m/sec, 1.7 m/sec, and 1.1 m/sec for every degree change at intermuscular, subcutaneous, and surface depths respectively. The sural sensory nerve conduction slowed .7 m/sec, 1.7 m/sec, and 1.7 m/sec for every degree change at intermuscular, subcutaneous, and surface depths respectively. Perhaps the drops in conduction time held constant due to the fact that the limb was immersed in 18.3º C water. If cooler temperatures were obtained, the rate of nerve conduction probably would have been slowed to a greater degree.

Many studies have been done with raw nerve dissected from animals. Denney-Brown (1945) cooled the sciatic nerve of a cat and noted motor weakness at 7-8º C, and complete motor and sensory paralysis at 5-6º C. When Stevenson, Collin, Randt and Sarwein (1958) cooled the core temperature of a cat from 37º C to 27º C, the nerve conduction from the superficial radial nerve to the thalamus slowed from 3.9 m/sec to 6.3 m/sec respectively. Conduction velocity in the dorsal column of the same cat also decreased from 2.0 m/sec to 3.95 m/sec as the core temperature dropped 10º C. While these temperatures seem extremely low, and nerve paralysis is never the goal of cryotherapy, we must remember that these studies cooled the nerve directly. When

applying a cold modality, most nerves will be protected by the surrounding tissues, and never reach these critical temperatures. Clinicians must be careful, however, when applying a cold modality to superficial nerves located in the lateral knee and the elbow (Knight, 1995).

Temperature has a direct effect upon nerve conduction velocity. Whether measuring conduction velocity with animal nerves, or human nerve conduction, the same patterns seem to follow. The nerve conduction begins to slow as the tissue cools. Further cooling will increase the rate of nerve conduction slowing until nerve conduction ceases altogether. The rate of this reaction is dependant upon the degree of cooling which is dependant upon the depth of the nerve, the type of cold modality used, the tissue which is being cooled, the environment and the length of application (Knight, 1995).

Effects Upon Action Potentials

Temperature and action potential duration are inversely related. As the tissue temperature decreases, action potential duration increases (Gasser, 1931; Buchtal, 1966; Murphy, 1960). The action potential duration in the sciatic nerve of a frog will begin to increase between 30º C and 20º C. As the temperature drops to 10º C, the action potential duration increases at an even quicker rate, until the nerve fails completely around 5º C (Gasser, 1931).

It has been suggested that the cold increases the nerve ending thresholds (McMaster, 1982), and pain thresholds (Lehmann et al., 1974). With these increased thresholds, the duration of nerve action potentials would increase and this would lead to

fewer fibers that can fire in a set time period, thus decreasing the transmission rate (Knight, 1995).

Another way cold could effect action potential durations is that cold decreases the transmission of ions across synapses (Murphy, 1960). Cooling below 20º C has been reported to decrease acetocholine transmission across nerve synapses (Bugaj, 1975).

Effects of Cold on Different Nerve Fibers

There seems to be controversies regarding which fibers are effected by cold first. Some believe that small diameter fibers loose their ability to conduct before larger fibers (Petajan et al., 1962; McMaster, 1982; Everall, 1976), while others believe that larger diameter fibers loose their ability to conduct before smaller fibers (Drez, Faust & Evans, 1981; Collins et al., 1986). Others say that small and large fibers are effected at the same temperatures (Collins et al., 1986; Paintal, 1965a), or at least changed at the same rate (De Jesus, Hausmanowa-Petrusewicz & Barchi, 1973). There is also conflict as to whether sensory fibers are blocked before motor fibers (Waylonis, 1967), or motor fibers are blocked before the sensory fibers (Drez et al., 1981).

Muscle Spindle and Tendon Organs

Cooling of nerve fibers inhibits muscle spindles and golgi tendon organs which could be a cause of decreased spasticity seen with cryotherapy (Newton & Lehmkuhl, 1965). Petajan et al. (1962) saw a decrease in reflex time of 338 msec pre treatment, to 610 msec post treatment when the leg was cooled in 12-13.5º C water.

Sensation of Pressure

For years, superficial sensation testing devices have been used and improved. Superficial sensation is measured by way of light touch (Weibers, Dale, Kikmen, & Swanson, 1998). Hand therapists have led the search for ways in which to measure light touch thresholds. Many techniques have been employed throughout the years, including von Frey's horse hairs, vibration, two-point discrimination, and the Semmes-Weinstein monofilaments (Bell-Krotoski, Weinstein, & Weinstein, 1993).

Von Frey Horse Hairs

The von Frey cutaneous sensation testing device was a predecessor of the monofilaments used today. A pinching device which could be opened and closed, was used to hold one horse hair. The length of the horse hair projecting from the device was the method of altering force. When applied to the skin, the subject would respond in the affirmative or the negative depending upon whether or not the hair was felt. Adjusting the hair involved unclamping the device, adjusting the hair (longer if less force was desired, shorter if more force was desired), reclamping the device, and recalibrating before applying the horse hair again.

The von Frey instrument had many flaws that made it unreliable. The horse hairs would absorb moisture, and the opening and closing of the clamp led to crimping of the hair which would alter the force. Also, there was significant time loss with the length change, and recalibration had to take place each time the force was changed (Weinstein, 1993). The diameter of the horse hairs could not be controlled, and they were designed to measure only light thresholds of touch sensation (Bell-Krotoski, & Tomancik, 1987).

While there were many flaws in this measuring device's reliability and it is no longer used today, it inspired the development of many presently used sensory testing devices.

Vibration

Tuning forks of 30-256 Hz have been used in sensory testing. A tuning fork of a certain hertz is applied either vertically or horizontally to the skin. The subject is asked to respond when vibrations are felt as the examiner chooses the tuning forks in much the same way he would alter the von Frey hairs. While vibration may detect central lesions, it is too uncontrolled for testing peripheral nerves (Bell-Krotoski et al., 1993).

Flaws with this technique are many when testing peripheral nerves. If the probe is applied in a manual manner, there will be much variation in the force each probe applies. Tuning forks do not apply a pure frequency, but produce high and low frequencies during the same application. Also, if an individual applies the fork with heavy force, the signal will die out quickly, whereas if it is applied lightly, the frequency will hold for a longer period. Tuning forks are too uncontrolled in testing peripheral nerves (Bell-Krotoski et al., 1993).

Two-Point Discrimination

Another sensory testing method is the use of two point discrimination. Many different devices (home made Styrofoam devices with thumb tacks protruding from it; popsickle sticks with paper clips attached at various distances from each other; manufactured protractor devices in which the points get closer as you tighten the screw) have been used to determine if an individual can distinguish between one point touching their skin or two points touching their skin. The individual will respond with "one" or

"two" when the device is applied. Testers are allowed to apply a single point at any time and in no particular order, in order to remain unpredictable. The distance between the two points, at which the subject can no longer distinguish one point from two points being applied, determines the sensory thresholds of the individual (Ingersoll, Knight & Merrick, 1992; Bell-Krotoski et al., 1988; Halar et al., 1987).

Two-point discrimination is a commonly used sensation test. However, the use of any hand held probe that doesn't bend has unreliable force production. Among testers, these hand held probes have been measured to produce force as small as a few grams to as many as several hundred grams (Bell-Krotoski et al., 1993). Some control of force has been established using skin blanching as a control, although this is still insufficient. Applying the instrument to the skin and allowing the instruments weight to control force has also been attempted with some improvement, but the vibration of the testers hand even exceeds the normal touch sensation threshold (Bell-Krotoski et al., 1987; Bell-Krotoski et al., 1993).

If the individual is able to distinguish between the single tip and the double tip, the two points on the double tipped instrument are brought closer together until indistinguishable from the single tipped instrument. The force applied between the single tip and the double tips are highly variable. Bell-Krotoski & Buford, 1988, found that application forces between six testers varied from 19.16 gm-36.49 gm with two points, and 13.49 gm-23.87 gm with one point in contact with the skin. This is a variation of 17 and 10 grams, respectively, and excessively beyond the sensitivity of the normal touch receptors (.068 grams of force).

Non-bending hand held instruments exceed the sensitivity of the normal touch receptors (two-point discrimination applies a mean of 26.01 gm of force, and normal sensation thresholds are .068 gm of force). Vibration from the examiners hand produces force at the time of application, and exceeds normal touch thresholds (at least 2 gm) (Bell-Krotoski et al., 1988). Because of the high variability of force, Bell-Krotoski et al. (1988) argue that the commonly known static two-point discrimination test cannot, indeed, be referred to as static. Yet, despite the reliability discrepancies of this test, 82% of hand therapists polled still use "static" two-point discrimination (Mielke, Novak, Mackinnon, & Feely, 1996).

Semmes-Weinstein Monofilaments

In the 60s, in an effort to find a set of valid and convenient tests to replace the von Frey hairs, Semmes and Weinstein developed the Semmes-Weinstein monofilaments. These are nylon filaments vary in diameter and length (Weinstein, 1993). A filament is chosen and applied perpendicular to the skin until it bends, held, and released in as fluid a motion as possible (1.5 seconds for application, hold and release sequences). When testing with the Semmes-Weinstein monofilaments, it is recommended that a series of three applications with the same monofilament be performed with two accurate responses indicating the desired threshold is met (Bell-Krotoski et al., 1993). If the monofilament is correctly felt, a smaller monofilament is chosen and applied. If no reply is given when the monofilament is applied, a larger filament is applied, until the last monofilament that is felt is determined as the pressure threshold.

If the length and diameters are correct, the monofilaments do produce repeatable forces within a predictable range (Bell-Krotoski et al., 1987). Because force is being measured by the monofilaments, there must be a control of velocity and time in its application. The velocity, or how fast or slow the monofilaments are applied, is controlled through the bending of the filament, and the estimated 1.5 second application, 1.5 second hold, and 1.5 second release. Time is also controlled with these standard application times. When applied in this manner, force is immediately increased and holds steady with little or no vibration, and will terminate rapidly and smoothly upon release (Bell-Krotoski et al., 1988; Mielke et al., 1996). Each monofilament is numbered in relation to the forces produced with that particular monofilament (Bell-Krotoski et al., 1988). The filament number is equal to $\log^{10}$ times the product of 10xF in mg.

The smallest monofilaments are also useful because they are the only instruments tested that apply forces that approach the normal sensation threshold of .068 gm force (Bell-Krotoski et al., 1988). Use of the monofilaments as measures of hand sensitivity have increased over the years. Of those hand therapist polled, 96% regularly include the monofilaments in their sensory evaluations, and 92% believe the monofilaments are accurate in their measures of hand sensitivity (Mielke et al., 1996).

Calibration done on a machine developed by a biomedical engineer determined that meeting standardized monofilament length and diameter will yield reliable monofilaments (Bell-Krotoski et al., 1988). Staying within the same manufacturing company is essential, as tremendous amounts of variation between corresponding sizes of monofilaments have been found (Bell-Krotoski, Fess, Fogarola, & Hiltz, 1995).

The Pain/Sensation of Pressure Conflict

Cryokinetics is a cryotherapy technique used to decrease injury pain, in the hopes of allowing motion. The basis of this study is to determine the most efficient time of immersion for inducing numbness. Numbness is assumed to be indicative of a decrease in injury pain. The Semmes-Weinstein monofilaments are used to determine varying degrees of pressure sensation loss, and are applied directly to the skin. So the question then becomes, can monofilaments (a pressure application) truly be used to measure injury pain alterations?

Clinically, a decrease in injury pain is reported by the patient, as is the loss of cutaneous sensation (increased numbness). Cryokinetics is effective when the individual is void of inhibiting pain. Numbness is noted at this time as well. However, can measuring numbness be a measure of injury pain?

Pain and temperature sensations are conducted along the lateral spinothalamic tract, and light touch, and pressure sensations are conducted along the anterior spinothalamic tract (Seeley, Stephens & Tate, 1995; Van De Graff, 2000). Lesions on the lateral spinothalamic tract will eliminate pain and temperature sensations below the point of the lesion on the opposite side of the body, while lesions on one side of the anterior spinothalamic tract will not eliminate all light-touch and pressure sensations on the opposite side of the body due to the large number of collateral branches that cross the cord at various levels. If these two tracts are separate then the use of pressure to determine pain may be flawed.

One more system may be of interest, however. Proprioception, two-point discrimination, pressure and vibration are transmitted along the dorsal column-medial lemniscal system (deGroot & Chusid, 1991; Van De Graff, 2000). Its origin is in the cutaneous receptors and joints. Tactile and mechanoreceptors are often activated by the same stimuli that affect pain receptors. Superficial pain is localized due to the activation of mechanoreceptors as well as pain receptors. Deep pain tends to be more diffuse and not highly localized, because of the absence of numerous mechanoreceptors.

The gate-control theory ties pain and the dorsal column-medial lemniscal system together as a pain relief technique. Primary neurons of the dorsal column-lemniscal system send out collateral branches that synapse with association neurons in the posterior horn of the spinal cord. These association neurons have an inhibitory effect on the secondary neurons in the lateral spinothalamic tract. Thus, pain action potentials from the lateral spinothalamic tract can be suppressed by action potentials that originate in the dorsal column-medial lemniscal system, and the pain "gate" is shut. Acupuncture, TENS units, massage, exercise, and vigorous rubbing tend to reduce the amount of pain felt by the individual indicating a cross-over effect between the lateral spinothalamic tract and the dorsal column-medial lemniscal system (Seeley et al., 1995). In this instance, the assumption that pressure can be a measure of pain is feasible.

Summary

Cryokinetics has been used since the sixties in order to allow early mobilization in the rehabilitation of injuries. While there are many ways to cool tissue, ice bath immersion is the most effective when treating highly contoured areas of the body, such as

the ankle. An ice bath temperature of 1º C has been recommended as an optimal temperature to induce numbness, and this study was designed to see which of 10,15, or 20 minutes immersion was most effective in inducing numbness.

Ice bath immersion causes some feelings of deep, aching pain, which progresses to a “pin and needles” sensation. The area, however, becomes numb within 5-12 minutes immersion. The use of a toe cap can greatly reduce the cold induced pain sensations felt at the forefoot and toes, yet it has no effect upon surface temperature of the ankle.

Contraindications to ice bath immersion may include frostbite, cold urticaria, nerve palsy, and Raynaud’s phenomenon. While the chances of frostbite increase in a cold environment when exposed to moisture, frostbite has never been reported after a 20 minute ice bath immersion in a controlled environment. Nerve palsy is typically reported after ice is compressed over areas of superficial nerve innervations such as the lateral knee and elbow. The chances of cold urticaria and Raynaud’s phenomenon may be reduced with the use of the cold hypersensitivity test, and a thorough medical history.

Skin temperatures during cryotherapy will drop dramatically as the cold modality is applied, and then continue to drop until a temperature, a few degrees above that of the modality, is reached. Upon removal of the modality, the skin temperature will increase at a rapid rate and then plateau until the pre-application temperatures are eventually reached.

Intermuscular temperature does not drop immediately upon cryotherapy application, or to the magnitude the skin temperatures did. Deeper tissues require longer cold treatment times. As the modality is removed, the deep tissue temperature continues

to drop before following the patterns of skin rewarming. Rewarming skin and intermuscular tissues after cold application can take hours and is effected by the length of cold application and activity levels after the treatment has ceased.

Cold has a direct effect upon nerve conduction. The cooler the nerve becomes, the slower the nerve conducts until transmission is ceased altogether. It would make sense then, that deeper nerves would transmit longer than superficial nerves because deeper tissues require longer treatment times to decrease temperature to the same degree as the surface tissues.

Action potential duration is increased as temperatures decrease. The action potential thresholds increase and the duration of action potential is increased, leading to fewer fibers that are ready to fire at the same time. This decreases the transmission rate. Action potential duration may also increase due to a decrease in acetocholine transmission across the nerve synapses.

The effect of cold upon different fiber types is controversial. Large and small diameter fibers could be effected at different temperatures, or could be effected at the same temperatures. There is also controversy as to whether motor or sensory nerves are effected by decreases in temperature first.

Cooling nerve fibers also inhibits muscle spindle and golgi tendon organs. Reflex times have been reported to increase with decreased tissue temperatures.

Many hand held sensation testing devices have been developed throughout the years to measure sensory perception thresholds. Von Frey horse hairs, and the use of tuning forks are two techniques that were flawed and are used rarely today. Two-point

discrimination is commonly used today, yet has unreliable force productions due to the variability of force produced among testers, and even between the single tip and the double tip applications. The Semmes-Weinstein monofilaments were developed to create reliable, and quantifiable forces. The length and variable diameters account for the different forces produced. Variation between testers is diminished because the monofilament bends once the desired force is met, and any extra force is absorbed in the bend. If the length and diameter of the monofilaments are correct, the same manufacturer is used during testing, and calibration is double checked, the monofilaments give reliable sensory perception threshold readings.

Chapter 3

Materials and Methods

The design for this study was a 3 X 7 factorial with repeated measures. The independent variables were immersion time (10, 15, and 20 minutes) and measurement time (before immersion, and 1 ½, 3, 5, 7, 9 and 11 minutes post immersion). Dependant variables were sensation of pressure (g), skin temperature (ºC), and perceived pain (cm). Perceived pain was used as a hypothesis generating variable. Treatment orders were established according to two 3 x 3 Balanced Latin Squares. Subjects were randomly assigned to one of the six treatment orders by means of a table of random numbers (Appendix B1).

Subjects

Eighteen healthy college volunteers participated in this study. Volunteers had no known adverse reactions to ice treatments as defined by the medical questionnaire (Appendix B2). A 3 minute ice massage was applied to the left lower leg in order to rule out any allergic reaction to cold (Knight, 1995), as well as to expose the subject to the monofilaments. The study was approved by the Institutional Review Board, and all subjects gave written informed consent.

Measurements

Numbness was quantified using a set of 48 Semmes-Weinstein monofilaments (Connecticut Bioinstruments, CT). The Semmes-Weinstein monofilaments are reliable when manufacture and calibrated correctly. The length and diameter of the monofilaments are more consistent when manufactured by the same company (Bell-

Krotoski et al., 1995). Monofilaments are able to measure both healthy individuals (typically .068 g), and individuals with compromised sensation (Bell-Krotoski et al., 1987).

Skin temperature was recorded with type-T thermocouples (TX-31; Columbus Instruments, Colombus, Ohio) interfaced with a 16-channel Isothermex (Columbus Instruments, Colombus, Ohio) that was interfaced with a personal computer. The thermocouples were applied with Leukotape P (Beiersdorf, Bangkok, Thailand), just over the anterior talofibular ligament. This location was marked with a permanent marker to insure consistent placement. A small piece of tape just proximal to the tip of the thermocouple insured the thermocouple remained in contact with the skin, but did not cover the thermocouple tip, or the entire ATF area. The tape was then crisscrossed at more proximal locations along the lower leg. Skin surface temperature was recorded every minute throughout the entire session (baseline, during immersion, and after immersion).

Perceived pain, induced by the ice bath, was measured with a visual analog scale and reported in cm (Appendix B3). Measurements were every 2 minutes during immersion (beginning with 1 minute), just as the foot was removed (10, 15, and 20 minutes), and immediately following each monofilament reading (baseline, 1 ½ , 3, 5, 7, 9, and 11 minutes post-treatment). Subjects were allowed to see their previously marked scale as a means of providing a reference point because most individuals think in terms of

change, rather than in absolute terms (Huskisson, 1983). Perceived pain was collected as a hypothesis generating variable.

A bucket of ice water (1º C) was placed on the floor in front of the seated subject, and the water was filled to cover approximately 5 cm above the lateral maleolus. This spot was marked with a permanent marker. To insure that the water stayed as close to 1º C as possible, a thermocouple (TX-31) was placed in the water and temperature readings were taken every minute. An air pump was placed in the water to insure constant water movement, thus inhibiting thermal barriers. Ice was added as needed to keep the temperature consistent.

Procedures

Subjects participated in three days of testing, each day at least 24 hours apart and at the same time of day. Upon agreeing to participate in the study, the subject was given a form (Appendix B4) which recommended the activities of daily living that should be engaged in and avoided while participating in the study. On the first day of testing, each subject arrived 10 minutes early in order to fill out the medical history questionnaire. The subjects were asked about the activities of the three hours prior to testing (if the recommendations for activities prior to participation had been violated, he or she was rescheduled). Responses were recorded on his or her data collection form (Appendix B5). At that time, they were informed as to procedure, taught how to use the visual analog scale, exposed to the three minute cold sensitivity test and monofilament practice, and asked to give written informed consent (Appendix B6).

Each day of testing began with the subject seated for 10 minutes while the thermocouple was attached and a baseline temperature was reached. All data, except temperatures, were compiled on an individual data collection table (Appendix B5). Their prior activities were discussed and recorded during this time. Just before the foot was immersed, a monofilament measurement was taken, and a toe cap (McDavid) was pulled over the toes. During immersion the subject was talked to, encouraged, and coached through the cold induced pain (Streator, 1994; Streator et al., 1995).

Following immersion, the subject sat as the monofilament measurements were taken (1.5, 3, 5, 7, 9, and 11 minutes post immersion). Each monofilament reading ended as close to 1.5, 3, 5, 7, 9, and 11 minutes as possible. The subject remained seated for the entire testing session. The monofilament readings were taken by the same individual. Visual confirmation of the application of the monofilament was prevented with a curtain drawn across the subjects lap.

Sensation Testing Procedures

Numbness (decrease in skin sensation) was noted as an increase in sensation of pressure as measured by the monofilaments. As skin sensation decreases, a larger diameter monofilament (more grams of force) was needed in order to stimulate sensory nerve endings. The desired force was met when the monofilament bent. Variability in tester application force is absorbed in the bend of the monofilament, the speed of application and having only one tester. The monofilament was applied perpendicular to the skin until it bowed, was held and released in approximately 1.5 second increments, so

as to insure consistency throughout application (Mielke et al., 1996). The application speed was practiced by the tester prior to data collection using a metronome.

Monofilaments were applied from a smaller force production to a larger force production (small to bigger monofilaments). The subject was instructed to say "yes" when the monofilament was felt, but was given no indication as to the actual time of application. Each monofilament was applied 2-3 times, and two out of three correct responses indicated the subject felt the monofilament (Mielke et al., 1996). False-positive responses (those in which a "yes" was said and no monofilament was applied) were ignored. If the subject did not respond two out of three times correctly, a larger monofilament was applied. To speed the process, a "leap-frog" technique was used. Three or more monofilaments were skipped at a time when the previous monofilament was not detected. When two out of three responses were correct, smaller filaments were applied and if not felt, the test was over and the larger monofilament was noted as the force felt. Practice, done by the tester, prior to the collection of data helped standardize the length of time needed to obtain the monofilament reading. The monofilament reading was obtained at 1.5, 3, 5, 7, 9, and 11 minutes post-immersion.

Data Analysis

Three Way ANOVAs were computed. If interaction was found in the Three Way ANOVAs, a Two Way ANOVA was performed. If interaction was found with Two Way ANOVAs, One Way ANOVAs were performed. Then Tukey-Kramer follow-up tests were computed.

References

1. Bell-Krotoski JA, Buford WL. The force/time relationship of clinically used sensory testing instruments. *Journal of Hand Therapy*. 1988;1:76-85.
2. Bell-Krotoski JA, Fess EE, Figarola JH, Hiltz D. Threshold detection and Semmes-Weinstein monofilaments. *Journal of Hand Therapy.* 1995; April-June:155-162.
3. Bell-Krotoski J, Tomancik E. The repeatability of testing with Semmes-Weinstein monofilaments. *Journal of Hand Surgery.* 1987;12A;1;155-161.
4. Bell-Krotoski J, Weinstein S, Weinstein C. Testing sensibility including touch-pressure, two-point discrimination, point localization, and vibration. *Journal of Hand Therapy.* 1993;6:114-123.
5. Bugaj R. The cooling, analgesic, and rewarming effects of ice massage on localized skin. *Physical Therapy.* 1975;55(1):11-19.
6. Buchtal F, Rosenfalck A. Evoked action potentials and conduction velocity in human sensory nerves. *Brain Research.* 1966;3:1-122.
7. Carman KW, Knight KL. Habituation to cold-pain during repeated cryokinetic sessions. *Journal of Athletic Training.* 1992;27(3):223-230.
8. Chesterton LS, Foster NE, Ross L, Dip G. Skin temperature response to cryotherapy. *Archives of Physical Medicine and Rehabilitation.* 2002;83:543-549.
9. Coffman JD. (1989). *Raynaud's Phenomenon.* New York: Oxford University Press.

10. Collins K, Storey M, Peterson KI. Peroneal nerve palsy after cryotherapy. *The Physician and Sportsmedicine.* 1986;14(5):105-108.
11. deGroot J, Chusid JG. (1991). *Correlative Neuroanatomy (21st ed.).* New Jersey: Appleton & Lange.
12. Denney-Brown D, Adams RD, Brenner C, Doherty MM. The pathology of injury to nerve induced by cold. *Journal of Neuropathology and Experimental Neurology.* 1945;4:305-323.
13. De Jesus PV, Hausmanowa-Petrusewicz I, Barchi RL. The effect of cold on nerve conduction of slow and fast nerve fibers. *Neurology.* 1973;23:1182-1189.
14. Drez D Jr, Faust DC, Evans JP. Cryotherapy and nerve palsy. *The American Journal of Sportsmedicine.* 1981;9(4):256-257.
15. Edholm OG, Fox RH, Lewis HE, MacPherson HE. Cold Injury. *Journal of Applied Physiology.* 1957; 139:14P-15P.
16. Enwemeka CS, Allen C, Avila P, Bina J, Konrade J, Munns S. Soft tissue thermodynamics before, during, and after cold pack therapy. *Medicine and Science in Sports and Exercise.* 2002;34(1):45-50.
17. Everall M. Cold therapy. *Nursing Times.* 1976;70:140-145.
18. Fox RH. Local cooling in man. *British Medical Bulletin.* 1962;17(1):14-18.
19. Gasser HS. Nerve activity as modified by temperature changes. *American Journal of Physiology.* 1931;97:254-281.

20. Grant AE. Massage with ice (cryokinetics) in the treatment of painful conditions of the musculoskeletal system. *Archives of Physical Medicine & Rehabilitation.* 1964;44:233-238.

21. Green GA, Zachzewski JE, Jordan SE. Peroneal nerve palsy induced by cryotherapy. *The Physician and Sportsmedicine.* 1989;17(9):63-70.

22. Halar EM, Hammond MC, La Cava EC, Camann C, Ward J. Sensory perception threshold measurement: An evaluation of semi-objective testing devices. *Archives of Physical Medicine and Rehabilitation.* 1987;68:499-507.

23. Halvorson GA. Therapeutic heat and cold for athletic injuries. *The Physician and Sportsmedicine.* 1990;18(5):87-94.

24. Harvey CK. An overview of cold injuries. *Journal of American Podiatric Medical Association.* 1992;82(8):436-438.

25. Hayden CA. Cryokinetics in an early treatment program. *Journal of American Physical Therapy Association.* 1964;44:990-993.

26. 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. *The American Journal of Sports Medicine.* 1995;23(1):74-76.

27. Hocutt JE Jr. Cryotherapy. *American Family Physician.* 1981;23(3):141-144.

28. Hocutt JE Jr, Jaffe R, Rylander CR, Beebe JK. Cryotherapy in ankle sprains. *The American Journal of Sportsmedicine.* 1982;10(5);316-319.

29. Huskisson EC. Visual analogue scales. In: Melzack R, ed. Pain Measurement and Assessment. New York, NY: Raven Press; 1983;33-40.

30. Ingersoll CD, Knight KL, Merrick MA. Sensory perception of the foot and ankle following therapeutic applications of heat and cold. *Journal of Athletic Training.* 1992;27(3):231-237.

31. Ingersoll CD, Mangus BC. Habituation to the perception of the qualities of cold-induced pain. *Journal of Athletic Training.* 1992;27(3):218-222.

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

33. Jutte L, Suzie K, Reynolds S, Knight KL. The effects of cold bath temperatures on perceived pain and numbness (abstract). *Journal of Athletic Training.* 2003;38(2):S-44.

34. Karanakara RG, Lephart SM, Pincivero DM. Changes in forearm blood flow during single and intermittent cold application. *Journal of Orthopeadic & Sports Physical Therapy.* 1999;29(3):177-180.

35. Keahey TM, Indrisano, J, Kaliner MA. A case study on the introduction of clinical tolerance in cold uticaria. *Journal of Allergy and Clinical Immunology.* 1988;82:256-261.

36. Keatinge WR. The effects of subcutaneous fat and of previous exposure to cold on the body temperature, peripheral blood flow and metabolic rate of men in cold water. *Journal of Physiology.* 1960;153:166-178.

37. Knight KL, Aquino J, Johannes SM, Urban CD. A re-examination of Lewis'cold-induced vasodilation in the finger and the ankle. *Journal of Athletic Training.* 1980;15:248-250.

38. Knight KL. Effects of hypothermia on inflammation and swelling. *Journal of Athletic Training.* 1976; 11:7-10.

39. Knight KL. Ankle rehabilitation with cryotherapy. *Physician and Sportsmedicine.* Nov. 1979;7:133.

40. Knight KL. *Cryotherapy in Sport Injury Management.* 1995; Champaign, IL: Human Kinetics.

41. Knight KL, Elam JF. Rewarming of the ankle, finger, and forearm after cryotherapy: further investigation of Lewis' cold-induced vasodilation. *Journal of Canadian Athletic Therapy Association.* September 1981;8:17-18

42. Knight KL, Londeree BR. Comparison of blood flow in the ankle of uninjured subjects during therapeutic applications of heat, cold, and exercise. *Medicine and Science in Sports and Exercise.* 1980;12(1):76-80.

43. Lehmann JF, Warren CG, Scham SM. Therapeutic heat and cold. *Clinical Orthopaedics.* 1974;99:207-245.

44. Lowdon BJ, Moore RJ. Determinants and nature of intramuscular changes during cold therapy. *American Journal of Physical Medicine.* 1975;54(5):223-233.

45. Malone TR, Englehardt DL, Kirkpatrick JS, Basserr FH III. Nerve injury in athletes caused by cryotherapy. *Journal of Athletic Training.* 1992;27:235-237.

46. Mancuso DL, Knight KL. Effects of prior physical activity on skin surface temperature response of the ankle after a 30-minute ice pack application. *Journal of Athletic Training.* 1992;27:242-249.

47. McMaster WC. Cryotherapy. *The Physician and Sportsmedicine.* 1982;10(11):112-119.

48. Merrick MA. Secondary injury after musculoskeletal trauma: a review and update. *Journal of Athletic Training.* 2002;37(2):209-217.

49. Merrick MA, Knight KL, Ingersol CD, Potteiger JA. The effects of ice and compression wraps on intramuscular temperatures at various depths. *Journal of Athletic Training.* 1993;28(3):236-245.

50. Michlovitz SL. (1996). *Thermal agents in Rehabilitation* (3rd ed.). Philadelphia, PA: F.A. Davis Company.

51. Mielke K, Novak CB, Mackinnon SE, Feely CA. Hand sensibility measures use by therapists. *Annuals of Plastic Surgery*. 1996;36:292-296.

52. Misasi S, Morin G, Kemler D, Olmstead PS, Pryzgocki K. The effect of a toe cap on perceived pain during cold water immersion. *Journal of Athletic Training.* 1995;30(1):49-52.

53. Murphy AJ. The physiological effects of cold application. *The Physical Therapy Review.* 1960;40(2):112-115.

54. Myrer JW, Measom G, Fellingham GW. Temperature changes in the human leg during and after two method of cryotherapy. *Journal of Athletic Training.* 1998;33:25-29.

55. Myrer JW, Myrer KA, Measom GJ, Fellingham GW, Evers SL. Muscle Temperature is affected by overlying adipose when cryotherapy is administered. *Journal of Athletic Training.* 2001;36(1):32-36.

56. Newton MJ, Lehmkuhl D. Muscle spindle response to body heating and localized muscle cooling: implications for relief of spasticity. *Journal of the American Physical Therapy Association.* 1965;45:91-105.

57. Nimchick PSR, Knight KL. Effects of wearing a toe cap or a sock on temperature and perceived pain during ice water immersion. *Journal of Athletic Training.* 1983;18:144-147

58. Paintal AS. Block of conduction in mammalian myelinated nerve fibers by low temperature. *Journal of Physiology.* 1965a;180:1-19.

59. Palmer JC, Knight KL. Ankle and thigh skin temperature changes with repeated ice pack application. *Journal of Athletic Training.* 1996;31(4):319-323.

60. Petajan JH, Watts N. Effects of cooling on the triceps surae reflex. *Journal of American Physical Medicine.* 1962;41:240-251.

61. Post JB, Knight KL. Ankle skin temperature changes with a repeated ice pack application. *Journal of Athletic Training.* 1992;27:136.

62. Prentice WE. *Therapeutic Modalities for Sports Medicine and Athletic Training* (5th ed.). New York, New York: McGraw-Hill, 2003.

63. Provins KA, Morton, R. Tactile discrimination and skin temperature. *Journal of Applied Physiology.* 1960;15(1):155-160.

64. Rogers JW, Increased ice massage application pressure results in increased calf skin numbing. [Masters Thesis]. Provo, UT: Department of Physical Education, Brigham Young University; 2001.

65. Seeley RR, Stephens TD, Tate P. *Anatomy and Physiology* (3rd ed.). St. Louis, MO: Mosby-Year Book; 1995.

66. Spraycar M (1995). *Stedman's Medical Dictionary* (26th ed.). Baltimore, MD: Williams & Wilkins.

67. Stevenson GC, Collin WF, Randt CT, Sarwein TD. Effects of induced hypothermia on subcortical evoked potentials in the cat. *American Journal of Physiology.* 1958;194:423-426.

68. Streator S. The role of sensory information on affective pain. *Journal of Athletic Training.* 1994; 29:166. Abstract.

69. Streator S, Ingersoll CD, Knight KL. Sensory information can decrease cold-induced pain perception. *Journal of Athletic Training.* 1995;30(4):293-296

70. Torg JS, Vegso JJ, Torg, E. *Rehabilitation of Athletic Injuries: An Atlas of Therapeutic Exercise.* Chicago: Yearbook Medical. 1987.

71. Tovel J. Ice immersion toe cap. *Journal of Athletic Training.* 1980;15:33.

72. Van De Graff K. (2000). *Human Anatomy (updated 5th ed.).* Tennessee: McGraw-Hill.

73. Washburn B. Frostbite: What is it-how to prevent it-emergency treatment. *The New England Journal of Medicine.* 1962;266:974-989.

74. Waylonis GW. The physiologic effects of ice massage. *Archives of Physical Medicine and Rehabilitation.* 1967;Jan:37-42.

75. Weeks VD, Travell J. How to give painless injections. *AMA Scientific Exhibits.* 1957;57:318-322.

76. Weinstein S. Fifty years of somatosensory research: From Semmes-Weinstein monofilaments to the Weinstein enhanced sensory test. *Journal of Hand Therapy.* 1993;Jan-Mar;11-22.

77. Wiebers DO, Dale AJD, Kokmen E, Swanson JW. (1998) *Mayo clinic examinations in neurology*. (7th ed.) St. Louis, MO: Mosby.

Appendix B

Additional Methods

Appendix B1. Treatment Orders as Determined by Two 3 X 3 Balanced Latin Squares

Subject	Treatment Order	Condition (applied on:) Day 1	Day 2	Day 3
2, 9, 17	1	10 min.	15 min.	20 min.
3, 6, 10	2	10 min.	20 min.	15 min.
4, 12, 14	3	15 min.	10 min.	20 min.
5, 13, 15	4	15 min.	20 min.	10 min.
11, 18, 16	5	20 min.	10 min.	15 min.
1, 7, 8	6	20 min.	15 min.	10 min.

Appendix B2. Subject Information and Medical History Questionnaire

Name:_____ Subject Number_____

Home Phone:_____ Work Phone:_____

Day Time Phone:_____ Evening Phone:_____

When is the best time to contact you?_____

Email Address:_____

How often do you check your email?_____

Gender (male/female) Height:_____(in.) Weight:_____(lbs.) Age:_____(yrs.)

Dates/Time scheduled to participate in the study_____

Medical History: Please circle the appropriate answer for the inquiries below:

Have you ever had an ice treatment before?	Yes	No
Have you ever suffered from frostbite?	Yes	No
Have you ever had an adverse reaction to cold?	Yes	No
Have you ever suffered from a neurological disorder?	Yes	No
Do you have any known cardiovascular disease, including circulatory disorders?	Yes	No
Have you injured your right ankle in the last six months?	Yes	No

If you answered yes to any of the previous questions, please explain here.

_____

_____

_____

Appendix B3. Visual Analog Scale

Name_____ Date_____ Subj. #_____ Cond #____

On the lines below, please mark the greatest amount of pain you feel, and name the location of the greatest pain.

Baseline

No Pain Severe Pain

1 Minute Immersion

No Pain Severe Pain

3 Minute Immersion

No Pain Severe Pain

5 Minute Immersion

No Pain Severe Pain

7 Minute Immersion

No Pain Severe Pain

9 Minute Immersion

No Pain Severe Pain

10 Minute Immersion (if applicable)

No Pain Severe Pain

11 Minute Immersion

No Pain Severe Pain

13 Minute Immersion

No Pain Severe Pain

15 Minute Immersion

No Pain Severe Pain

17 Minute Immersion

No Pain Severe Pain

19 Minute Immersion

No Pain Severe Pain

20 Minute Immersion

No Pain Severe Pain

1 Minute Post-Immersion

No Pain Severe Pain

3 Minutes Post-Immersion

No Pain Severe Pain

5 Minutes Post-Immersion

No Pain Severe Pain

7 Minutes Post-Immersion

No Pain Severe Pain

9 Minutes Post-Immersion

No Pain Severe Pain

11 Minutes Post-Immersion

No Pain Severe Pain

Appendix B4. Subject Instructions Prior to Participation

Many activities of daily living can have an adverse influence on the data collection of this study. Circulation and skin temperature can be influenced by exercise, eating within three hours of participation, menstruation, irregular sleep patterns, and stress. In order to limit outside influences, we ask that you abide by the following suggestions:

1) Get a typical night's rest while participating in this study.
2) Do not eat within three hours prior to participating in this study.
3) Do not workout, mow the lawn, sun bathe, etc. within the three hours prior to participation in this study.
4) Females: If you are, or will be menstruating during your scheduled time of participation, you will not be excluded from the study, but will be rescheduled to a time when menstruation has ceased.

If these guidelines are not observed prior to your participation of this study, the session will need to be rescheduled.

Thank you for your participation. If you have any questions you may contact me at any time. Betsy Johnson: Home (801) 374-9723, Cell (801) 310-4238,
Email: nej6@email.byu.edu.

Appendix B5. Data Collection Table

Name_____ Subject Number_____			
Height:_____(in.) Weight:_____(lbs.) Age:_____(yrs) Gender (male/female)			
Have you eaten a meal in the past three hours?	_____	_____	_____
Have you been under more or less than normal pressure today?	_____	_____	_____
Have you exercised within the last three hours?	_____	_____	_____
Did you get a normal night's sleep last night?	_____	_____	_____
Was today a typical day regarding your activity level?	_____	_____	_____
Females: Are you currently menstruating?	_____	_____	_____
Measurements	10 min.	15 min.	20 min.
Treatment Order	_____	_____	_____
Calendar Date	_____	_____	_____
File Name	_____	_____	_____
Room Temperature	_____	_____	_____
Baseline SoP*	_____	_____	_____
Baseline VaS*	_____	_____	_____
1 min. immersion VaS	_____	_____	_____
3 min. immersion VaS	_____	_____	_____
5 min. immersion VaS	_____	_____	_____
7 min. immersion VaS	_____	_____	_____
9 min. immersion VaS	_____	_____	_____
10 min. immersion VaS	_____	_____	_____
11 min. immersion VaS	_____	_____	_____
13 min. immersion VaS	_____	_____	_____
15 min. immersion VaS	_____	_____	_____
17 min. immersion VaS	_____	_____	_____
19 min. immersion VaS	_____	_____	_____
20 min. immersion VaS	_____	_____	_____
1.5 min. SoP	_____	_____	_____
1.5 min. VaS	_____	_____	_____
3 min. SoP	_____	_____	_____
3 min. VaS	_____	_____	_____
5 min. SoP	_____	_____	_____
5 min. VaS	_____	_____	_____
7 min. SoP	_____	_____	_____
7 min. VaS	_____	_____	_____
9 min. SoP	_____	_____	_____
9 min. VaS	_____	_____	_____
11 min. SoP	_____	_____	_____
11 min. VaS	_____	_____	_____

* SoP: Sensation of pressure, VaS: Visual analog scale

Appendix B6. Informed Consent

The purpose of this study is to determine if one ice bath immersion time is more effective than two others at inducing and prolonging numbness in the ankle. This study is being conducted by Betsy Johnson (graduate student), under the direction of Dr. Ken Knight (professor). You were selected to participate in this study because you have not been injured recently, you do not suffer from any cold related maladies, and you have shown an interest in participating.

Procedures

You will be asked to report to the Richard's Building room #123 on three different occasions that will last one hour each. If you have never experienced a cold treatment, we will perform a 3-minute cold hypersensitivity test. This test will consist of a three minute ice massage to the left lower leg. If you do not show any adverse reactions, you will be asked to participate.

At each session, you will be asked to immerse your ankle in a 1º C (33.8º F) water bath for one of three different lengths of time (10 min, 15 min, 20 min). During immersion, you will sit on a chair and your foot will be immersed in a cold-water bath. After immersion, you will sit while the monofilament readings are taken, and remain seated in-between subsequent readings. You will be asked to fill out a pain scale before immersion, every 2 minutes during immersion, and 1, 3, 5, 7, 9, and 11 minutes post immersion. Skin surface temperature will be measured with a small probe attached to the skin with a small piece of tape. Numbness will be measured before immersion, and 1, 3, 5, 7, 9, and 11 minutes post-immersion. Nylon filaments, similar to a hairbrush bristle, but with differing diameters, will be applied to the skin and as the desired force is met, the filament will bend. It will be applied for 1.5 second increments, and you will be asked to respond when the monofilament is felt. If you can feel the monofilament, a smaller one will be applied. If you can't feel the monofilament, a larger one will be applied, until your sensation threshold is found. During the monofilament testing, you will pull a curtain over your lap to prohibit you from seeing when the monofilaments are being applied.

It is our intention to report and publish the mean values and statistical differences that arise from this study. All individual and personal data will be kept confidential. Upon your request, you will be given copies of the data collected and an explanation of the results.

Risks and Benefits

The risks associated with cold application are minimal. There is a risk of allergic reaction to cold if you have never experienced a cold treatment. However, this should be avoided with the three minute cold hypersensitivity test. In addition, immersion of a body part in cold water may cause some discomfort. We will attempt to minimize this discomfort with the use of a toe cap. We cannot and do not guarantee or promise that you will receive any benefits from this study, besides a learning experience, and the personal satisfaction of expanding our knowledge regarding cryotherapy.

Your decision whether or not to participate will not prejudice your future relation with BYU or the investigators. If you decide to participate, you are free to withdraw your consent and to discontinue participation at any time without any consequences. The investigator may terminate your participation at any time.

Do you have any questions (please circle one)? Yes No

If yes, then write your question(s) on the back of this sheet and DO NOT sign below until your questions have been answered satisfactorily. You may take as much time as necessary to think this over.

AUTHORIZATION:
You are making a decision whether or not to participate. Your signature indicates that you have decided to participate, having read the information provided above and all questions have been answered to your satisfaction.

_____ _____
Subject Signature Date

_____ _____
Witness Principle Investigator

If you have any questions regarding this research project, you may contact:

Betsy Johnson
755 E. 620 N.
Provo, UT 84606
nej6@email.byu.edu
(801) 374-9723

Dr. Ken Knight
120-D RB
Brigham Young University
(801) 378-2984

If you have any questions regarding your rights as a participant in this research project, you may contact Dr. Shane Schulthies, Chair of the Institutional Review Board, 120 C RB, Brigham Young University, Provo, Utah 84602; (801) 422-5490.

Appendix C

Additional Data and Results

Table C1. Appendix C Tables

Table C2. Subject Descriptive Data (Means ± SD)

	Men	Women	All
Age (yrs)	23.89 ± 2.42	21.78 ± 2.17	23.89 ± 2.42
Height (in)	69.78 ± 1.86	65.78 ± 2.73	69.78 ± 1.86
Weight (lbs)	172.11 ± 18.81	145 ± 14.58	172.11 ± 18.81

C3. Summary of Significant Statistics

	Prob. Level	Summary
Bath Temperature		
3-Way ANOVA		no diff in or between gender, condition and time
Skin Temperature		
3-Way ANOVA		
Cond * Time	.004	
2-Way ANOVA		
Cond * Time	.004	
1-Way ANOVAs		
Condition		
11 min. post	.0005	cond10>cond20
Time		
Cond 10, 15 & 20	.000001	baseline>11 min post>at 10 min. & last immersion
Visual Analog Pain Scale		
3-Way ANOVA		
Time	.000001	
2-Way ANOVA		
Time (during immersion)	.000001	see 1-Way ANOVAs
Condition (post-immersion)	.001	cond20>cond10 & cond15
Time (post-immersion)	.000001	1.5, 3, 5 & 7 are > and < any time two time slots away
1-Way ANOVAs		
Time (during immersion)		
Condition 10, 15 & 20	.000001	0<all; 1>5 and up; 1&3>7 and up; 3&5>all, but <1
Sensation of Pressure		
3-Way ANOVA		
Cond * Time	.000001	
2-Way ANOVA		
Cond * Time	.000001	
1-Way ANOVA		
Condition		
1.5 min post	.002	cond20>cond10
3 min post	.001	cond20>cond10
5 min post	.00006	cond20 & cond15>cond10
7 min post	.003	cond20>cond10 & cond15
9 min post	.0006	cond20>cond10 & cond15
11 min post	.009	cond20>cond10 & cond15
Time		
Cond 10	.000001	1.5>3>5,7,9,11&0
Cond 15	.000001	1.5>3>5,7>9, 11 & 0
Cond 20	.000001	1.5&3>7,9,11&0; 1.5>5>0

Table C4. Bath Temperature (°C; Mean ± SD)*

Time	10 Min.	15 Min.	20 Min.
0	0.94 ± 0.12	1.00 ± 0.12	0.98 ± 0.12
1	1.10 ± 0.11	1.11 ± 0.09	1.09 ± 0.09
3	1.07 ± 0.11	1.12 ± 0.15	1.09 ± 0.15
5	1.04 ± 0.14	1.06 ± 0.14	0.99 ± 0.10
7	1.02 ± 0.07	1.06 ± 0.16	1.00 ± 0.09
9	1.04 ± 0.08	1.03 ± 0.09	1.02 ± 0.09
10	1.04 ± 0.08	1.03 ± 0.07	1.00 ± 0.09
11		1.01 ± 0.08	1.00 ± 0.07
13		0.99 ± 0.16	1.03 ± 0.08
15		1.10 ± 0.20	1.05 ± 0.09
17			1.08 ± 0.09
19			1.04 ± 0.08
20			1.03 ± 0.08

* Overall water temperature: 1.04ºC ± .12ºC

Table C5. Skin Temperature (°C; Mean ± SD)

Time	10 Min.*	15 Min.*	20 Min.*
0	31.41 ± 1.0	31.73 ± 1.2	31.26 ± 1.1
1	7.65 ± 2.5	8.41 ± 2.2	8.30 ± 3.1
3	5.13 ± 1.5	5.45 ± 1.5	5.23 ± 1.9
5	4.59 ± 1.2	4.77 ± 1.5	4.36 ± 1.1
7	3.90 ± 0.9	4.19 ± 1.2	4.30 ± 1.0
9	3.93 ± 0.9	3.77 ± 1.1	3.85 ± 1.0
10	3.77 ± 0.7		
11		3.41 ± 1.0	3.59 ± 1.0
13		3.63 ± 0.6	3.37 ± 1.0
15		3.69 ± 1.5	3.42 ± 0.7
17			3.20 ± 0.7
19			3.05 ± 1.0
20			3.13 ± 0.7
21.5	11.32 ± 1.0	10.45 ± 1.1	9.53 ± 1.0
23	14.47 ± 1.2	13.51 ± 1.2	12.45 ± 1.4
25	17.23 ± 1.4	16.43 ± 1.3	15.40 ± 1.6
27	18.91 ± 1.4	18.25 ± 1.4	17.38 ± 1.6
29	19.76 ± 1.3	19.21 ± 1.3	18.45 ± 1.4
31†	20.24 ± 1.3	19.68 ± 1.3	18.98 ± 1.2

***** Time (Tukey-Kramer): baseline>11 min post>at 10 min & last immersion (for all three conditions)
† Condition (Tukey-Kramer): Skin temp 11 min post immersion was higher after 10 min immersion than skin temp 11 min post immersion after 20 min immersion.

Table C6. Visual Analog Pain Scale (CM; Mean ± SD)

Time	10 min.*	15 min.*	20 min.*
0	0.00 ± 0.00	0.00 ±0.00	0.00 ±0.00
1	5.41 ± 2.6	5.63 ± 2.6	5.55 ± 2.6
3	4.52 ± 2.1	5.11 ± 2.3	5.09 ± 2.4
5	3.63 ± 1.8	4.24 ± 1.9	4.08 ± 2.0
7	3.00 ± 1.7	3.42 ± 1.8	3.48 ± 1.9
9	2.58 ± 1.4	3.19 ± 1.7	3.24 ± 1.8
10	2.37 ± 1.6		
11		3.06 ± 1.9	2.96 ± 1.9
13		2.90 ± 1.9	2.83 ± 1.6
15		2.73 ± 2.2	2.87 ± 1.9
17			2.76 ± 1.7
19			2.78 ± 1.9
20			2.81 ± 1.9
21.5†	2.02 ± 1.3	2.22 ± 1.7	3.14 ± 2.0
23†	1.71 ± 1.4	1.82 ± 1.6	2.67 ± 1.9
25†	1.11 ± 1.1	1.28 ± 1.3	2.13 ± 1.7
27†	0.60 ± 0.7	0.76 ± 0.9	1.50 ± 1.6
29	0.33 ± 0.5	0.43 ± 0.5	1.04 ± 1.3
31	0.22 ± 0.4	0.21 ± 0.2	0.73 ± 1.1

* Post-Immersion: cond20 > cond10 & cond15
† Post-Immersion: 1.5, 3, 5 & 7 are > and < every time point at least two away.

Table C7. Sensation of Pressure (Grams; Mean ± SD, Statistical Summaries)

Time	10 min	15 min	20 min	Statistical Differences*
0	0.72 ± 1.2	0.71 ± 1.0	0.73 ± 1.2	
1.5	4.03 ± 2.7	6.28 ± 3.8	9.25 ± 9.3	cond20>cond10
3	2.75 ± 2.4	4.58 ± 3.7	6.35 ± 6.7	cond20>cond10
5	1.46 ± 1.1	2.90 ± 2.7	4.04 ± 3.7	cond15&20>cond10
7	1.10 ± 1.1	1.62 ± 1.1	2.80 ± 2.8	cond20>cond10&15
9	0.96 ± 1.1	1.07 ± 0.7	2.10 ± 2.0	cond20> cond10&15
11	0.87 ± 1.1	0.92 ± 0.6	1.54 ± 1.5	cond20>cond10&15
Statistical Differences*	1.5>3>5,7,9,11&0	1.5>3>5,9,11&0 7<1.5&3	1.5&3>7,9,11&0 1.5>5>0	

* Tukey-Kramer $p<.05$

Table C8. Summary of Statistical Analysis: Three Way ANOVAs

Source Term	DF	F-Ratio	Prob Level	Power (Alpha=0.05)
Bath Temperature: baseline, at 10 min, last immersion time, 11 min post-immersion				
Gender	1, 16	0.95	0.34	0.15
Condition	2, 32	0.87	0.43	0.19
Gender∗Cond	2, 32	0.91	0.41	0.19
Time	3, 48	2.21	0.10	0.53
Gender∗Time	3, 48	0.96	0.42	0.25
Cond∗Time	6, 96	1.03	0.41	0.39
Gender∗Cond∗Time	6, 96	1.06	0.39	0.40
Skin Temperature: baseline, at 10 min, last immersion time, 11 min post-immersion				
Gender	1, 16	1.75	0.20	0.24
Condition	2, 32	3.66	0.04	0.63
Gender∗Cond	2, 32	0.37	0.70	0.10
Time	3, 48	5335.68	0.000001	1.00
Gender∗Time	3, 48	0.24	0.87	0.09
Cond∗Time	6, 96	3.41	0.004*	0.93
Gender∗Cond∗Time	6, 96	0.62	0.71	0.24
Visual Analog Pain Scale				
Gender	1, 336	3.41	0.07	0.45
Cond	2, 336	2.14	0.12	0.44
Gender∗Cond	2, 336	0.24	0.79	0.09
Time	6, 336	47.34	0.000001†	1.00
Gender∗Time	6, 336	0.41	0.87	0.17
Condition∗Time	12, 336	0.11	1.0	0.09
Gender∗Cond∗Time	12, 336	0.07	1.0	0.07
Sensation of Pressure				
Gender	1, 16	2.05	0.17	0.27
Condition	2, 32	11.24	0.0002	0.99
Gend∗Cond	2, 32	0.97	0.39	0.20
Time	6, 96	29.80	0.000001	1.00
Gender∗Time	6, 96	2.03	0.07	0.71
Cond∗Time	12, 192	5.88	0.000001*	1.0
Gend∗Cond∗Time	12, 192	0.71	0.74	0.41

* The significant interaction necessitated Two Way ANOVA's
† Further analyzed with Two Way ANOVA

Table C9. Summary of Statistical Analysis: Two Way ANOVAs

Source Term	DF	F-Ratio	Prob Level	Power (Alpha=0.05)	Tukey-Kramer Summary
Skin Temperature: Time: baseline, at 10 min, last immersion time, 11 min post					
Condition	2, 34	3.80	0.03	0.65	
Time	3, 51	5585.14	0.000001	1.00	
Condition∗Time	6, 102	3.48	0.004*	0.94	
Visual Analog Pain Scale: During Immersion					
Cond	2, 34	2.00	0.15	0.38	
Time	6, 102	55.11	0.000001 †	1.00	
Condition∗Time	12, 204	0.86	0.59	0.50	
Visual Analog Pain Scale: Post-Immersion					
Condition	2, 34	8.17	0.001	0.94	cond20>cond10 & cond15
Time	5, 85	37.26	0.000001	1.00	1.5>5, 7, 9 & 11 3>7, 9 & 11 5>9 & 11 7>11
Condition∗Time	10, 170	1.19	0.30	0.61	
SOP: Post-Immersion					
Condition	2, 34	11.26	0.0002	0.99	
Time	6, 102	28.10	0.000001	1.00	
Cond∗Time	12, 204	5.98	0.000001*	1.00	

* The significant interaction necessitated One Way ANOVA's
† Data requires One-Way ANOVAs for cond10, 15, and 20

Table C10. Summary of Statistical Analysis: One Way ANOVA's

Source Term	DF	F-Ratio	Prob Level	Power (Alpha=0.05)	Tukey-Kramer Summary
Skin Temperature					
Time					
10 min immersion					
	3, 51	5688.81	0.000001	1.00	baseline>11 post>at 10 min & last immer
15 min immersion					
	3, 51	2416.52	0.000001	1.00	baseline>11 post>at 10 min & last immer
20 min immersion					
	3, 51	3381.54	0.000001	1.00	baseline>11 post>at 10 min & last immer
Condition					
Baseline					
	2, 34	1.53	0.23	0.30	
At 10 minutes					
	2, 34	0.45	0.64	0.12	
Last Immersion Measurement					
	2, 34	2.51	0.10	0.47	
11 Minute Post-Immersion					
	2, 34	9.53	0.0005	0.97	cond10 > cond20
Visual Analog Pain Scale: During Immersion					
Time					
Condition 10					
	6, 102	47.81	.000001		0<all; 1>5 and up; 1&3>7 and up; 3&5>all, but <1; 5<1
Condition 15					
	6, 102	31.21	.000001		same as above
Condition 20					
	6, 102	26.93	.000001		same as above
Sensation of Pressure					
Time					
10 min immersion					
	6, 102	36.96	0.000001	1.00	1.5>3>5, 7, 9, 11 & 0
15 min immersion					
	6, 102	32.74	0.000001	1.00	1.5>3>5, 9, 11 & 0 7<1.5 & 3
20 min immersion					
	6, 102	15.68	0.000001	1.00	1.5, 3>7, 9, 11 & 0 1.5>5>0
Condition					
1.5 min post-immersion					
	2, 34	7.67	0.002	0.93	cond20>cond10
3 min post-immersion					
	2, 34	8.25	0.001	0.95	cond20>cond10
5 min post-immersion					
	2, 34	13.08	0.00006	1.0	cond10<cond20 & cond15
7 min post-immersion					
	2, 34	10.54	0.0003	0.98	cond20>cond10 & cond15
9 min post-immersion					
	2, 34	9.36	0.0006	0.97	cond20>cond10& cond15
11 min post-immersion					
	2, 34	5.39	0.009	0.81	cond20>cond10 & cond15

Table C11. Bath Temperature Three Way ANOVA
Time: baseline, at 10 min, last immersion time, 11 min post

Source Term	DF	Sum of Squares	Mean Square	F-Ratio	Prob Level	Power (Alpha=0.05)
Gender	1	1.975206	1.975206	0.95	0.343240	0.150951
Subject∗(Gender)	16	33.12695	2.070434			
Condition	2	3.876986	1.938493	0.87	0.430209	0.185656
Gender∗Cond	2	4.055674	2.027837	0.91	0.414241	0.192474
Subj∗Cond∗(Gender)	32	71.62093	2.238154			
Time	3	13.75241	4.584137	2.21	0.098601	0.527301
Gender∗Time	3	5.97002	1.990007	0.96	0.418842	0.246268
Subj∗Time∗(Gender)	48	99.39982	2.070829			
Cond∗Time	6	13.60037	2.266728	1.03	0.409660	0.389812
Gender∗Cond∗Time	6	13.96957	2.328261	1.06	0.392248	0.400266
Subj∗Cond∗Time∗ (Gender)	96	210.9286	2.197173			
S	0					
Total (Adjusted)	215	472.2766				
Total	216					

Table C12. Skin Temperature Three Way ANOVA
Time: baseline, at 10 min, last immersion time, 11 min post

Source Term	DF	Sum of Squares	Mean Square	F-Ratio	Prob Level	Power (Alpha=0.05)
Gender	1	4.36	4.36	1.75	0.20	0.24
Subject∗(Gender)	16	39.82	2.49			
Condition	2	9.26	4.63	3.66	0.04	0.63
Gender∗Cond	2	0.93	0.46	0.37	0.70	0.10
Subj∗Cond∗(Gender)	32	40.45	1.26			
Time	3	29701.52	9900.51	5335.68	0.000001	1.00
Gender∗Time	3	1.34	0.45	0.24	0.87	0.09
Subj∗Time∗(Gender)	48	89.07	1.86			
Cond∗Time	6	12.09	2.01	3.41	0.004*	0.93
Gender∗Cond∗Time	6	2.216	0.37	0.62	0.71	0.24
Subj∗Cond∗Time∗ (Gender)	96	56.79	0.59			
S	0					
Total (Adjusted)	215	29957.83				
Total	216					

* The significant interaction necessitated Two Way ANOVA

Table C13. Skin Temperature Two Way ANOVA
Time: baseline, at 10 min, last immersion time, 11 min post

Source Term	DF	Sum of Squares	Mean Square	F-Ratio	Prob Level	Power (Alpha=0.05)
Subject	17	44.18	2.60			
Condition	2	9.26	4.63	3.80	0.03	0.65
Subject∗Condition	34	41.38	1.22			
Time	3	29701.52	9900.51	5585.14	0.000001	1.00
Subject∗Time	51	90.41	1.77			
Condition∗Time	6	12.09	2.01	3.48	0.004*	0.94
Subject∗Cond∗Time	102	59.01	0.58			
S	0					
Total (Adjusted)	215	29957.83				
Total	216					

* The significant interaction necessitated One Way ANOVA

Table C14. Skin Temperature, One Way ANOVA: Condition 1
Time: baseline, at 10 min, last immersion time, 11 min post

Source Term	DF	Sum of Squares	Mean Square	F-Ratio	Prob Level	Power (Alpha=0.05)
Subject	17	31.72	1.87			
Time	3	9884.25	3294.75	5688.81	0.000001*	1.00
Subject∗Time	51	29.54	0.58			
S	0					
Total (Adjusted)	71	9945.52				
Total	72					

* Tukey-Kramer multiple range test results. (Count=18)

Time	Mean	Times that are different than time in column one
Last immer	3.77	11 min post, baseline
At 10 min	3.77	11 min post, baseline
11 min post	20.24	last immer, at 10 min, baseline
Baseline	31.41	last immer, at 10 min, 11 min post

Table C15. Skin Temperature, One Way ANOVA: Condition 2
Time: baseline, at 10 min, last immersion time, 11 min post

Source Term	DF	Sum of Squares	Mean Square	F-Ratio	Prob Level	Power (Alpha=0.05)
Subject	17	30.59	1.80			
Time	3	10055.73	3351.91	2416.52	0.000001*	1.00
Subject∗Time	51	70.74	1.39			
S	0					
Total (Adjusted)	71	10157.06				
Total	72					

* Tukey-Kramer multiple range test results. (count=18)

Time	Mean	Times that are different than time in column one
At 10 min	3.62	11 min post, baseline
Last immer	3.69	11 min post, baseline
11 min post	19.68	last immer, at 10 min, baseline
Baseline	31.73	last immer, at 10 min, 11 min post

Table C16. Skin Temperature, One Way ANOVA: Condition 3
Time: baseline, at 10 min, last immersion time, 11 min post

Source Term	DF	Sum of Squares	Mean Square	F-Ratio	Prob Level	Power (Alpha=0.05)
Subject	17	23.25	1.37			
Time	3	9773.62	3257.87	3381.54	0.000001*	1.00
Subject∗Time	51	49.13	0.96			
S	0					
Total (Adjusted)	71	9846.00				
Total	72					

* Tukey-Kramer multiple range test results. (count=18)

Time	Count	Mean	Times that are different than time in column one
Last immer	18	3.127646	11 min post, baseline
At 10 min	18	3.874587	11 min post, baseline
11 min post	18	18.97638	last immer, at 10 min, baseline
Baseline	18	31.25877	last immer, at 10 min, 11 min post

Table C17. Skin Temperature One Way ANOVA's

Source Term	DF	Sum of Squares	Mean Square	F-Ratio	Prob Level	Power (Alpha=0.05)
Baseline						
Subject	17	34.70	2.04			
Condition	2	2.05	1.02	1.53	0.23	0.30
Subject∗Condition	34	22.70	0.67			
S	0					
Total (Adjusted)	53	59.44				
Total	54					
10 Minutes						
Subject	17	20.60	1.21			
Condition	2	0.59	0.30	0.45	0.64	0.12
Subject∗Condition	34	22.48	0.66			
S	0					
Total (Adjusted)	53	43.67				
Total	54					
Last Immersion Measurement						
Subject	17	24.03	1.41			
Condition	2	4.38	2.19	2.51	0.10	0.47
Subject∗Condition	34	29.66	0.87			
S	0					
Total (Adjusted)	53	58.06				
Total	54					
11 Minute Post-Immersion						
Subject	17	55.26	3.25			
Condition	2	14.33	7.16	9.53	0.0005*	0.97
Subject∗Condition	34	25.56	0.75			
S	0					
Total (Adjusted)	53	95.15				
Total	54					

* Tukey-Kramer multiple range test results. (Count=18)

Condition	Mean	Conditions that are different than condition in column one
cond10	20.23554	cond20
cond15	19.67639	
cond20	18.97638	cond10

Table C18. Visual Analog Pain Scale Three Way ANOVA

Source Term	DF	Sum of Squares	Mean Square	F-Ratio	Prob Level	Power (Alpha=0.05)
Gender	1	12.49	12.49	3.41	0.07*	0.45
Cond	2	15.68	7.84	2.14	0.12	0.44
Gender∗Condition	2	1.75	0.87	0.24	0.79	0.09
Time	6	1038.64	173.11	47.34	0.000001†	1.00
Gender∗Time	6	9.04	1.51	0.41	0.87	0.17
Condition∗Time	12	4.76	0.40	0.11	1.0	0.09
Gender∗Cond∗Time	12	2.90	0.24	0.07	1.0	0.07
S	336	1228.60	3.66			
Total (Adjusted)	377	2313.86				
Total	378					

***** Tukey-Kramer multiple range test results. (count=189)

Gender	Mean	Different From Groups
M	3.179365	
F	3.542857	

† Further analyzed with Two Way ANOVA

Table C19. Visual Analog Pain Scale Two Way ANOVA: Post-Immersion

Source Term	DF	Sum of Squares	Mean Square	F-Ratio	Prob Level	Power (Alpha=0.05)
Subject	17	302.95	17.82			
Condition	2	48.03	24.01	8.17	0.001*	0.94
Subject∗Condition	34	99.96	2.94			
Time	5	185.17	37.03	37.26	0.000001†	1.00
Subject∗Time	85	84.48	0.99			
Condition∗Time	10	2.39	0.24	1.19	0.30	0.61
Subject∗Cond∗Time	170	34.15	0.20			
S	0					
Total (Adjusted)	323	757.12				
Total	324					

*Tukey-Kramer multiple range test results. (count=108)

Condition	Mean	Conditions that are different than condition in column one
cond10	1.00	cond20
cond15	1.12	cond20
cond20	1.87	cond10, cond15

†Tukey-Kramer multiple range test results. (count=54)

Time (post-immersion)	Mean	Times that are different than time in column one
11	0.39	7, 5, 3, 1.5
9	0.60	5, 3, 1.5
7	0.95	11, 3, 1.5
5	1.51	11, 9, 1.5
3	2.07	11, 9, 7
1.5	2.46	11, 9, 7, 5

Table C20. Visual Analog Pain Scale Two Way ANOVA: During Immersion (time < 12)

Source Term	DF	Sum of Squares	Mean Square	F-Ratio	Prob Level	Power (Alpha=0.05)
Subject	17	706.94	41.58			
Cond	2	15.68	7.84	2.00	0.15	0.38
Subject∗Condition	34	133.35	3.92			
Time	6	1038.64	173.11	55.11	0.000001*	1.00
Subject∗Time	102	320.40	3.14			
Condition∗Time	12	4.76	0.40	0.86	0.59	0.50
Subject∗Cond∗Time	204	94.08	0.46			
S	0					
Total (Adjusted)	377	2313.86				
Total	378					

* Further analyzed with One Way ANOVA

Table C21. Visual Analog Pain Scale One Way ANOVA: Condition 10

Source Term	DF	Sum of Squares	Mean Square	F-Ratio	Prob Level	Power (Alpha=0.05)
Subject	17	252.30	14.84			
Time	6	324.98	54.16	47.81	0.000001*	1.00
Subject∗Time	102	115.54	1.13			
S	0					
Total (Adjusted)	125	692.82				
Total	126					

*Tukey-Kramer multiple range test results. (Count=18)

Time During Immersion	Mean	Times that are different than time in column one
0	0	10, 9, 7, 5, 3, 1
1	5.41	0, 10, 9, 7, 5
3	4.52	0, 10, 9, 7
5	3.63	0, 10, 1
7	3	0, 3, 1
9	2.58	0, 3, 1
10	2.37	0, 5, 3, 1

Table C22. Visual Analog Pain Scale One Way ANOVA: Condition 15

Source Term	DF	Sum of Squares	Mean Square	F-Ratio	Prob Level	Power (Alpha=0.05)
Subject	17	368.49	21.68			
Time	8	378.54	47.32	31.21	0.000001*	1.00
Subject∗Time	136	206.17	1.52			
S	0					
Total (Adjusted)	161	953.20				
Total	162					

*Tukey-Kramer multiple range test results. (Count=18)

Time During Immersion	Mean	Times that are different than time in column one
0	0.00	15, 13, 11, 9, 7, 5, 3, 1
1	5.63	0, 15, 13, 11, 9, 7, 5
3	5.11	0, 15, 13, 11, 9, 7
5	4.24	0, 15, 13, 1
7	3.42	0, 3, 1
9	3.19	0, 3, 1
11	3.06	0, 3, 1
13	2.9	0, 5, 3, 1
15	2.73	0, 5, 3, 1

Table C23. Visual Analog Pain Scale One Way ANOVA: Condition 20

Source Term	DF	Sum of Squares	Mean Square	F-Ratio	Level	ProbPower (Alpha=0.05)
Subject	17	495.57	29.15			
Time	11	376.36	34.21	26.93	0.000001*	1.00
Subject∗Time	187	237.55	1.27			
S	0					
Total (Adjusted)	215	1109.48				
Total	216					

*Tukey-Kramer multiple range test results. (Count=18)

Time	Mean	Times that are different than time in column one
0	0.00	17, 19, 20, 13, 15, 11, 9, 7, 5, 3, 1
1	5.55	0, 17, 19, 20, 13, 15, 11, 9, 7, 5
3	5.09	0, 17, 19, 20, 13, 15, 11, 9, 7
5	4.08	0, 17, 19, 20, 13, 1
7	3.48	0, 3, 1
9	3.24	0, 3, 1
11	2.96	0, 3, 1
13	2.83	0, 5, 3, 1
15	2.87	0, 3, 1
17	2.76	0, 5, 3, 1
19	2.78	0, 5, 3, 1
20	2.81	0, 5, 3, 1

Table C24. Sensation of Pressure Three Way ANOVA

Source Term	DF	Sum of Squares	Mean Square	F-Ratio	Prob Level	Power (Alpha=0.05)
Gender	1	214.45	214.45	2.05	0.17	0.27
Subject (Gender)	16	1672.99	104.56			
Condition	2	288.56	144.28	11.24	0.0002	0.99
Gend∗Cond	2	24.85	12.43	0.97	0.39	0.20
Subj∗Cond ∗(Gender)	32	410.92	12.84			
Time	6	1457.42	242.90	29.80	0.000001	1.00
Gender∗Time	6	99.22	16.54	2.03	0.07	0.71
Subj∗Time ∗(Gender)	96	782.57	8.15			
Cond∗Time	12	181.01	15.08	5.88	0.000001*	1.0
Gend∗Cond∗Time	12	21.95	1.83	0.71	0.74	0.41
Subj∗Cond∗Time∗ (Gend)	192	492.95	2.57			
S	0					
Total (Adjusted)	377	5646.90				
Total	378					

* Significant interaction necessitated Two Way ANOVA

Table C25. Sensation of Pressure Two Way ANOVA: Post-Immersion

Source Term	DF	Sum of Squares	Mean Square	F-Ratio	Prob Level	Power (Alpha=0.05)
Subject	17	1887.44	111.03			
Condition	2	288.56	144.28	11.26	0.0002	0.99
Subject∗Cond	34	435.78	12.82			
Time	6	1457.42	242.90	28.10	0.000001	1.00
Subject∗Time	102	881.79	8.64			
Cond∗Time	12	181.01	15.08	5.98	0.000001*	1.00
Subject∗Cond∗Time	204	514.90	2.52			
S	0					
Total (Adjusted)	377	5646.90				
Total	378					

* Significant interaction necessitated One Way ANOVA

Table C26. Sensation of Pressure One Way ANOVA: Condition 10

Source Term	DF	Sum of Squares	Mean Square	F-Ratio	Prob Level	Power (Alpha=0.05)
Subject17	260.19	15.31				
Time	6	164.69	27.45	36.96	0.000001*	1.00
Subject∗Time	102	75.75	0.74			
S	0					
Total (Adjusted)	125	500.63				
Total	126					

*Tukey-Kramer multiple range test results. (Count=18)

Time	Mean	Times that are different than time in column one
0	0.72	3, 1.5
11	0.87	3, 1.5
9	0.96	3, 1.5
7	1.10	3, 1.5
5	1.46	3, 1.5
3	2.75	0, 11, 9, 7, 5, 1.5
1.5	4.03	0, 11, 9, 7, 5, 3

Table C27. Sensation of Pressure One Way ANOVA: Condition 15

Source Term	DF	Sum of Squares	Mean Square	F-Ratio	Prob Level	Power (Alpha=0.05)
Subject	17	391.12	23.01			
Time	6	490.33	81.72	32.74	0.000001*	1.00
Subject∗Time	102	254.63	2.50			
S	0					
Total (Adjusted)	125	1136.08				
Total	126					

*Tukey-Kramer multiple range test results. (Count=18)

Time	Mean	Times that are different than time in column one
0	0.71	5, 3, 1.5
11	0.92	5, 3, 1.5
9	1.07	5, 3, 1.5
7	1.62	3, 1.5
5	2.90	0, 11, 9, 3, 1.5
3	4.58	0, 11, 9, 7, 5, 1.5
1.5	6.28	0, 11, 9, 7, 5, 3

Table C28. Sensation of Pressure One Way ANOVA: Condition 20

Source Term	DF	Sum of Squares	Mean Square	Prob F-Ratio	Power Level (Alpha=0.05)	
Subject	17	1671.90	98.35			
Time	6	983.42	163.90	15.68	0.000001*	1.00
Subject*Time	102	1066.31	10.45			
S	0					
Total (Adjusted)	125	3721.63				
Total	126					

*Tukey-Kramer multiple range test results. (Count=18)

Time	Mean	Times that are different than time in column one
0	0.73	5, 3, 1.5
11	1.54	3, 1.5
9	2.10	3, 1.5
7	2.80	3, 1.5
5	4.04	0, 1.5
3	6.35	0, 11, 9, 7
1.5	9.25	0, 11, 9, 7, 5

Table C29. Sensation of Pressure One Way ANOVA: 1.5 min post-immersion

Source Term	DF	Sum of Squares	Mean Square	F-Ratio	Prob Level	Power (Alpha=0.05)
Subject	17	1306.72	76.87			
Condition	2	246.39	123.19	7.67	0.002*	0.93
Subject*Condition	34	546.33	16.07			
S	0					
Total (Adjusted)	53	2099.44				
Total	54					

*Tukey-Kramer multiple range test results. (Count=18)

Condition	Mean	Conditions that are different than condition in column one
cond10	4.03	cond20
cond15	6.28	
cond20	9.25	cond10

Table C30. Sensation of Pressure One Way ANOVA: 3 min post-immersion

Source Term	DF	Sum of Squares	Mean Square	F-Ratio	Prob Level	Power (Alpha=0.05)
Subject	17	852.67	50.16			
Condition	2	116.40	58.20	8.25	0.001*	0.95
Subject∗Condition	34	239.72	7.05			
S	0					
Total (Adjusted)	53	1208.80				
Total	54					

*Tukey-Kramer multiple range test results. (Count=18)

Condition	Mean	Conditions that are different than condition in column one
cond10	2.75	cond20
cond15	4.58	
cond20	6.35	cond10

Table C31. Sensation of Pressure One Way ANOVA: 5 min post-immersion

Source Term	DF	Sum of Squares	Mean Square	F-Ratio	Prob Level	Power (Alpha=0.05)
Subject	17	290.80	17.11			
Condition	2	60.11	30.06	13.08	0.00006*	1.0
Subject∗Condition	34	78.15	2.30			
S	0					
Total (Adjusted)	53	429.06				
Total	54					

*Tukey-Kramer multiple range test results. (Count=18)

Condition	Mean	Conditions that are different than condition in column one
cond10	1.46	cond15, cond20
cond15	2.90	cond10
cond20	4.04	cond10

Table C32. Sensation of Pressure One Way ANOVA: 7 min post-immersion

Source Term	DF	Sum of Squares	Mean Square	F-Ratio	Prob Level	Power (Alpha=0.05)
Subject	17	130.54	7.68			
Condition	2	27.35	13.68	10.54	0.0003*	0.98
Subject*Condition	34	44.13	1.30			
S	0					
Total (Adjusted)	53	202.02				
Total	54					

*Tukey-Kramer multiple range test results. (Count=18)

Condition	Mean	Conditions that are different than condition in column one
cond10	1.10	cond20
cond15	1.62	cond20
cond20	2.80	cond10, cond15

Table C33. Sensation of Pressure One Way ANOVA: 9 min post-immersion

Source Term	DF	Sum of Squares	Mean Square	F-Ratio	Prob Level	Power (Alpha=0.05)
Subject	17	73.03	4.30			
Condition	2	14.27	7.13	9.36	0.0006*	0.97
Subject*Condition	34	25.92	0.76			
S	0					
Total (Adjusted)	53	113.22				
Total	54					

*Tukey-Kramer multiple range test results. (Count=18)

Condition	Mean	Conditions that are different than condition in column one
cond10	0.96	cond20
cond15	1.07	cond20
cond20	2.10	cond10, cond15

Table C34. Sensation of Pressure One Way ANOVA: 11 min post-immersion

Source Term	DF	Sum of Squares	Mean Square	F-Ratio	Prob Level	Power (Alpha=0.05)
Subject	17	49.70	2.92			
Condition	2	5.06	2.53	5.39	0.009*	0.81
Subject*Condition	34	15.94	0.47			
S	0					
Total (Adjusted)	53	70.69				
Total	54					

*Tukey-Kramer multiple range test results. (Count=18)

Condition	Mean	Conditions that are different than condition in column one
cond10	0.87	cond20
cond15	0.92	cond20
cond20	1.54	cond10, cond15

Appendix D

Suggestions for Future Research

- Investigate the relationship between level of numbness and duration of therapeutic exercise possible by an injured subject.
- Investigate the relationship between subject's perception of numbness and sensation of pressure.
- Investigate the effect of therapeutic exercise on return of sensation following cryotherapy.
- Compare the effects ice bag application, ice bag massage, and ice bath immersion on numbness and perceived pain during and following application.