2009-04-23

The Effects of Cold Water Immersion on Fractioned Response Time

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THE EFFECT OF COLD WATER IMMERSION

ON FRACTIONED RESPONSE TIME

by

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A thesis submitted to the faculty of

Brigham Young University

in partial fulfillment of the requirements for the degree of

Masters of Science

Department of Exercise Sciences

Brigham Young University

August 2009

BRIGHAM YOUNG UNIVERSITY

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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ABSTRACT

THE EFFECT OF COLD WATER IMMERSION

ON FRACTIONED RESPONSE TIME

Patricia J. Romney

Department of Exercise Sciences

Master of Science

Objectives: Quantify the effects of cold water immersion of the ankle on fractioned response time of the dominant lower limb. **Design and Setting:** A 2x2x5x5 crossover design with repeated measures on time and treatment directed data collection. The independent variables were gender, treatment, time (pretreatment, and post 15 seconds, 3 minutes 6 minutes and 9 minutes) and trial (5 trials for each time group). Response time (T_{resp}), reaction time (T_{reac}), trial and surface temperature were measurement variables. **Subjects:** Thirty-six subjects, 18 females and 18 males were recruited from a physically active volunteer college student population. **Measurements:** Fractioned response time was tested following a 20 minute treatment. Response time and T_{reac} were recorded by the reaction timer, and T_{mov} was calculated by taking the difference between T_{resp} and $T_{reac.}$ For each time/subject the high and low T_{resp} were discarded and the middle three trials were averaged and used for statistical analysis. A

2x2x5 ANOVA was used to determine overall differences between gender, treatment and time followed by Newman-Keuls multiple comparison tests. **Results:** Males were faster than females for T_{resp}, T_{reac} and T_{mov}. Movement time and T_{resp} were slower with cold water immersion, but T_{reac} was unaffected. Movement time and T_{resp} were fastest pretreatment, and slowest during the post 15-second time group. Though both T_{mov} and T_{resp} progressively sped up from the post 15-second through the post 9-minute time group, they did not return to pretreatment values when data collection discontinued. **Conclusions:** Immersing the dominant ankle in cold water for 20 minutes increases T_{mov} of the dominant lower limb; thereby increasing fractioned response time (T_{resp}). **Key Words:** Cold water immersion, fractioned response time, response time, reaction time, movement time, cryotherapy.

ACKNOWLEDGMENTS

Special thanks go to Dr. Knight for all of his help and time running statistics, interpreting results and editing this paper. Thanks also to Dr. Hall and Dr. Hopkins for their help in completing this research. Thanks to the department for use of the equipment and space for data collection. Lastly, thanks to my family for their support and encouragement.

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Abstract

The effect of cold water immersion on fractioned response time.

Objectives: Quantify the effects of cold water immersion of the ankle on fractioned response time of the dominant lower limb. **Design and Setting:** A 2x2x5x5 crossover design with repeated measures on time and treatment directed data collection. The independent variables were gender, treatment, time (pretreatment, and post 15 seconds, 3 minutes 6 minutes and 9 minutes) and trial (5 trials for each time group). Response time (T_{resp}), reaction time (T_{reac}), trial and surface temperature were measurement variables. **Subjects:** Thirty-six subjects, 18 females and 18 males were recruited from a physically active volunteer college student population. **Measurements:** Fractioned response time was tested following a 20 minute treatment. Response time and T_{reac} were recorded by the reaction timer, and T_{mov} was calculated by taking the difference between T_{resp} and $T_{reac.}$ For each time/subject the high and low T_{resp} were discarded and the middle three trials were averaged and used for statistical analysis. A 2x2x5 ANOVA was used to determine overall differences between gender, treatment and time followed by Newman-Keuls multiple comparison tests. **Results:** Males were faster than females for T_{resp}, T_{reac} and T_{mov}. Movement time and T_{resp} were slower with cold water immersion, but T_{reac} was unaffected. Movement time and T_{resp} were fastest pretreatment, and slowest during the post 15-second time group. Though both T_{mov} and T_{resp} progressively sped up from the post 15-second through the post 9-minute time group, they did not return to pretreatment values when data collection discontinued.

Conclusions: Immersing the dominant ankle in cold water for 20 minutes increases T_{mov} of the dominant lower limb; thereby increasing fractioned response time (T_{resp}).

Key Words: Cold water immersion, fractioned response time, response time, reaction time, movement time, cryotherapy.

Introduction

Competitive and recreational athletes are limited in their ability to compete following a common ankle injury, due to pain.[5, 6, 16, 17] The use of cryotherapy is an accepted and common practice to control the pain of acute and sub acute ankle sprains,[5, 6, 16, 17] but is believed by clinicians to inhibit the athlete's performance.[11]

Scientists have looked at the effects of cryotherapy on simple movements of the fingers and hand,[4] complex functional tasks using timed tests such as shuttle runs, hop tests, carioca,[11] or time to stabilization from a jump landing.[18] The effects of cryotherapy on these tasks vary. Tests such as the carioca,[4] co-contraction,[4] 6-m hop test,[2] ground reaction forces during a 2-legged landing from a 2-legged jump[11] and time to stabilization from a jump landing[18] are unaffected by cryotherapy. Results for the shuttle run are equivocal. One study reported no effect,[4] while another reported a negative effect.[2] The height of a single-leg vertical jump following cryotherapy was also negatively effected.[2]

There have been numerous studies on the affects of cryotherapy on complex functional tests,[2, 4, 11] but there is limited research concerning the initiation of these functional movements such as the initiation or first step of a shuttle run or a carioca. One way to test this is by studying fractioned response time (T_{resp}) or the measure of how long it takes to perform a specific movement in reaction to an external stimulus.[3, 15] Fractioned response time is the sum of T_{reac} (the time from presentation of the stimulus to the beginning of the response), plus T_{mov} (the time period from initiation of movement to completion of the desired response).[3, 15]

In one published and two unpublished studies it was reported that cryotherapy treatment increased T_{reac} and T_{mov} of the hand[13] and increased T_{mov} [7, 20] and T_{reac} [20] of the ankle for 15[13] to 20[7] minutes postcryotherapy.

Tissue rewarming may account for the variation in results regarding complex functional tasks because of the time delay between removal of cryotherapy and performing the task. This time delay can be due to putting on shoes and socks or relocating to a different venue to perform the task. [19, 21] By using a simplified task, timing and tissue rewarming will be less of a factor because preparation is minimal and can be performed within 15 seconds of removal from the ice bath.

During this study we investigated the effects of cold water immersion on fractioned response time with the hypothesis that T_{reac}, T_{mov} and T_{resp} would all increase. The results of this study add to clinical understanding regarding the intensity of excersise used following cryotherapy.

Methods

A 2x2x5x5 crossover design with repeated measures on 2 of the factors (time and treatment) guided data collection. The independent variables were sex (male and female), treatment (control and ice), time (preapplication and 15 seconds, 3 minutes, 6 minutes, and 9 minutes postapplication) and trial (5 trials for each time). Time intervals were chosen to observe any changes in fractioned response time as tissue rewarming occurs. The measurement variables were T_{resp}, T_{reac}, trial and surface temperature.

Thirty-six subjects were recruited from a physically active volunteer college student population: 18 females (age, 22 ± 2.4 years; height, 65.61 ± 2.1 in; weight, (146.28 ± 26.1 lbs) and 18 males (age, 22.22 ± 2.4 years; height, 70.67 ± 4.1 in; weight, 182.72 ± 23.6 lbs). They were randomly assigned to one of two treatment orders (cold water immersion and control) by drawing a number from one of two containers (male and female). Informed consent was obtained and a health questionnaire was completed, as approved by the university Institutional Review Board, before participating in this study.

A cold water bath of approximately 1ºC was used to submerge the subject's dominant ankle up to the base of the calf.[12] Skin temperature was recorded with thermocouples (copper-constantan, type-T, Physiotemp, Clifton, NJ) attached to a 16-channel Isothermex (Columbus Instruments, Columbus, OH). Fractioned response time was measured using a Reaction/Movement Timer (model #63017, Lafayette Instrument Company, Lafayette, IN).

Procedures

Each subject reported for a familiarization day and two research sessions with 1 or 2 days between sessions. The subjects attended the information and familiarization meeting to introduce them to the study and were given instructions on the testing procedure. On the testing days they underwent the control or the treatment condition based upon their assigned treatment order.

On the familiarization day, subjects filled out all necessary paperwork and were randomly assigned to one of the two treatment orders. Subjects familiarized themselves with the response time machine by performing 25 familiarization trials in 5 sets of 5 trials with 2 minutes between sets.

Testing was performed no less than 24 hours and no more than 72 hours following familiarization; at approximately the same time of day for each subject.[23] They were instructed to be consistent in their activities of daily living for each testing day. For each session they were asked to refrain from physical activity that might cause muscle soreness for 48 hours prior to testing, activity that might be fatiguing 6 hours prior to testing, and to maintain consistent and healthy sleeping and eating patterns. Subjects responded verbally to questions regarding their consistency, and their answers were recorded on the data collection sheet. They wore shorts and removed their shoes and socks for the familiarization and testing day. Treatment time for both the control and cold water immersions was 20 minutes measured by a hand-held stopwatch.

Upon arrival, subjects performed their pretreatment fractioned response time trials, and a dot was applied with permanent marker over the anterior talofibular ligament (ATF) of the dominant ankle. One thermocouple was applied to the skin 1 cm posterior to the dot, the second was placed in the bucket (ice/control) to measure temperature and the third measured room air temperature. Water temperature was approximately 0 degrees Celsius. Surface temperature recordings started prior to the pretreatment set of 5 trials and continued until the set of trials at 9 minutes posttreatment were completed. Subjects wore a toecap for comfort during the 20-minute cold-water bath. For each testing interval (pre, 15 seconds post, 3 minute post, 6 minutes post, and 9 minutes post) T_{resp} and T_{reac} were recorded from the reaction timer. Five trials lasted approximately 50 to 60 seconds. During the time between sets, subjects sat in a chair. If a score was not recorded due to error, the trial was repeated.

The specified movement used to measure fractioned response time started with the subject in a standing position with feet shoulder width apart and staggered with the dominant leg behind and the nondominant leg 3-6 inches in front. The subject stood with equal weight on both feet with the foot of the dominant leg depressing the first button. When the subject heard the beep from the machine, they performed a walking motion over a rectangular block (3 in W X 3 in H X 6 in L), 3 inches in front of the dominant leg, to a target button, 10 inches in front of them (See Figure 1). A 3-second foreperiod was used as set by a switch on the reaction timer. The tester sat behind the subject, and the subject was not given any feedback concerning their performance including allowing them to see their times.

Statistical Analysis

Movement time was calculated by taking the difference between T_{resp} and $T_{reac,}$. For each time/subject the high and low T_{resp} were discarded and the middle three trials were averaged and used for statistical analysis. A 2x2x5 ANOVA was used to determine overall differences among sex, treatment and time for the three dependent variables. Newman-Keuls multiple range tests were computed to evaluate differences between groups when indicated. Effect size was calculated using Cohen's d equation.[24]

Results

Males were faster than females for all three dependent variables (Table 1); T_{reac} ($F_{1,34} = 5.22$, $P = 0.03$), T_{mov} ($F_{1,34} = 5.41$, $P = 0.03$) and T_{resp} ($F_{1,34} = 5.79$, $P = 0.02$). Movement time ($F_{1,34} = 28.29$, P = 0.000007) and T_{resp} ($F_{1,34} = 12.22$, $P = 0.001$) were significantly slower with cold water immersion, but T_{reac} ($F_{1,34} = 5.22$, $P = 0.53$) was unaffected (Table 1). The fastest T_{mov} ($F_{1,34}$ = 26.32, P = 0.000000) and T_{resp} ($F_{1,34}$ = 18.78, P = 0.000000) were performed in the pretreatment time group, and the slowest T_{mov} ($F_{1,34}$ = 26.32, P = 0.000000) and T_{resp} ($F_{1,34}$ = 18.78, P = 0.000000) were performed in the post 15-second time group (Table 1). Both T_{mov} ($F_{1,34}$ = 18.73, P = 0.000000) and T_{resp} ($F_{1,34}$ = 9.06, P = 0.000002) progressively sped up from the post 15-second time group through the post 9-minute time group, but did not return to pretreatment values when data collection discontinued (Table 1). Effect sizes ranged from 0.40 to 6.93 (Table 2).

The overall temperature of the environment was 20.5 ± 0.3 degrees Celcius, and the overall temperature of the water was 22.4 ± 1.6 degrees Celcius for the control and 0.2 ± 0.4 degrees Celcius for the slush bath (Table 3). Temperature values for the control were consistent within 1 degree Celcius throughout data collection (Table 3). Surface temperature for pretreatment during the cold water immersion research session was 28.4 ± 5.3 (ice) for males and 28.9 ± 1.6 (ice) for females (Table 3). Temperatures began to increase immediately upon removal from the slush bath, but did not return to normal by the time we discontinued data collection at 9 minutes post with males at 17.7 ± 1.3 degrees Celcius and females at 18.2 ± 2.7 degrees Celcius.(Table 3).

Discussion

The hypotheses were that T_{resp}, T_{mov} and T_{reac} would increase following cold water immersion, and our results both agree and disagree with these hypotheses. In agreement, T_{mov} and T_{resp} both increased. Reaction time, however, did not increase as hypothesized. The increase in T_{resp} and T_{mov} found in our study is consistent with one published[13] and two unpublished[7, 20] studies which similarily reported an increase in T_{mov} with cryotherapy, but also reported an increase in T_{reac}.[13, 20]

Haskvitz et al[7] looked at the effects of cold water immersion on T_{reac} and T_{mov} to the ankle with a resulting increase in T_{mov}, and no effect on T_{reac}.[7] Subjects underwent a 20 minute treatment session, control or cold water immersion and then performed a movement of the ankle/subtalar joint using two foot switches connected to an electrical circuit with a signal switch and two timers. It appears that this study is most similar to ours, but they did not report what movement was used, making it difficult to completely compare results.

Narodowy et al[20] also looked at the effects of cooling on T_{reac} and T_{mov} using four separate treatment conditions; cooling the ankle joint, cooling the peroneal muscle group, cooling both the ankle and the peroneals, and a control to delineate between joint and muscle cooling. Movement time increased following ankle, peroneal and ankle/peroneal cooling; whereas, T_{reac} only increased following peroneal and ankle peroneal cooling. The Narodowy et al[20] results suggest that T_{reac} is affected when muscles are cooled in agreement with two recent studies which reported that peroneus longus T_{reac} is not affected by ankle joint cooling.[1, 9]

An explanation for the different effects on T_{reac} between Narodowy et al[20] and our study is the type of movement performed. The movement in the Narodowy et al[20] study held the heels stationary with the movement occurring entirely in the forefoot. The foot moved laterally from the starting switch to the ending switch.[20] In contrast, the movement in our study involved the entire lower extremity by asking the subject to perform a forward walking motion over a block. Both movements required dorsiflexion, but the movement in our study also required hip flexion, knee flexion/extension and plantarflexion. The number of muscles involved, and the complexity of the movement in our study make comparison difficult.

Narodowy et al[20] cooled the ankle and peroneal muscles, which were the muscles primarily responsible for the movement; whereas, the movement in our study involved muscles that were not cooled. Because of this, it is reasonable to suggest that T_{reac} may have been affected in our study if the entire lower extremity and all muscles responsible for the movement had been cooled.

Kauranen et al[13] looked at the effects of hot and cold pack application on motor performance of the hand. A 15-minute cold pack application to the forearm, from elbow to wrist, increased simple T_{reac}, and speed of movement (T_{mov}) of the hand.[13] The differing results may again be attributed to the difference between cryotherapy methods and not cooling all the muscles involved in our required movement, but may also be attributed to differences between cooling the upper[13] versus lower extremities.

We found that T_{mov} and T_{resp} times did not return to pretreatment values before we discontinued data collection after the post 9-minutes time group, nor did surface temperature . Haskvitz et al[7] followed the effects of cooling every 5 minutes for 30 minutes following treatment, and reported that T_{mov} values did not approach pretreatment values until 20 minutes post treatment. Kauranen et al[13] reported that both T_{reac} and T_{mov} returned to pretreatment values at 15 minutes following treatment. If we had recorded data for 15 to 20 minutes, it is possible that we would have also seen T_{mov} and T_{resp} times return to pretreatment values. Future research should take this into account when determining how long to collect data following cryotherapy removal.

The results of our study indicate that the physiological responses of muscle tissue cooling are responsible for the increase in T_{mov} and T_{resp}. Some physiological responses to muscle tissue cooling include anesthesia,[18] decreased amplitude of action potentials and twitch contractions,[2] decreased cross bridge formation,[10] decreased muscle spindle activity,[8, 9, 22] slower muscle contraction time due to decreased nerve conduction velocity,[8, 9] decreased muscular strength,[14] and tissue (connective tissue and/or muscle) stiffness.[22] By at least partially cooling the muscles of the lower leg, the muscles may have experienced some of these physiological responses, and a delay in the motor response of the lower extremity and muscles cooled may have resulted.

This study implies that clinicians should be conscious of the effects of cold water immersion on T_{mov} and T_{resp}. The differences in times appear minimal and beg the question of clinical significance. It is possible that the increase in performance may lead an athlete to perform the movement differently, thereby leading to injury. It is difficult to say how meaningful these results are, but they do represent a need for further research in this area.

There were limitations in this study that need to be mentioned. First, healthy subjects were used in our study, but it is possible subjects with an ankle injury may respond differently. Second, was the use of a constant foreperiod of 3 seconds. By not changing the foreperiod, anticipation of the beep was easier and responses may have been faster. Third, not all muscles involved in the required movement were cooled. We cooled the ankle joint and used the walking motion for better clinical application. Clinicians rarely ice the entire lower extremity from the waist to treat an ankle sprain, and many athletic tests and movements require a first step similar to the movement we used.

It is possible that a greater difference in T_{mov} and T_{resp} would result if the entire lower limb was cooled and thus should be included in future research. Other future research should address the effects of cryotherapy on fractioned response time by looking at the differences between joint, muscle and joint/muscle cooling, and the difference between cooling and not cooling all muscles involved in the movement.

Conclusion

The study suggests that immersing the dominant ankle in cold water for 20 minutes increases T_{mov} of the dominant lower limb; thereby increasing fractioned response time (T_{resp}) for greater than 9 minutes. Cryotherapy during rehabilitation to manage pain and improve results is widely accepted and proven successful. Clinicians should be aware of the results when and look to further research to delineate how and when it should be used and what precautions, if any should be taken.

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Table 1. Response, reaction, and movement times over time. Average of 3 middle trials of 5 total trials, as determined by T_{resp},for each of 18 subjects (msec, mean ± standard deviation; n=54 per cell)

	Pre	Post 0:15	Post 3:00	Post 6:00	Post 9:00
Female					
Control					
T_{resp}	773 ± 17	801 ± 20	796 ± 19	794 ± 22	787 ± 19
T_{reac}	477 ± 12	487 ± 13	488 ± 13	483 ± 14	478 ± 11
T_{mov}	296 ± 08	314 ± 10	308 ± 08	311 ± 10	309 ± 09
Ice					
T_{resp}	759 ± 18 [b]	855 ± 21 [b]	818 ± 19 [b]	808 ± 22 [b]	799 ± 22 [b]
T_{reac}	466 ± 12	493 ± 13	472 ± 11	480 ± 13	481 ± 14
T_{mov}	293 ± 07 [a]	362 ± 10 [a]	347 ± 11 [a]	328 ± 10 [a]	317 ± 09 [a]
Male					
Control					
T_{resp}	664 ± 12	675 ± 14	661 ± 11	648 ± 11	653 ± 12
T_{reac}	412 ± 08	414 ± 09	410 ± 07	398 ± 07	404 ± 07
T_{mov}	252 ± 05	261 ± 06	251 ± 06	250 ± 05	249 ± 06
Ice					
T_{resp}	644 ± 10 [b]	737 ± 13 [b]	711 ± 12 [b]	698 ± 14 [b]	678 ± 13 [b]
T_{reac}	403 ± 07	427 ± 07	425 ± 07	420 ± 08	410 ± 08
T_{mov}	242 ± 04 [a]	310 ± 08 [a]	286 ± 06 [a]	278 ± 07 [a]	268 ± 06 [a]

[a] T_{mov} Post 3 min & Post 15 sec > Post 6 min & Post 9 min > Pre
[b] T_{resp} Post 15 sec > Post 3 min & Post 6 min > Post 9 min > Pre

Table 2. Effect size for response, reaction, and movement times over time for each of 18 subjects (n=36 per cell)

	Pre	Post 0:15	Post 3:00	Post 6:00	Post 9:00
Female					
T_{resp}	0.80	2.63	1.16	0.64	0.58
T_{mov}	0.40	4.80	4.06	1.70	0.89
Male					
T_{resp}	1.81	4.59	4.34	3.97	2.00
T_{mov}	2.21	6.93	5.83	4.60	3.17

Table 3. Temperature Means for the environment, ankle and times associated with fractioned response time trials at 0, 20, 21, 23, 26 and 29 minutes. (degrees Celcisus, mean ± standard deviation; n=18 per cell)

	$Temp_{environment}$	$Temp_{bucket}$	$Temp_{ankle}$
Female			
Control			
0	20.6 ± 0.8	21.3 ± 1.1	29.3 ± 2.0
20	20.5 ± 0.8	23.2 ± 1.0	29.4 ± 1.8
21	20.6 ± 0.8	22.6 ± 0.8	28.8 ± 2.0
23	20.6 ± 0.8	22.4 ± 0.9	29.0 ± 2.0
26	20.5 ± 0.8	22.1 ± 1.0	28.9 ± 1.8
29	20.5 ± 0.8	22.0 ± 1.1	28.7 ± 2.0
Ice			
0	20.6 ± 0.8	0.2 ± 0.2	28.9 ± 1.6
20	20.6 ± 0.9	0.2 ± 0.3	4.6 ± 5.0
21	20.5 ± 0.9	0.2 ± 0.3	8.7 ± 4.0
23	20.5 ± 0.9	0.0 ± 0.6	13.4 ± 3.5
26	20.4 ± 1.1	0.2 ± 0.3	16.7 ± 3.0
29	20.5 ± 0.9	0.1 ± 0.1	18.2 ± 2.7
Male			
Control			
0	20.6 ± 0.9	21.3 ± 2.3	28.3 ± 3.2
20	20.5 ± 0.8	23.4 ± 1.7	28.6 ± 2.7
21	20.4 ± 0.8	23.0 ± 1.7	28.0 ± 2.6
23	20.5 ± 0.8	22.7 ± 1.9	27.8 ± 2.9
26	20.6 ± 0.7	22.4 ± 1.8	28.1 ± 2.8
29	20.5 ± 0.8	22.3 ± 1.9	28.0 ± 2.7
Ice			
0	20.5 ± 0.8	0.2 ± 0.4	28.4 ± 5.3
20	20.6 ± 0.9	0.5 ± 1.0	5.3 ± 2.9
21	20.5 ± 0.8	0.1 ± 0.2	10.6 ± 2.5
23	20.5 ± 0.8	0.3 ± 0.4	14.0 ± 1.9
26	20.5 ± 0.8	0.2 ± 0.4	16.6 ± 1.7
29	20.5 ± 0.9	0.2 ± 0.4	17.7 ± 1.3

$Temp_{environment}$ overall, 20.5 ± 0.8
$Temp_{water}$
Treat 1(control): 22.4 ± 1.6
Treat 2(cold water immersion): 0.2 ± 0.4

Figure 1. Picture of setup and movement.

Appendix A

Prospectus

Chapter 1

Introduction

Ankle sprains are one of the most common injuries in competitive and recreational sports.[17, 21, 49, 52] Treatment of ankle sprains commonly includes cryotherapy in various forms.

Cryotherapy is the oldest and simplest therapeutic modality.[36, 46, 56] Today it is commonly used for two purposes, to reduce metabolism and limit secondary hypoxic injury during immediate care[39] and to decrease pain and arthrogenic muscle inhibition[26, 28] thereby facilitating active exercise during sub acute care.[39] Various methods of cryotherapy are used in rehabilitation. One common practice is the use of cold water immersion because the clinician can control the temperature of the water.[34] A water temperature of 1º C, despite greater initial discomfort, is most effective to induce numbness, and facilitate movement.[34]

Many clinicians believe that an athlete should not begin competition or return to competition immediately following cryotherapy, fearing an overall decrease in performance or athletic capabilities. More specifically they fear that the resulting decrease in neurological response may reduce an individual's ability to react to stimuli.[33] As a result, athletes are prevented from performing because of the pain.

Scientists report a decrease in simple movements such as finger and hand dexterity with cryotherapy,[16] but the effects of cryotherapy on functional tasks varies. Functional tests such as a carioca,[16] co-contraction[16] or 6-m hop test[8] are not affected by cryotherapy, but there are contrasting results for the shuttle run. There is research supporting both no effect[16] and an increase in time, or negative effect,[8] on a timed shuttle run following cryotherapy. Ground reaction forces during a 2-legged landing from a 2-legged jump are unaffected,[33] but the height of a single leg vertical jump decreased following cryotherapy.[8] The length of time between cooling and performing the task may account for some of the variation since tissue begins warming after the cryotherapy application is removed.[55, 62] The longer the time interval, the less affect the cold would have.[55, 62]

There have been numerous studies on the affects of cryotherapy on functional (timed) tests,[8, 16, 33] but there is little research concerning the initiation of these functional movements such as the initiation or first step of a shuttle run or a carioca. One way to test this is by studying fractioned response time or the measure of how long it takes to perform a specific movement in reaction to an external stimulus.[14, 48] Fractioned response time is the sum of reaction time, the time from presentation of the stimulus to the beginning of the response, plus movement time, the time period from initiation of movement to completion of the desired response.[14, 48]

In one published and two unpublished studies it was reported that cold pack treatment delayed reaction time of the hand[37] and significantly decreased movement time[24, 57] and reaction time[57] of the ankle for up to 5 minutes post cryotherapy application with measurements not reaching baseline until 20 minutes post.[24] These studies concluded that cryotherapy slows an athlete's ability to react to stimuli and perform simple movements.[24, 57] No known research exists concerning the affects of cryotherapy on all of the components of fractioned response time when performing the first step of a functional movement. Time and tissue re-warming will be less of a factor when looking at fractioned response time of a simplified task, because preparation for the test is minimal and can be performed within 15 seconds of removal from the ice bath.

Both competitive and recreational athletes are limited in their ability to compete following a common ankle injury[17, 21, 49, 52] because of pain. The use of cryotherapy is an accepted and common practice to control the pain of acute and sub acute ankle sprains,[17, 21, 49, 52] but is believed by clinicians to inhibit the athlete's performance.[33] Scientists have looked at the effects of cryotherapy on functional tasks using timed tests such as shuttle runs, hop tests, carioca, etc. [33] but they have not adequately studied the initiation of these movements in response to a stimulus which can be measured using fractioned response time. They have also not looked at how long these effects last. During this study we will investigate the effects of cold water immersion on fractioned response time to add clinical understanding regarding when cryotherapy can be used to facilitate movement.

Statement of Purpose

The purpose of this study is to answer the following question: Does cold water immersion to of the ankle affect fractioned response time of the dominant lower limb?

Research Hypotheses

1. Fractioned response time will be greater 15 seconds following cold water immersion of the dominant ankle to the base of the calf than prior to immersion.
2. Fractioned response time will be slower than baseline 3 minutes following cold water immersion, but faster than 15 seconds following cold water

immersion of the dominant ankle to the base of the calf than prior to immersion.

3. Fractioned response time will be slower than baseline 6 minutes following cold water immersion, but faster than 15 seconds and 3 minutes following cold water immersion of the dominant ankle to the base of the calf than prior to immersion.
4. Fractioned response time will be slower than baseline 9 minutes following cold water immersion, but faster than 15 seconds, 3 minutes and 6 minutes following cold water immersion of the dominant ankle to the base of the calf than prior to immersion..

Operational Definitions

Fractioned response time, aka response time – The time it takes to respond to a stimulus. It is divided into two parts: reaction time and movement time[14, 48]

Reaction time – The time from onset of a stimulus to initiation of movement as measured by a Reaction/Movement Timer.[14, 48]

Movement time – The time from initiation of movement to completion of response as measured by a Reaction/Movement Timer.[14, 48]

Dominant leg – The leg with which an individual would use to step/land on when falling forward.

Assumptions

This study will be based on the following assumptions:

1. A faster response time is indicative of improved functional ability during physical activity.
2. A slower response time is indicative of deficit in functional ability during physical activity.

Delimitations

This study will be delimited to

1. Physically active healthy college-age students
2. Dominant ankle

Limitations

1. The whole leg is used in the movement pattern not just the ankle.

Significance of the Study

Results of this study will quantify the effects of cold water immersion of the dominant ankle on fractioned response time of the dominant lower limb. Application of these results may lead to increased understanding on how and when cryotherapy might be used to facilitate movement without affecting performance.

Chapter 2

Review of Literature

This chapter is organized into the following sections:

Data Bases Searched

Cryotherapy

Neuro-physiological Control of Movement

Neurological and Neuromuscular Responses to Cold

Fractioned Response Time

Factors that Affect Fractioned Response Time

Summary

Data Bases Searched

Sports Medicine texts (Table 1) and databases (Table 2) were searched to write the review of literature.

Table 1. Text literature search

Book	Author	Year	Page
Therapeutic Modalities 2nd Edition	Starkey	1999	149-151
Cryotherapy in Sport Injury Management	Knight	1995	127-148
Evidence-Based Guide to Therapeutic Physical Agents	Belanger	2003	299-321
Neuromechanics of Human Movement	Enoka	2002	
Neurophysiological Basis of Movement	Latash	1998	

Table 2. Database literature search

Key Words	Medline 1966-2005	Sports Discus 1962-2005	Web of Science 1970-2005
Cryotherapy & injury	X	X	X
Cryotherapy & ankles		X	X
Intramuscular temperature & cold	X	X	X
Subcutaneous temperature & cold	X		X
Components of response time			X
Measuring response time	X		X
Response time & reaction time & movement time	X	X	X
Reaction time & cold			
Most common athletic injuries	X	X	X
Ice & performance	X	X	X
Measuring surface temperature	X	X	X
Neuro-muscular and neuro-physiological response to cold	X		
Hoffman reflex and cryotherapy	X	X	

(X denotes relevant literature found in the specific database)

Cryotherapy

Cryotherapy is the oldest and simplest therapeutic modality,[5] and dates back to the Greeks.[46, 56, 66] Hippocrates reportedly used ice and snow to relieve pain.[56, 66] Today it is commonly used for two purposes: acute musculoskeletal injury management and rehabilitation.[30, 35, 37, 39, 56, 58, 66] Acutely, ice is applied primarily to reduce metabolism and limit secondary hypoxic injury.[39] During rehabilitation it is used to decrease pain facilitating active exercise.[39] Both purposes are important, but are used to achieve different results.

There are many therapeutic and physiologic effects of ice. Therapeutically, tissue temperature decreases, thereby lowering the cellular metabolic rate,[16, 30] lowering rate of nerve impulses,[16, 30, 46, 48] and decreasing muscle spasm.[16, 46, 47, 64, 67] Ice causes a decrease in pain.[2, 16, 30, 46, 47, 66, 67] Physiologically, the reduction in secondary injury and metabolic processes is of most importance,[5] but is a lengthy discussion. A detailed description of these physiological responses to cryotherapy can be found in reviews by Merrick[51] and Knight.[16] Table 3 discusses the effects of cold treatments taken from Starkey's book *Therapeutic Modalities, 2nd Edition.*[67]

Table 3 Effects of cold treatments[67]

Characteristic	Physiological Response
Depth of Penetration	5 cm
Duration of effects	Hours
Blood Flow	Decreased (vasoconstriction)
Rate of cell metabolism	Decreased
Oxygen consumption	Decreased
Cell Wastes	Decreased
Fluid Viscosity	Increased
Capillary permeability	Decreased
Inflammation	Decreased
Pain	Decreased
Muscle spasm	Decreased by reducing the sensitivity of muscle spindled and decreasing pain
Muscle contraction velocity	Decreased by reducing nerve conduction velocity and increasing fluid viscosity

Method and duration of cryotherapy application vary based upon many factors. Some of these factors include site of application, desired tissue depth, and adipose tissue thickness.[67] There are conflicting results regarding the effects of adipose tissue thickness. Jutte et al[35] reported a positive correlation between tissue temperature and time, but only a slight correlation between tissue temperature and adipose thickness. In contrast, Myrer et al[56] and Otte et al[58] reported an inverse relationship between amount of subcutaneous fat and intramuscular temperature. Jutte et al[34] looked at the effects of different cold water bath temperatures on perceived numbness using water bath temperatures, 1ºC, 4ºC and 10ºC, with the premise that numbness facilitates cryokinetic therapy. They concluded that despite an increase in subject discomfort, 1ºC was more effective at inducing numbness.

Activity following cryotherapy enhances the rate of tissue rewarming.[55, 62] Myrer et al[55] found that moderate walking for 10 minutes following application of an ice pack to the calf for 20 minutes resulted in a greater degree of subcutaneous tissue rewarming. At 31 minutes post cryotherapy removal the ice-rest group was 8.05ºC colder than pretreatment levels, but the ice-exercise group was only 0.61ºC colder.[55] In another study, Palmer et al[62] studied the effects of activities such as taking a shower, changing clothes and returning home after competition and how these might affect the rate of tissue rewarming. They concluded that ice should be immediately reapplied after an activity for best results at maintaining a decreased tissue temperature.[62]

Neuro-physiological Control of Movement

The body's response to a stimulus begins with the stimulation of a sensory receptor from a wide variety of stimuli.[13, 42] Mechanoreceptors detect mechanical stimuli including pressure, stretch, vibration, etc.[13, 42] Thermoreceptors detect temperature changes.[13, 42] Nociceptors detect damage to tissues.[13, 42] Photoreceptors detect light, and Chemoreceptors detect molecules such as with taste, smell and body fluid chemistry.[13, 42]

Next, the sensation is converted into action potentials that describe the location, intensity and modality of the stimulus that is propagated by sensory neurons to the Central Nervous System (CNS), where it is interpreted and where a response is initiated.[13, 42] Afferent motor neurons carry the action potential to the Peripheral Nervous System (PNS) to illicit the appropriate response.[42]

Reflexes are the body's rapid responses to unexpected, possibly dangerous stimuli.[13, 42] All reflex pathways follow the same basic path; sensory receptor → sensory neuron → integrating center → motor neuron → effector (muscle or gland).[13, 42] There is a time delay between stimulus and the resulting reaction called reflex latency.[42] Reflex latency is made up of three components, afferent conduction time or time it takes for the stimulus to travel from the PNS to the CNS, central delay within the CNS and efferent conduction or the time it take from the stimulus to travel from the CNS back to the PNS.[42]

Neurological and Neuromuscular Responses to Cold

A decrease in temperature affects neurological and neuromuscular structures in a variety of ways. As temperature decreases, sensory nerve impulse transmission gradually decreases until transmission is completely blocked.[6, 9, 11, 12, 16, 23, 43-45, 60, 61] Large diameter (fast) sensory nerves slow first progressing to the small diameter (slow) sensory nerves.[59] Also affected are action potentials and refractory periods.[6, 16, 19, 44, 45, 60] Action potential will increase in duration as temperature decreases,[6, 19, 44, 45, 60] and absolute and relative refractory periods increase.[16, 44, 60] Peripheral motor nerve conduction velocity also decreases[1, 16, 22, 23, 47] due to an increase in the threshold for nerve stimulation with a decrease in temperature.[7, 10, 16, 72] A decrease in temperature will also cause a decrease in synaptic transmission[7, 18, 68, 70] and a lengthened latency and duration of muscle action potential.[7, 10, 16]

Muscle spindles and Golgi tendon organs are affected by cold, but the response depends on the core temperature of the body, state of activation, and organ from which it initiates.[16, 50, 53] Golgi tendon organs are not as easily affected.[16, 50]

In theory, proprioception should be altered by a decrease in temperature because cutaneous input from sensory nerves decreases[4, 60, 65] and the sensitivity of muscle spindles decreases.[12, 16, 31] Cutaneous input and muscle spindle sensitivity are important for normal proprioception,[54] but research results vary on the effects of cryotherapy on proprioception.[5, 15, 16, 20, 32, 41, 71]

The Hoffmann reflex, or H reflex, is a measurement researchers use to measure the function of the CNS.[40] Researchers measure H reflex to observe the availability of motor neurons within a motor neuron pool.[29, 40] Two studies have looked at the effects of cryotherapy on an uninjured ankle and the resulting effects on the H reflex of the ipsilateral soleus muscle.[29, 40] Both studies found an increase in H reflex when compared to a baseline H reflex taken before the treatment.[29, 40] In another study, the effect of cryotherapy on the knee where arthrogenic muscle inhibition was induced resulted in a disinhibition of the vastus medialis muscle when compared to the control.[29] An unpublished study saw an initial inhibition of the soleus H-reflex following both ankle and axillary cooling.[40] All four studies suggest that cryotherapy treatment may affect the body indirectly where tissue temperature change did not occur.[29, 40]

Scientists have looked at the effects of cryotherapy on various simple and functional tasks such as finger and hand dexterity,[16] shuttle runs,[8, 16] carioca,[16] vertical jump,[8] co-contraction[16] and the vertical ground reaction force associated with a two-legged jump.[33] Both finger and hand dexterity decrease with cryotherapy treatments,[16] but the effects of cryotherapy on functional tasks is inconclusive. Carioca,[16] co-contraction,[16] 6-m hop test[8] and vertical ground-reaction forces during a 2-legged landing from a 2-legged jump were not affected by cryotherapy, but there are contrasting results for the shuttle run. Evans et al[16] found that there was a difference in agility time scores between ice immersion and control sessions, but Cross et al[8] found that the shuttle run times increased following ice immersion as well as a decrease in height from a single leg vertical jump, but no change in the 6-m hop test after immersion of the leg to the knee. Scientists have looked at various functional activities and a subject over all performance of these activities, but there is no research looking at the effects of cryotherapy, specifically cold water immersion, on the initiation of movement

Fractioned Response Time

Fractioned response time is the measure of how long it takes to perform a specified movement,[48] or the measurement of an individuals ability to process a stimulus and make the appropriate response. It is the combination of reaction time and movement time. Reaction time, the first component, is the time from the presentation of the stimulus to the beginning of the response.[2, 67] Put another way, it is the time from stimulus onset to initiation of movement from the first button to the second or target button.[14] Movement time, the second component, is the time from the release of the first button by initiating movement to release or depression of the target button.[14]

Taimela[69] has reported two reasons for researching reaction time: 1) these measures are components of real life tasks and 2) reaction times measure the time taken for mental events such as stimulus processing, decision making, and response programming." Because reaction time is a component of the more encompassing measurements of fractioned response time, the same significance can be applied. In rehabilitation it might be used to identify if an athlete should return to play.

There are two categories of measuring response time. Simple reaction time consists of testing how fast an individual responds to a single stimulus. Choice reaction time tests the individual's responses to several signals.[69] For example, the subject might be placed in front of several target buttons with corresponding lights for each button. As the light for each target button goes off one at a time, they are asked to hit that corresponding button. Choice reaction time is used to mimic real life situations where not only the reaction time is important, but also the choice of movement is important.[48]

Factors that Affect Fractioned Response Time

There are several factors that affect fractioned response time. Some factors are testing procedure dependent (Table 4) and some are subject dependent (Table 5). Table 4 illustrates the factors that should be assessed when setting a procedural protocol. The type of stimulus used will affect a subject's fractioned response time. Visual stimuli will produce a longer fractioned response time than auditory or proprioceptive stimuli. To ensure the appropriate response, the stimulus must also be bright enough, loud enough or strong enough. The type of movement required must be considered. If the task is really complex, the fractioned response time will be longer than it would be for a simple movement.

Table 4. Factors of fractioned response time measurement dependent on testing procedure.[69]

Factors	Considerations
Sensory Factors	• Intensity of stimulus • Type of stimulus (auditory, visual, proprioceptive)
Response Characteristics	• Size and Distance of Target • Type of Movement • Complexity of Movement
Preparation	• Warning stimulus before stimulus • Length of fore period
Complexity of Choice	• Hicks Law: Choice reaction time is linearly related to the log of the number of stimulus alternatives.[69]
Practice	• Number of practice trials • Number of test trials
Time of Day	• Later in the day when an individual is ready to retire for the day may decrease reaction time performance.

Table 5. Subject dependent factors of fractioned response time measurement.

Factors	Considerations	Reference
Gender	• Males are faster than females	Taimela[69]
Age	• Response time is negatively related to age • Performance increases from childhood to early adulthood and then decreases	Taimela[69] & Etneir et al[14] & Kauranen et al[36]
IQ	• "slow reaction times are related to low IQ scores"	Taimela[69]
Aerobic Fitness	• Aerobic fitness may aide older individuals in resisting response time declines	Etnier et al[14]
Limb Dominance	• Dominant limb performs better than non-dominant	Kauranen et al[36]

Length and variation of the foreperiod and any cues given to ready a subject will also affect fractioned response time. If it is always the same, the subject will be affected by learning. Any cues given should be the same for each trial. Practice trials to familiarize the subject to the desired movement should be performed to limit the effects of learning as well. If too few practice trials are performed, the subject may not have completely learned the movement, if too many they might be fatigued. Lastly time of day can affect fractioned response time. If it is too late in the day when the subject is too tired their fractioned response time will be slower than it would be at times during the day when they are more active. If multiple days are used for testing, the testing should occur at the same time of day when the subject has been doing the same types of activities.

The other set of factors that will affect fractioned response time measurement are subject dependent (Table 5). Gender is important to note because males are faster than females.[69] Age is critical to assess, because fractioned response time increases from childhood to early adulthood and then decreases. An individual with a higher intelligence score will have a faster fractioned response time. Aerobic fitness may not be directly correlated with fractioned response time, but studies suggest that aerobic fitness may help decrease the rate at which an older individual's fractioned response time slows down.

Pilot work was performed to assess the adequate testing protocol by taking into account the testing dependent and subject dependent factors affecting fractioned response time. The first pilot work was performed using three subjects over a period of 17 days to determine how far apart testing could be performed. The subjects performed 25 trials in five sets of five. All three subjects alternated turns, performing the trial resulting in approximately 2 minutes between each set performed. They performed a stepping movement with their dominant leg. Cold water immersion was not performed and the movement was not controlled. The results of this pilot indicate that no more than 3 days between testing sessions is adequate to prevent the subjects from becoming unfamiliar with the testing procedure. Table A1 in Appendix A presents the results.

Another pilot study was performed using the testing protocol. The subjects reported for testing on 4 days within 3 days on either side. The first day they performed 25 practice trials in 5 sets of 5 with 2 minutes between sets. The second, third and fourth days were testing days. They performed 2 practice trials followed by 5 pretreatment testing trials followed by 20 minutes on the treatment table. No treatment was performed during the pilot work. After 20 minutes they performed 5 trials within 15 seconds, then again at 3 minute, 6 minutes, and 9 minutes. A controlled movement was performed where they stood bearing equal weight on both feet and were asked to perform a walking motion over a rectangular block (3 in W X 3 in H X 6 in L), 4 inches in front of them, to a target button, 10 inches in front of them. The tester was positioned behind the subject giving no feedback, and the subject was not allowed to see their times. Results from this pilot indicated that the testing procedure is adequate. The movement was simple enough that the subject was able to perform the desired number of trials without fatigue and normal variation. The results of this pilot study can be found in Table A2 in Appendix A.

Summary

Cryotherapy is common in acute injury care and rehabilitation performed by health care professionals. A decrease in temperature affects blood flow, rate of cell metabolism, oxygen consumption, cell wastes, fluid viscosity, capillary permeability, inflammation, pain, muscle spasm ,and muscle contraction as presented in Table 4.[67] Duration of application is affected by the site of application, desired depth of penetration and underlying adipose tissue thickness.[56, 58, 67] The desired effect, desired depth of temperature change, and timing of the application must be taken into account when using cryotherapy to treat acute or sub acute injuries.

Cold water immersion is the method of choice when performing cryokinetics. The purpose is to induce numbness that will help facilitate movement. A water bath temperature of 1ºC is most effective to induce numbness, but the numbness will decrease and eventually go away with activity.

The neuro-physiological and neuro-muscular responses to cold vary. Scientists have looked at these responses by looking at the effects of cryotherapy on functional tests.[8, 16, 33] Varying results exist, but research on the effects of cryotherapy on the initiation of movement does not exist.

Fractioned response time is the measure of reaction time plus movement time, or the measure of how long it takes to perform a specified movement. There are 2 different categories of measuring response time. Simple reaction time consists of testing how fast an individual responds to a single stimulus. Choice reaction time tests the individual's responses to several signals.[69]

There are several factors that affect fractioned response time measurement and several components that affect an individuals fractioned response time as presented in Tables 4. and 5. These factors and components should be taken into account when performing fractioned response time research.

Chapter 3

Methods

Research Design

Data for this study will be collected according to a 2x2x5 factorial design with repeated measures on 2 of the factors (time and treatment). The independent variables will be sex (male and female), treatment (control and ice), and time (pre-application and 15 seconds, 3 minutes, 6 minutes, and 9 minutes postapplication). Time intervals were chosen to observe any changes in fractioned response time as tissue re-warming occurs. The dependent variables will be fractioned response time, reaction time, movement time and surface temperature measured at each of the 5 times. Surface temperature will be a categorical variable.

Subjects

Thirty-six subjects will be recruited from a physically active volunteer college student population: 18 females and 18 males. General information including geographic information, height, weight, age and any medical history that would exclude them from participation in the study will be collected for each subject. An answer of "yes" to a personal medical history of injury to the dominant lower extremity in the last year, ice/cold allergies, sensory deficits, and/or serious neurovascular or cardiovascular diseases will exclude a subject from the study (Table A3 of Appendix A).

Subjects will be randomly assigned to one of two treatment orders. There will be 2 hats, 1 for male and 1 for females, with equal numbers of "1" and "2" in each hat. The subjects will draw their treatment order from their respective hat.

Subjects will give informed consent and the study will be approved by The University Institutional Review Board.

Instruments

A cold water bath of 1ºC will be used to submerge the subject's dominant ankle to the base of the calf.[34] Skin temperature will be recorded with thermocouples (copper-tipped type, type-T, Physiotemp, Clifton, NJ) attached to a 16-channel Isothermex (Columbus Instruments, Columbus, OH). Fractioned response time will be measured using a Reaction/Movement Timer (model #63017, Lafayette Instrument Company, Lafayette, IN). The Reaction/Movement Timer includes all buttons, switches and sounds.

Treatment Conditions

The specified movement used to measure fractioned response time will start with the subject in a standing position with feet shoulder width apart and staggered with the dominant leg behind and the nondominant in front resulting in a distance between of approximately 3 to 6 inches based upon the subject's comfort to maximize the movement at the ankle joint. The subject will bear equal weight on both feet. The subject's foot of the dominant leg will be depressing the first button. When the subject hears the beep from the machine, they will be instructed to perform a walking motion over a rectangular block (3 in W X 3 in H X 6 in L), 3 inches in front of the dominant leg, to a target button, 10 inches in front of them. An optimal foreperiod of 1 to 4 seconds will be used to minimize anticipation, and will be randomly assigned by the machine.

Distractions will be controlled by allowing only the subject and the tester in the testing room. The tester will sit behind the subject, and the subject will not be given any feedback concerning their performance including allowing them to see their times. The subject will be asked to refrain from physical activity that might cause muscle soreness for 48 hours prior to testing, activity that might be fatiguing 6 hours prior to testing, and to maintain consistent and healthy sleeping and eating patterns. Questions will be asked prior to each treatment and will be recorded on the data collection sheet (Table A4).

Treatment time for both the control and cold water immersion will be 20 minutes as measured by a hand-held stopwatch. Each subject will report for a familiarization day and 2 research sessions totaling 3 different days with no more than 2 days between each session.

Testing

The subjects will attend an information and familiarization meeting to introduce them to the study where they will be given instructions on the testing procedure. On the testing days they will undergo the control or the treatment condition based upon their assigned treatment order

Information Meeting and Familiarization. The subjects will fill out all necessary paperwork and be randomly assigned to one of the four treatment orders. They will be asked to wear shorts and remove their shoes and socks for all of the training and testing days. Each subject will familiarize themselves with the response time machine by performing 25 familiarization trials in 5 sets of 5 trials with 2 minutes between sets.

Testing Days. Testing will be performed no less than 24 hours and no more than 72 hours following familiarization. The subject will be tested at the same time of day for each testing session. They will be instructed to be consistent in their activities of daily living for each testing day. This includes the amount of sleep they received, when and what they eat, and their general routine.

Upon arrival, subjects will perform their pretreatment fractioned response time trials. They will then have a dot applied with permanent marker over the anterior talofibular ligament (ATF) of the dominant ankle. One thermocouple will be applied to the skin 1 cm posterior to the dot, and the second will be placed in the water to measure temperature. Water temperature will be maintained by adding ice and/or stirring when needed. One of the 2 possible treatments will be applied for 20 minutes dependent on their assigned treatment order. For each testing interval (pre, 15 seconds post, 3 minutes post, 6 minutes post, and 9 minutes post) fractioned response time will be recorded 5 times, lasting 1 minute. During the resulting 1 minute 45 second (between 15 second and 3 minute time interval) to 2 minutes (for all other time intervals) between testing, the subject will sit in a chair and relax. If a score is not recorded due to error, the trial will be repeated. The high and low score will be thrown out and the mean of the resulting three trials will be calculated for each testing interval. Surface temperature will be recorded prior to the specified treatment and continuously following treatment until the subject has completed the 9 minutes post fractioned response time testing.

Statistical Analysis

The SAS system will be used for statistical analysis by performing a 3 way MANOVA omnibus test followed by 3 three-way ANOVAS, 1 for each significant dependent variable, and then Tukey multiple range tests to differentiate differences within significant main effects.

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Appendix B

Additional Methods

Table A1. Pilot work to determine time between testing sessions. Subjects were not iced and movement was uncontrolled.

		Response Time				Reaction Time				Movement Time			
		Mean	Median	Range		Mean	Median	Range		Mean	Median	Range	
Sub 1				Fast	Slow			Fast	Slow			Fast	Slow
Day 1		0.556 ± 0.051	0.555	0.479 (14&16)*	0.651 (2)#	0.327 ± 0.045	0.326	0.256 (14)*	0.412 (23)#	0.230 ± 0.016	0.232	0.201 (6&13)*	0.263 (2)#
Day 15		0.503 ± 0.049	0.484	0.440 (23)	0.639 (10)	0.217 ± 0.037	0.217	0.176 (14&18)	0.333 (17)	0.279 ± 0.023	0.278	0.253 (21)	0.339 (10)
Day 16		0.461 ± 0.034	0.453	0.409 (14)	0.582 (2)	0.209 ± 0.028	0.208	0.135 (14)	0.301 (2)	0.252 ± 0.018	0.248	0.225 (6)	0.290 (20)
Day 17		0.459 ± 0.034	0.452	0.389 (1)	0.551 (11)	0.201 ± 0.029	0.198	0.159 (10)	0.308 (11)	0.258 ± 0.021	0.257	0.212 (1)	0.317 (18)
Sub 2													
Day 1		0.496 ± 0.048	0.499	0.404 (25)	0.613 (12)	0.242 ± 0.040	0.239	0.174 (25)	0.372 (12)	0.253 ± 0.028	0.245	0.212 (16)	0.328 (5)
Day 15		0.441 ± 0.027	0.440	0.400 (13)	0.518 (6)	0.193 ± 0.020	0.191	0.156 (22)	0.254 (6)	0.249 ± 0.017	0.248	0.215 (1)	0.278 (7)
Day 17		0.424 ± 0.027	0.417	0.366 (10)	0.494 (14)	0.183 ± 0.020	0.177	0.149 (4)	0.241 (14)	0.241 ± 0.015	0.242	0.210 (10)	0.268 (13)
Sub 3													
Day 1		0.566 ± 0.038	0.573	0.489 (4)	0.646 (2)	0.268 ± 0.037	0.267	0.208 (4)	0.360 (2)	0.298 ± 0.022	0.301	0.239 (10)	0.342 (1)
Day 15		0.562 ± 0.044	0.550	0.492 (10)	0.671 (20)	0.235 ± 0.036	0.222	0.178 (13)	0.341 (20)	0.327 ± 0.024	0.319	0.278 (10)	0.396 (9)
Day 17		0.480 ± 0.033	0.488	0.367 (17)	0.516 (19)	0.192 ± 0.025	0.197	0.107 (24)	0.226 (8)	0.288 ± 0.021	0.288	0.217 (17)	0.327 (25)

* Parentheses represent the trial were the fastest time occurred for each testing interval.

Parentheses represent the trial were the slowest time occurred for each testing interval.

Table A2. Pilot work to finalize testing procedure. Subjects were not iced, but movement was controlled

Subject 1		Response Time				Reaction Time				Movement Time			
		Mean	Median	Range		Mean	Median	Range		Mean	Median	Range	
				Fast	Slow			Fast	Slow			Fast	Slow
Familiar.		0.7736 ± 0.0670	0.755	0.656 (12) *	0.911(1) #	0.4494 ± 0.0660	0.433	0.303 (12) *	0.601 (1) #	0.3242 ± 0.0312	0.316	0.283 (10) *	0.419 (4) #
Test 1	PRE	0.799 ± 0.1025	0.835	0.719 (5)	0.864 (1)	0.4244 ± 0.0573	0.436	0.355 (5)	0.489 (4)	0.3746 ± 0.0453	0.346	0.346 (4)	0.428 (1)
	15 s	0.722 4± 0.0163	0.728	0.691 (4)	0.757 (5)	0.3928 ± 0.0050	0.385	0.355 (4)	0.429 (5)	0.3296 ± 0.0113	0.329	0.312 (1)	0.343 (2)
	3 m	0.7192 ± 0.0269	0.716	0.685 (4)	0.773 (2)	0.4048 ± 0.0396	0.411	0.355 (1)	0.458 (2)	0.3144 ± 0.0127	0.315	0.297 (3)	0.337 (1)
	6 m	0.7212 ± 0.0269	0.715	0.672 (3)	0.777 (2)	0.4074 ± 0.0346	0.401	0.373 (1& 3)	0.468 (2)	0.3138 ± 0.0078	0.314	0.299 (3)	0.329 (1)
	9 m	0.706 ± 0.0127	0.690	0.687 (4)	0.767 (2)	0.3984 ± 0.0184	0.387	0.349 (1)	0.468 (2)	0.3076 ± 0.0311	0.300	0.297 (5)	0.341 (1)
Test 2	PRE	0.6564 ± 0.0983	0.672	0.573 (1)	0.712 (5)	0.362 ± 0.0615	0.363	0.329 (1)	0.416 (5)	0.2944 ± 0.0368	0.299	0.244 (1)	0.324 (3)
	15 s	0.6500 ± 0.0622	0.647	0.595 (4)	0.735 (1)	0.369 ± 0.0537	0.370	0.311 (4)	0.452 (1)	0.281 ± 0.0085	0.283	0.271 (5)	0.285 (3)
	3 m	0.7268 ± 0.0481	0.738	0.677 (2)	0.791 (4)	0.410 ± 0.0488	0.396	0.371 (2)	0.471 (4)	0.3168 ± 0.0152	0.309	0.305 (2)	0.342 (3)
	6 m	0.7138 ± 0.0212	0.717	0.660 (2)	0.758 (4)	0.3942 ± 0.0198	0.405	0.272 (2)	0.477 (4)	0.3196 ± 0.0014	0.310	0.281 (4)	0.388 (2)
	9 m	0.7408 ± 0.0106	0.740	0.722 (5)	0.754 (4)	0.416 ± 0.0615	0.405	0.390 (5)	0.477 (1)	0.3248 ± 0.0509	0.335	0.260 (1)	0.351 (4)
Test 3	PRE	0.7426 ± 0.1131	0.769	0.614 (1)	0.823 (2)	0.3996 ± 0.0863	0.419	0.297 (1)	0.472 (2)	0.343 ± 0.0269	0.351	0.317 (1)	0.370 (4)
	15 s	0.7082 ± 0.0057	0.728	0.657 (2)	0.755 (3)	0.3808 ± 0.0219	0.403	0.329 (2)	0.434 (5)	0.3274 ± 0.0276	0.332	0.294 (5)	0.350 (3)
	3 m	0.7042 ± 0.0219	0.708	0.649 (1)	0.758 (4)	0.3536 ± 0.0156	0.373	0.290 (1)	0.410 (4)	0.3488 ± 0.0136	0.348	0.335 (2)	0.359 (1&5)
	6 m	0.7158 ± 0.0057	0.715	0.689 (4)	0.737 (1)	0.376 ± 0.0530	0.384	0.334 (3)	0.417 (2)	0.3398 ± 0.0474	0.327	0.298 (2)	0.394 (5)
	9 m	0.7092 ± 0.0495	0.702	0.314 (4)	0.759 (5)	0.3662 ± 0.0445	0.359	0.314 (4)	0.407 (3&5)	0.343 ± 0.0050	0.345	0.296 (3)	0.388 (4)

* Parentheses represent the trial were the fastest time occurred for each testing interval.
# Parentheses represent the trial were the slowest time occurred for each testing interval

Table A2. (continued) Pilot work to finalize testing procedure. Subjects were not iced, but movement was controlled

Subject 2		Response Time				Reaction Time				Movement Time			
		Mean	Median	Range		Mean	Median	Range		Mean	Median	Range	
				Fast	Slow			Fast	Slow			Fast	Slow
Training		0.8176 ± 0.0659	0.811	0.723 (24) *	0.956 (8) #	0.4936 ± 0.0662	0.486	0.274 (3) *	0.611 (5) #	0.3241 ± 0.0643	0.315	0.276 (19) *	0.597 (3) #
Test 1	PRE	0.762 ± 0.0346	0.773	0.705 (3)	0.822 (5)	0.4666 ± 0.0226	0.479	0.415 (3)	0.521 (5)	0.2954 ± 0.0120	0.294	0.284 (1)	0.308 (4)
	15 s	0.7876 ± 0.0219	0.786	0.755 (5)	0.814 (2)	0.4776 ± 0.0099	0.477	0.453 (3)	0.510 (2)	0.3202 ± 0.0240	0.321	0.304 (2)	0.343 (5)
	3 m	0.7838 ± 0.0735	0.785	0.730 (5)	0.834 (1)	0.4524 ± 0.0601	0.446	0.417 (5)	0.502 (1)	0.3314 ± 0.0134	0.332	0.313 (5)	0.347 (4)
	6 m	0.8116 ± 0.4101	0.795	0.773 (4)	0.866 (3)	0.496 ± 0.0495	0.490	0.453 (4)	0.542 (1)	0.3156 ± 0.0085	0.311	0.299 (1)	0.343 (3)
	9 m	0.7806 ± 0.0255	0.768	0.754 (4)	0.828 (1)	0.476 ± 0.0495	0.455	0.444(4)	0.550 (1)	0.3046 ± 0.0240	0.310	0.278 (1)	0.313 (2)
Test 2	PRE	0.6612 ± 0.0255	0.661	0.617 (2)	0.688 (4)	0.3936 ± 0.0247	0.385	0.350 (2)	0.430 (4)	0.2676 ± 0.0007	0.268	0.258 (4)	0.276 (3)
	15 s	0.671 ± 0.0071	0.673	0.664 (5)	0.678 (2)	0.4046 ± 0.0134	0.397	0.376 (5)	0.429 (4)	0.2664 ± 0.0064	0.269	0.244 (4)	0.288 (5)
	3 m	0.6882 ± 0.0170	0.674	0.644 (5)	0.760 (4)	0.4134 ± 0.0035	0.409	0.394 (3)	0.449 (4)	0.2748 ± 0.0134	0.280	0.239 (5)	0.311 (4)
	6 m	0.7006 ± 0.1082	0.711	0.601 (5)	0.754 (1)	0.4258 ± 0.1230	0.439	0.311 (5)	0.485 (1)	0.2748 ± 0.0148	0.272	0.252 (2)	0.291 (4)
	9 m	0.7056 ± 0.0120	0.713	0.662 (3)	0.749 (1)	0.4334 ± 0.0283	0.432	0.398 (3)	0.483 (1)	0.2722 ± 0.0163	0.266	0.261 (4)	0.289 (5)
Test 3	PRE	0.7558 ± 0.0325	0.773	0.694 (2)	0.811 (4)	0.465 ± 0.0247	0.463	0.415 (2)	0.498 (4)	0.2908 ± 0.0078	0.281	0.270 (1)	0.313 (4)
	15 s	0.7846 ± 0.0346	0.776	0.727 (1)	0.860 (2)	0.4766 ± 0.0375	0.486	0.414 (1)	0.523 (2)	0.308 ± 0.0375	0.313	0.255 (4)	0.337 (2)
	3 m	0.7372 ± 0.0099	0.728	0.707 (2)	0.776 (3)	0.4512 ± 0.0304	0.458	0.423 (5)	0.482 (3)	0.286 ± 0.0205	0.291	0.262 (1)	0.303 (4)
	6 m	0.726 ± 0.0346	0.729	0.693 (5)	0.755 (4)	0.4392 ± 0.0269	0.433	0.417 (5)	0.471 (4)	0.2868 ± 0.0078	0.287	0.276 (5)	0.296 (2)
	9 m	0.7518 ± 0.0339	0.745	0.735 (3)	0.788 (1)	0.4492 ± 0.0339	0.443	0.428 (3)	0.317 (2)	0.3026 ± 0.0050	0/302	0.290 (1)	0.317 (2)

* Parentheses represent the trial were the fastest time occurred for each testing interval.
# Parentheses represent the trial were the slowest time occurred for each testing interval.

Table A2. (continued) Pilot work to finalize testing procedure. Subjects were not iced, but movement was controlled

Subject 3		Response Time				Reaction Time				Movement Time			
		Mean	Median	Range		Mean	Median	Range		Mean	Median	Range	
				Fast	Slow			Fast	Slow			Fast	Slow
Training		0.6016 ± 0.0548	0.604	0.521 (12) *	0.714 (15) #	0.3337 ± 0.0576	0.334	0.230 (8) *	0.466 (10) #	0.2679 ± 0.0431	0.261	0.224 (21) *	0.440 (8) #
Test 1	PR	0.5842 ± 0.0523	0.572	0.524 (4)	0.635 (5)	0.298 ± 0.0488	0.297	0.217 (2)	0.366 (5)	0.2665 ± 0.0035	0.269	0.264 (1)	0.355 (2)
	15 s	0.6218 ± 0.0304	0.630	0.568 (1)	0.652 (4)	0.3766 ± 0.0028	0.367	0.345 (5)	0.411 (2&4)	0.2452 ± 0.0332	0.241	0.219 (1)	0.266 (5)
	3 m	0.5646 ± 0.0240	0.558	0.536 (3)	0.592 (1)	0.317 ± 0.0290	0.319	0.286 (3)	0.363 (1)	0.2476 ± 0.0050	0.250	0.229 (1)	0.269 (4)
	6 m	0.5822 ± 0.0021	0.593	0.558 (2)	0.601 (4)	0.3142 ± 0.0297	0.303	0.294 (3)	0.345 (5)	0.268 ± 0.0276	0.267	0.251 (5)	0.290 (1)
	9 m	0.5786 ± 0.0686	0.549	0.546 (4&5)	0.643 (1)	0.3386 ± 0.0651	0.320	0.272 (2)	0.412 (1)	0.24 ± 0.0035	0.231	0.211 (3)	0.277 (2)
Test 2	PR	0.525 ± 0.0884	0.497	0.489 (4)	0.497 (5)	0.279 ± 0.0912	0.270	0.207 (4)	0.270 (3)	0.246 ± 0.0028	0.249	0.230 (2)	0.282 (4)
	15 s	0.5288 ± 0.0071	0.524	0.469 (4)	0.524 (1)	0.2652 ± 0.0085	0.273	0.162 (3)	0.273 (5)	0.2636 ± 0.0156	0.255	0.215 (4)	0.348 (3)
	3 m	0.4978 ± 0.0035	0.489	0.460 (3)	0.489 (5)	0.2564 ± 0.0148	0.263	0.206 (3)	0.263 (5)	0.2414 ± 0.0113	0.242	0.22 (5)	0.254 (3)
	6 m	0.5206 ± 0.0106	0.505	0.490 (1)	0.505 (5)	0.277 ± 0.0007	0.255	0.246 (5)	0.255 (2)	0.2436 ± 0.0113	0.245	0.222 (3)	0.259 (5)
	9 m	0.4976 ± 0.0205	0.493	0.454 (5)	0.493 (4)	0.2578 ± 0.0148	0.256	0.236 (1)	0.256 (4)	0.2398 ± 0.0354	0.244	0.197 (5)	0.274 (3)
Test 3	PR	0.5354 ± 0.0431	0.515	0.454 (5)	0.642 (4)	0.3108 ± 0.0438	0.290	0.228 (5)	0.434 (4)	0.2246 ± 0.0007	0.225	0.208 (4)	0.245 (3)
	15 s	0.5824 ± 0.0071	0.572	0.544 (3)	0.656 (2)	0.3374 ± 0.0460	0.316	0.283 (3)	0.439 (2)	0.245 ± 0.0389	0.256	0.217 (2)	0.273 (5)
	3 m	0.5002 ± 0.0346	0.492	0.483 (2)	0.535 (1)	0.2632 ± 0.0134	0.273	0.220 (2)	0.292 (1)	0.238 ± 0.0212	0.243	0.213 (5)	0.263 (2)
	6 m	0.54 ± 0.0127	0.510	0.505 (2)	0.651 (4)	0.2972 ± 0.0156	0.273	0.243 (2)	0.410 (4)	0.2428 ± 0.0028	0.241	0.233 (5)	0.262 (2)
	9 m	0.5184 ± 0.0601	0.503	0.487 (2)	0.588 (5)	0.2878 ± 0.0375	0.285	0.242 (2)	0.338 (5)	0.2306 ± 0.0226	0.218	0.213 (4)	0.258 (2)

* Parentheses represent the trial were the fastest time occurred for each testing interval.
# Parentheses represent the trial were the slowest time occurred for each testing interval.

Table B3. Health Information and Injury History Questionnaire

Name: ____

Address: ____

City/Town: __________________ State: _____________ Zip Code: ____________

Home Phone: ______________ - ______________ - ______________

Work Phone or Cell Phone: ______________ - ______________ - ______________

Email: ____

Age: ______________ Height: ______________ Weight: ______________

TO THE BEST OF YOUR KNOWLEDGE, HAVE YOU HAD ANY OF THE FOLLOWING IN THE PAST YEAR?

Circle all that apply

Y	N		Y	N	
□	□	Ankle Injury	□	□	Cardiac Disorder
□	□	Leg Injury	□	□	Hypertension
□	□	Cold Hypersensitivity	□	□	Vasospastic Diseases
□	□	Allergic Reaction to Ice Directly on Your Skin	□	□	Nervous Disorder
□	□	Sensory Deficits in Lower Leg	□	□	Compromised Local Circulation
□	□	Frostbite	□	□	Diabetes

Explain any conditions you circled above:

Examiners Notes:

Table B4. Data Recording Sheet

Name: ______________________ Phone #: _________________ Subject #: _________
Age:___________ Wt:___________ Ht:___________

Training **Time In:** **Time Out:**

	Set 1			Set 2			Set 3			Set 4			Set 5		
	T_{resp}	T_{reac}	T_{mov}	T_{resp}	T_{reac}	T_{mov}	T_{resp}	T_{reac}	T_{mov}	T_{resp}	T_{reac}	T_{mov}	T_{resp}	T_{reac}	T_{mov}
T1															
T2															
T3															
T4															
T5															

DAY 1 Treatment: __________ **Time In:** **Time Out:**

YES	NO	QUESTION
□	□	Have you refrained from physical activity in the last 48 hours that might cause muscle soreness?
□	□	Have you refrained from activities that might be fatiguing in the last 6 hours?
□	□	Have you been getting a consistent amount of sleep?
□	□	Have you been eating a consistent diet?

		Pre	**15 s**	**3 m**	**6 m**	**9m**
Trial 1	T_{resp}					
	T_{reac}					
	T_{mov}					
	Temp					
Trial 2	T_{resp}					
	T_{reac}					
	T_{mov}					
	Temp					
Trial 3	T_{resp}					
	T_{reac}					
	T_{mov}					
	Temp					
Trial 4	T_{resp}					
	T_{reac}					
	T_{mov}					
	Temp					
Trial 5	T_{resp}					
	T_{reac}					
	T_{mov}					
	Temp					

DAY 2 Treatment: ___________ **Time In:** **Time Out:**

YES	NO	QUESTION
□	□	Have you refrained from physical activity in the last 48 hours that might cause muscle soreness?
□	□	Have you refrained from activities that might fatiguing in the last 6 hours?
□	□	Have you been getting a consistent amount of sleep?
□	□	Have you been eating a consistent diet?

		Pre	**15 s**	**3 m**	**6 m**	**9m**
Trial 1	T_{resp}					
	T_{reac}					
	T_{mov}					
	Temp					
Trial 2	T_{resp}					
	T_{reac}					
	T_{mov}					
	Temp					
Trial 3	T_{resp}					
	T_{reac}					
	T_{mov}					
	Temp					
Trial 4	T_{resp}					
	T_{reac}					
	T_{mov}					
	Temp					
Trial 5	T_{resp}					
	T_{reac}					
	T_{mov}					
	Temp					

Appendix C

Addition Data and Results

Table C1. Table of Appendix C Tables

Table	Title
C2	Subject Descriptive Statistics
C3	Response, reaction, and movement times over time. Average of 3 middle trials for each of 18 subjects (msec, mean ± standard deviation; n=54 per cell)
C4	Response times over time. Average of high, middle 3 trials and low trials for each of 18 subjects (sec, mean ± standard deviation; n=18 high/low and n=54 middle 3 per cell)
C5	Effect size for response, reaction, and movement times over time for each of 18 subjects (n=36 per cell)
C6	Cohen's d – Effect Size Equation
C7	Expected Mean Squares Section for Overall 3 Way ANOVA
C8	Reaction Time Overall 3 Way ANOVA
C9	Movement Time Overall 3 Way ANOVA
C10	Response Time Overall 3 Way ANOVA
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C12	Response Time (HighLow) Overall 3 Way ANOVA
C13	Temperature Means for times associated with fractioned response time trials (degrees Celcisus, mean ± standard deviation; n=18 per cell)
C14	Temperature of the environment over time for each of 18 subjects (min, mean ± standard deviation; n=18 per cell)
C15	Temperature of bucket (control/water) over time for each of 18 subjects (min, mean ± standard deviation; n=18 per cell)
C16	Surface temperature of the ankle over time for each of 18 subjects (min, mean ± standard deviation; n=18 per cell)
C17	Conclusions

Table C2. Subject Descriptive Statistics

	Male Mean	Standard Deviation	Female Mean	Standard Deviation
Age	22.2	2.4	22	2.4
Ht, inch	70.7	4.1	65.6	2.1
Ht, cm	179.5	10.5	166.7	5.3
Wt, lbs	182.7	23.6	146.3	26.1
Wt, kg	82.9	10.7	66.4	11.9

Table C3. Response, reaction, and movement times over time. Average of 3 middle trials of 5 total trials, as determined by T_{resp}, for each of 18 subjects (msec, mean ± standard deviation; n=54 per cell)

	Pre	Post 0:15	Post 3:00	Post 6:00	Post 9:00
Female					
Control					
T_{resp}	773 ± 17	801 ± 20	796 ± 19	794 ± 22	787 ± 19
T_{reac}	477 ± 12	487 ± 13	488 ± 13	483 ± 14	478 ± 11
T_{mov}	296 ± 08	314 ± 10	308 ± 08	311 ± 10	309 ± 09
Ice					
T_{resp}	759 ± 18 [b]	855 ± 21 [b]	818 ± 19 [b]	808 ± 22 [b]	799 ± 22 [b]
T_{reac}	466 ± 12	493 ± 13	472 ± 11	480 ± 13	481 ± 14
T_{mov}	293 ± 07 [a]	362 ± 10 [a]	347 ± 11 [a]	328 ± 10 [a]	317 ± 09 [a]
Male					
Control					
T_{resp}	664 ± 12	675 ± 14	661 ± 11	648 ± 11	653 ± 12
T_{reac}	412 ± 08	414 ± 09	410 ± 07	398 ± 07	404 ± 07
T_{mov}	252 ± 05	261 ± 06	251 ± 06	250 ± 05	249 ± 06
Ice					
T_{resp}	644 ± 10 [b]	737 ± 13 [b]	711 ± 12 [b]	698 ± 14 [b]	678 ± 13 [b]
T_{reac}	403 ± 07	427 ± 07	425 ± 07	420 ± 08	410 ± 08
T_{mov}	242 ± 04 [a]	310 ± 08 [a]	286 ± 06 [a]	278 ± 07 [a]	268 ± 06 [a]

[a] T_{mov} Post 3 min & Post 15 sec > Post 6 min & Post 9 min > Pre
[b] T_{resp} Post 15 sec > Post 3 min & Post 6 min > Post 9 min > Pre

Table C4. Response times over time. Average of high, middle 3 trials and low trials for each of 18 subjects (sec, mean ± standard deviation; n=18 high/low and n=54 middle 3 per cell)

	Low*	Middle 3*	High*
Female			
Control	727 ± 17	787 ± 19	864 ± 21
Ice	740 ± 17	803 ± 19	890 ± 24
Male			
Control	609 ± 10	657 ± 11	720 ± 13
Ice	642 ± 10	691 ± 12	754 ± 15

*High > Middle 3 > Low

Table C5. Effect size for response, reaction, and movement times over time. (n=18 per cell)

	Pre	Post 0:15	Post 3:00	Post 6:00	Post 9:00
Female					
T_{resp}	-0.80	2.63	1.16	0.64	0.58
T_{mov}	-0.40	4.80	4.06	1.70	0.89
Male					
T_{resp}	-1.81	4.59	4.34	3.97	2.00
T_{mov}	-2.21	6.93	5.83	4.60	3.17

Table C6. Cohen's d – Effect Size Equation[24]

$$d = \frac{\bar{x}_1 - \bar{x}_2}{s}, \qquad s = \sqrt{\frac{(n_1 - 1)s_1^2 + (n_2 - 1)s_2^2}{n_1 + n_2}},$$

Table C7. Expected Mean Squares Section for Overall 3 Way ANOVA

Source Term	DF	Term Fixed?	Denominator Term	Expected Mean Square
A: Sex	1	Yes	B(A)	S+cdesB+bcdesA
B(A): Subj	34	No	S(ABCDE)	S+cdesB
C: Treat	1	Yes	BC(A)	S+desBC+abdesC
AC	1	Yes	BC(A)	S+desBC+bdesAC
BC(A)	34	No	S(ABCDE)	S+desBC
D: TimeGp	4	Yes	BD(A)	S+cesBD+abcesD
AD	4	Yes	BD(A)	S+cesBD+bcesAD
BD(A)	136	No	S(ABCDE)	S+cesBD
CD	4	Yes	BCD(A)	S+esBCD+abesCD
ACD	4	Yes	BCD(A)	S+esBCD+besACD
BCD(A)	136	No	S(ABCDE)	S+esBCD
S(ABCDE)	1440	No		S

Note: Expected Mean Squares are for the balanced cell-frequency case

Table C8. Reaction Time Overall 3 Way ANOVA

Source Term	DF	Sum of Squares	Mean Square	F-Ratio	Prob Level	Power (alpha=0.05)
Sex	1	2.10125	2.10125	5.22	0.028648*	0.602801
Sex*subj	34	13.67836	0.402305			
Treat	1	0.003088	0.003088	0.40	0.533227	0.093875
Treat*Sex	1	0.020686	0.020686	2.65	0.112541	0.353322
Treat*subj	34	0.265032	0.007795			
TimeGp	4	0.050849	0.012712	3.66	0.007248*	0.870338
TimeGp*Sex	4	0.008080	0.002020	0.58	0.676177	0.189079
TimeGp*subj	136	0.472034	0.003471			
Treat*Time	4	0.023964	0.005991	1.62	0.172920	0.488452
Sex*Trt*Time	4	0.016592	0.005958	1.12	0.349171	0.345449
S*Trt*Time*subj	136	0.503173	0.003700			
S	1440	4.330227	0.003007			
Total (Adj)	1799	21.47333				
Total	1800					

*Sex and TimeGp significant

Tukey-Kramer Multiple-Comparison Test

Response: T_{reac} Term D: TimeGp

1 > 0 & 4

Table C9. Movement Time Overall 3 Way ANOVA

Source Term	DF	Sum of Squares	Mean Square	F-Ratio	Prob Level	Power (alpha=0.05)
Sex	1	1.302283	1.302283	5.41	0.03*	0.617716
Sex*subj	34	8.187884	0.240820			
Treat	1	0.237406	0.237406	28.29	0.000007*	0.999322
Treat*Sex	1	0.000448	0.000448	0.05	0.82	0.055799
Treat*subj	34	0.285283	0.008391			
TimeGp	4	0.335906	0.008398	26.32	0.000000*	1.000000
TimeGp*Sex	4	0.006052	0.001512	0.47	0.75	0.159819
TimeGp*subj	136	0.43397	0.003191			
Treat*Time	4	0.161931	0.040483	18.73	0.000000*	1.000000
Sex*Trt*Time	4	0.005960	0.001490	0.69	0.60	0.219244
S*Trt*Time*subj	136	0.293877	0.002161			
S	1440	1.856566	0.001289			
Total (Adj)	1799	13.10757				
Total	1800					

*Sex, Treat, TimeGp, all significant

Tukey-Kramer Multiple-Comparison Test

Response: T_{mov}Term CD: Treat, TimeGp

2,2 & 2,1 > 2,3 & 2,4 > 2, 0

Table C10. Response Time Overall 3 Way ANOVA

Source Term	DF	Sum of Squares	Mean Square	F-Ratio	Prob Level	Power (alpha=0.05)
Sex	1	6.711959	6.711959	5.79	0.02*	0.647619
Sex*subj	34	39.38118	1.15827			
Treat	1	0.294656	0.294656	12.22	0.001*	0.924449
Treat*Sex	1	0.027222	0.027222	1.13	0.3	0.178296
Treat*subj	34	0.818717	0.024109			
TimeGp	4	0.644813	0.161203	18.78	0.00000*	1.000000
TimeGp*Sex	4	0.015430	0.038575	0.45	0.8	0.153253
TimeGp*subj	136	1.167631	0.008586			
Treat*Time	4	0.27262	0.068155	9.06	0.000002*	0.999275
Sex*Trt*Time	4	0.023833	0.005958	0.79	0.53	0.248733
S*Trt*Time*subj	136	1.022907	0.007521			
S	1440	5.978078	0.004151			
Total (Adj)	1799	56.36005				
Total	1800					

*Sex, Treat, TimeGp, all significant

Tukey-Kramer Multiple-Comparison Test

Response: T_{res} Term CD: Treat, TimeGp

2,1 > 2,2 & 2,3 > 2,4 > 2,0

Table C11. Expected Mean Squares Section (HighLow)for Overall 3 Way ANOVA

Source Term	DF	Term Fixed?	Denominator Term	Expected Mean Square
A: Sex	1	Yes	B(A)	S+cdesB+bcdesA
B(A): Subj	34	No	S(ABCDE)	S+cdesB
C: Treat	1	Yes	BC(A)	S+desBC+abdesC
AC	1	Yes	BC(A)	S+desBC+bdesAC
BC(A)	34	No	S(ABCDE)	S+desBC
D: TimeGp	2	Yes	BD(A)	S+cesBD+abcesD
AD	2	Yes	BD(A)	S+cesBD+bcesAD
BD(A)	68	No	S(ABCDE)	S+cesBD
CD	2	Yes	BCD(A)	S+esBCD+abesCD
ACD	2	Yes	BCD(A)	S+esBCD+besACD
BCD(A)	68	No	S(ABCDE)	S+esBCD
S(ABCDE)	1584	No		S

Note: Expected Mean Squares are for the balanced cell-frequency case

Table C12. Response Time (HighLow) Overall 3 Way ANOVA

Source Term	DF	Sum of Squares	Mean Square	F-Ratio	Prob Level	Power (alpha=0.05)
Sex	1	5.253717	5.253717	4.54	0.04*	0.543595
Sex*subj	34	39.38118	1.15827			
Treat	1	0.236008	0.236008	9.79	0.004*	0.859770
Treat*Sex	1	0.019003	0.019003	0.79	0.38	0.138692
Treat*subj	34	0.819717	0.024109			
HighLow	2	2.961345	1.480673	156.41	0.000000*	1.000000
HighLow*Sex	2	0.047497	0.023748	2.51	0.09	0.486643
HighLow *subj	68	0.643732	0.009467			
Treat* HighLow	2	0.002140	0.001070	0.56	0.57	0.139909
Sex*Trt* HighLow	2	0.001859	0.000930	0.49	0.61	0.127254
S*Trt* HiLo*subj	68	0.128928	0.001896			
S	1584	5.339811	0.003371			
Total (Adj)	1799	56.36005				
Total	1800					

*Sex, Treatment and HighLow all significant

Tukey-Kramer Multiple-Comparison Test

Response: T_{res} Term D: HighLow

5 > 3 > 1

Table 3. Temperature Means for the environment, ankle and times associated with fractioned response time trials at 0, 20, 21, 23, 26 and 29 minutes. (degrees Celcisus, mean ± standard deviation; n=18 per cell)

	$Temp_{environment}$	$Temp_{bucket}$	$Temp_{ankle}$
Female			
Control			
0	20.6 ± 0.8	21.3 ± 1.1	29.3 ± 2.0
20	20.5 ± 0.8	23.2 ± 1.0	29.4 ± 1.8
21	20.6 ± 0.8	22.6 ± 0.8	28.8 ± 2.0
23	20.6 ± 0.8	22.4 ± 0.9	29.0 ± 2.0
26	20.5 ± 0.8	22.1 ± 1.0	28.9 ± 1.8
29	20.5 ± 0.8	22.0 ± 1.1	28.7 ± 2.0
Ice			
0	20.6 ± 0.8	0.2 ± 0.2	28.9 ± 1.6
20	20.6 ± 0.9	0.2 ± 0.3	4.6 ± 5.0
21	20.5 ± 0.9	0.2 ± 0.3	8.7 ± 4.0
23	20.5 ± 0.9	0.0 ± 0.6	13.4 ± 3.5
26	20.4 ± 1.1	0.2 ± 0.3	16.7 ± 3.0
29	20.5 ± 0.9	0.1 ± 0.1	18.2 ± 2.7
Male			
Control			
0	20.6 ± 0.9	21.3 ± 2.3	28.3 ± 3.2
20	20.5 ± 0.8	23.4 ± 1.7	28.6 ± 2.7
21	20.4 ± 0.8	23.0 ± 1.7	28.0 ± 2.6
23	20.5 ± 0.8	22.7 ± 1.9	27.8 ± 2.9
26	20.6 ± 0.7	22.4 ± 1.8	28.1 ± 2.8
29	20.5 ± 0.8	22.3 ± 1.9	28.0 ± 2.7
Ice			
0	20.5 ± 0.8	0.2 ± 0.4	28.4 ± 5.3
20	20.6 ± 0.9	0.5 ± 1.0	5.3 ± 2.9
21	20.5 ± 0.8	0.1 ± 0.2	10.6 ± 2.5
23	20.5 ± 0.8	0.3 ± 0.4	14.0 ± 1.9
26	20.5 ± 0.8	0.2 ± 0.4	16.6 ± 1.7
29	20.5 ± 0.9	0.2 ± 0.4	17.7 ± 1.3

$Temp_{environment}$ overall, 20.5 ± 0.8
$Temp_{water}$
Treat 1(control): 22.4 ± 1.6
Treat 2(cold water immersion): 0.2 ± 0.4

Table C14. Environment temperature over time for each of 18 subjects (min, mean ± standard deviation; n=18 per cell)

Time (min)	Female		Male	
	Control	Ice	Control	Ice
-1	20.68 ± 0.77	20.63 ± 0.86	20.59 ± 0.74	20.67 ± 0.75
0	20.60 ± 0.81	20.59 ± 0.84	20.57 ± 0.86	20.52 ± 0.79
1	20.61 ± 0.79	20.58 ± 0.83	20.61 ± 0.75	20.66 ± 0.82
2	20.67 ± 0.79	20.64 ± 0.80	20.70 ± 0.86	20.53 ± 0.83
3	20.61 ± 0.78	20.59 ± 0.78	20.62 ± 0.76	20.72 ± 1.24
4	20.59 ± 0.77	20.57 ± 0.80	20.59 ± 0.85	20.51 ± 0.83
5	20.61 ± 0.72	20.59 ± 0.77	20.53 ± 0.83	20.51 ± 0.80
6	20.58 ± 0.74	20.58 ± 0.78	20.56 ± 0.83	20.49 ± 0.83
7	20.57 ± 0.71	20.59 ± 0.75	20.53 ± 0.85	20.53 ± 0.83
8	20.60 ± 0.70	20.54 ± 0.80	20.52 ± 0.86	20.51 ± 0.82
9	20.59 ± 0.70	20.59 ± 0.80	20.54 ± 0.91	20.52 ± 0.86
10	20.58 ± 0.72	20.69 ± 1.10	20.57 ± 0.89	20.52 ± 0.84
11	20.59 ± 0.73	20.59 ± 0.83	20.53 ± 0.81	20.57 ± 0.91
12	20.59 ± 0.69	20.59 ± 0.80	20.53 ± 0.85	20.58 ± 0.91
13	20.56 ± 0.73	20.58 ± 0.83	20.54 ± 0.88	20.52 ± 0.84
14	20.60 ± 0.74	20.58 ± 0.83	20.56 ± 0.97	20.52 ± 0.83
15	20.61 ± 0.77	20.64 ± 0.93	20.54 ± 0.92	20.53 ± 0.88
16	20.54 ± 0.74	20.64 ± 0.82	20.54 ± 0.85	20.53 ± 0.82
17	20.61 ± 0.73	20.58 ± 0.86	20.48 ± 0.83	20.46 ± 0.83
18	20.57 ± 0.74	20.58 ± 0.87	20.46 ± 0.83	20.45 ± 0.80
19	20.57 ± 0.74	20.60 ± 0.88	20.47 ± 0.81	20.44 ± 0.78
20	20.54 ± 0.76	20.61 ± 0.87	20.46 ± 0.84	20.59 ± 0.88
21	20.57 ± 0.80	20.53 ± 0.95	20.38 ± 0.81	20.49 ± 0.83
22	20.63 ± 0.74	20.65 ± 0.86	20.46 ± 0.87	20.74 ± 1.00
23	20.60 ± 0.77	20.52 ± 0.93	20.47 ± 0.81	20.52 ± 0.79
24	20.60 ± 0.79	20.52 ± 0.96	20.66 ± 0.85	20.59 ± 0.85
25	20.58 ± 0.85	20.49 ± 0.98	20.56 ± 0.77	20.54 ± 0.82
26	20.50 ± 0.81	20.43 ± 1.06	20.55 ± 0.75	20.50 ± 0.80
27	20.56 ± 0.81	20.52 ± 0.99	20.54 ± 0.75	20.57 ± 0.86
28	20.52 ± 0.85	20.53 ± 0.93	20.57 ± 0.77	20.52 ± 0.87
29	20.52 ± 0.84	20.53 ± 0.92	20.54 ± 0.79	20.54 ± 0.86
30	20.63 ± 1.06	20.53 ± 0.92	20.56 ± 0.77	20.53 ± 0.87

Table C15. Bucket (control/water) temperature over time for each of 18 subjects (min, mean ± standard deviation; n=18 per cell)

Time (min)	Female		Male	
	Control	Ice	Control	Ice
-1	21.63 ± 1.60	0.14 ± 0.10	21.40 ± 2.62	0.27 ± 0.48
0	21.28 ± 1.06	0.15 ± 0.23	21.28 ± 2.25	0.23 ± 0.40
1	21.83 ± 0.89	0.19 ± 0.24	21.69 ± 2.41	0.28 ± 0.40
2	21.98 ± 0.92	0.12 ± 0.19	22.06 ± 2.11	0.20 ± 0.36
3	22.16 ± 0.93	0.15 ± 0.12	22.37 ± 2.13	0.18 ± 0.31
4	22.17 ± 0.95	0.13 ± 0.13	22.63 ± 2.40	0.18 ± 0.26
5	22.34 ± 0.89	0.13 ± 0.12	22.71 ± 2.29	0.24 ± 0.47
6	22.54 ± 0.91	0.12 ± 0.12	22.74 ± 1.92	0.15 ± 0.20
7	22.50 ± 0.94	0.16 ± 0.12	23.04 ± 2.45	0.16 ± 0.18
8	22.57 ± 1.03	0.16 ± 0.18	23.19 ± 2.42	0.16 ± 0.14
9	22.74 ± 0.96	0.12 ± 0.09	23.27 ± 2.58	0.14 ± 0.13
10	22.80 ± 0.97	0.18 ± 0.19	23.34 ± 2.53	0.15 ± 0.14
11	22.83 ± 0.98	0.11 ± 0.09	23.11 ± 1.79	0.13 ± 0.13
12	22.85 ± 0.87	0.13 ± 0.08	23.23 ± 1.82	0.12 ± 0.14
13	22.94 ± 0.97	0.14 ± 0.14	23.36 ± 1.82	0.13 ± 0.11
14	22.92 ± 1.02	0.12 ± 0.10	23.39 ± 1.72	0.13 ± 0.12
15	22.92 ± 1.05	0.13 ± 0.09	23.47 ± 1.70	0.25 ± 0.51
16	23.15 ± 0.93	0.16 ± 0.13	23.57 ± 1.81	0.21 ± 0.36
17	23.07 ± 0.89	0.14 ± 0.09	23.49 ± 1.74	0.26 ± 0.45
18	23.20 ± 1.04	0.13 ± 0.07	23.48 ± 1.76	0.23 ± 0.43
19	23.16 ± 1.02	0.12 ± 0.17	23.58 ± 1.76	0.23 ± 0.49
20	23.19 ± 1.00	0.21 ± 0.31	23.44 ± 1.69	0.46 ± 0.95
21	22.63 ± 0.82	0.20 ± 0.26	23.01 ± 1.71	0.14 ± 0.21
22	22.42 ± 1.03	0.15 ± 0.15	22.63 ± 1.69	0.26 ± 0.43
23	22.39 ± 0.91	0.03 ± 0.61	22.69 ± 1.86	0.27 ± 0.44
24	22.35 ± 0.87	0.17 ± 0.18	22.53 ± 1.66	0.24 ± 0.46
25	22.21 ± 1.05	0.15 ± 0.16	22.43 ± 1.74	0.24 ± 0.40
26	22.13 ± 1.04	0.23 ± 0.28	22.37 ± 1.84	0.24 ± 0.38
27	22.10 ± 0.93	0.06 ± 0.29	22.32 ± 1.91	0.23 ± 0.40
28	22.07 ± 0.98	0.12 ± 0.10	22.28 ± 1.79	0.27 ± 0.38
29	22.00 ± 1.10	0.11 ± 0.11	22.32 ± 1.90	0.24 ± 0.37
30	21.90 ± 1.00	0.12 ± 0.09	22.16 ± 1.92	0.18 ± 0.42

Table C16. Surface temperature of the ankle over time for each of 18 subjects (min, mean ± standard deviation; n=18 per cell)

Time (min)	Female		Male	
	Control	Ice	Control	Ice
-1	29.57 ± 1.86	29.15 ± 1.90	28.39 ± 3.15	28.20 ± 5.45
0	29.29 ± 2.02	28.91 ± 1.58	28.29 ± 3.24	28.41 ± 5.30
1	29.45 ± 1.98	11.05 ± 8.32	28.60 ± 2.95	10.09 ± 6.78
2	29.52 ± 1.92	9.31 ± 6.13	28.66 ± 2.98	9.09 ± 3.99
3	29.56 ± 1.89	8.87 ± 5.99	28.77 ± 2.93	8.55 ± 3.57
4	29.61 ± 1.85	8.32 ± 5.98	28.85 ± 2.89	8.15 ± 3.34
5	29.61 ± 1.87	7.72 ± 5.97	28.77 ± 2.89	7.87 ± 3.16
6	29.63 ± 1.83	7.21 ± 5.89	28.79 ± 2.82	7.37 ± 2.89
7	29.65 ± 1.81	6.79 ± 5.66	28.77 ± 2.89	7.06 ± 2.83
8	29.64 ± 1.86	6.43 ± 5.55	28.78 ± 2.79	6.85 ± 2.80
9	29.68 ± 1.80	6.21 ± 5.46	28.79 ± 2.79	6.68 ± 2.56
10	29.65 ± 1.79	5.91 ± 5.36	28.79 ± 2.71	6.50 ± 2.58
11	29.61 ± 1.87	5.76 ± 5.30	28.76 ± 2.78	6.28 ± 2.60
12	29.59 ± 1.89	5.60 ± 5.22	28.74 ± 2.70	6.17 ± 2.72
13	29.66 ± 1.78	5.60 ± 5.09	28.73 ± 2.70	6.04 ± 2.55
14	29.67 ± 1.79	5.35 ± 5.07	28.82 ± 2.69	5.90 ± 2.60
15	29.66 ± 1.81	5.19 ± 5.05	28.77 ± 2.65	5.76 ± 2.36
16	29.64 ± 1.80	5.10 ± 5.04	28.77 ± 2.70	5.41 ± 2.33
17	29.62 ± 1.76	5.10 ± 5.01	28.79 ± 2.74	4.97 ± 2.42
18	29.60 ± 1.80	4.92 ± 5.06	28.79 ± 2.76	5.08 ± 2.07
19	29.56 ± 1.76	4.93 ± 4.95	28.76 ± 2.79	5.35 ± 2.57
20	29.38 ± 1.76	4.64 ± 4.97	28.61 ± 2.72	5.34 ± 2.92
21	28.83 ± 1.96	8.68 ± 4.03	28.03 ± 2.61	10.57 ± 2.45
22	28.58 ± 1.81	11.25 ± 3.64	27.61 ± 2.90	12.67 ± 2.10
23	28.98 ± 1.96	13.35 ± 3.47	27.76 ± 2.91	14.02 ± 1.94
24	28.71 ± 2.07	14.67 ± 3.21	27.48 ± 3.00	15.16 ± 1.90
25	28.85 ± 1.84	15.78 ± 2.63	27.58 ± 2.86	16.03 ± 1.80
26	28.85 ± 1.84	16.70 ± 2.97	28.11 ± 2.79	16.59 ± 1.66
27	28.71 ± 1.89	17.21 ± 2.73	27.67 ± 3.00	17.02 ± 1.42
28	28.77 ± 1.88	17.67 ± 2.48	28.04 ± 2.76	17.56 ± 1.36
29	28.67 ± 1.97	18.15 ± 2.67	27.98 ± 2.72	17.74 ± 1.26
30	28.44 ± 1.95	18.35 ± 2.79	27.49 ± 2.71	17.87 ± 1.36

Table C17. Conclusions

Reaction Time

1. Males are faster than females.
2. T_{rec} was slowest during the post 15-second time group.

Movement Time

1. Males are faster than females.
2. T_{mov} slower after cold water immersion than after control.
3. T_{mov} was fastest pre-treatment and slowest post 15-seconds.
4. T_{mov} decreased from post 15-seconds to post 9 minutes, but did not return to pre-treatment values by the time data collection discontinued.
5. Time group did not effect T_{mov} during the control, but did effect T_{mov} after cold water immersion where the pre-treatment time group was fastest and post 15-second time group the slowest.

Response Time

1. Males are faster than females.
2. T_{res} slower after cold water immersion than after control.
3. T_{res} was fastest pre-treatment and slowest post 15-seconds.
4. T_{res} decreased from post 15-seconds to post 9 minutes, but did not return to pre-treatment values by the time data collection discontinued.
5. Time group did not effect T_{res} during the control, but did effect T_{res} after cold water immersion where the pre-treatment time group was fastest and post 15-second time group the slowest.

Appendix D

Suggestions for Future Research

Suggestions for Future Research

1. Repeat the study comparing cold water immersion of the entire dominant lower limb, immersion of the ankle to the base of the calf, and immersion of the ankle joint.
2. Repeat the study comparing ice pack to the ankle joint and cold water immersion to the base of the calf
3. Repeat the study comparing subjects with previous, significant ankle immersion experience to those without experience.
4. Repeat the study comparing injured subjects vs. uninjured subjects.
5. Repeat the study and extend to time to see when values return to pretreatment levels.