THE EFFECT OF CRYOTHERAPY ON MUSCLE FATIGUE BETWEEN MAXIMAL ENDURANCE EXERCISE BOUTS

by

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CHAPTER I

INTRODUCTION

The external application of cryotherapy is a reasonably new concept when considering the age of human medicine. Cryotherapy use in sports medicine programs has become one of the most common treatments for acute injuries. Since the early 1950s, cryotherapy was becoming an essential part of any sports medicine injury management care.[1] At that time, physicians suggested cold treatments to only be used on acute injuries up to 30 minutes after initial injury.[1] Limited research and numerous theories on proper treatment protocols of cryotherapy application remains unknown to medical specialists. Sports medicine professionals need more evidence to employ day-to-day treatment operations in order to allow athletes to compete at the highest, safest level possible.

Athletes work endlessly to delay the onset of fatigue and improve their efficiency at functional movements. In order to achieve this, athletes train to enhance several components of physical fitness, such as, strength training, cardiovascular endurance, skill development, body composition, and flexibility.[2] By training at high enough intensities tissues undergo microtrauma that need recovery in order to heal the micro tears caused by exercise.[2] Cryotherapy application after exercise has become a common treatment for allowing athletes to speed recovery and train more frequently. Allowing elite athletes another safe opportunity to recover quickly from fatigue could enhance their physical performance. Routinely, athletes rely on cryotherapy application for acute injuries and a recovery strategy after practice and competition.[1,3-8] Cryotherapy treatment for acute injuries poses physiological effects to slow cell metabolism, decreases nerve conduction velocity, cause cold-induced vasodilation, and limit secondary hypoxic injury.[1] Due to cryotherapy being a relatively misunderstood concept within research, sports medicine professionals continue to apply cryotherapy treatments based on what was developed in ancient times.[1]

Cryotherapy treatment became popular as more sports medicine programs implemented recovery strategies into their injury management systems. As further research was conducted, new protocols of cryotherapy were being presented into sports medicine.[1] Cryokinetics, the combination of cold application with exercise, was introduced into sports medicine to decrease pain during exercise of acute musculoskeletal injuries.[1] Even though the rational for this treatment remains unclear, thousands of patients have seen quicker benefits of this treatment.[1] With similarities between cryokinetics and interval cryotherapy treatment, more intensive interval cryotherapy research needs to be conducted to understand if similar benefits exist with healthy subjects.

As allied health professions continue implementing evidence-based practice, it is important for athletic trainers to improve and employ the most effective treatment to their athletes. Unfortunately, due to several varied cryotherapy theories and lack of controlled studies, sports medicine professionals continue to provide cryotherapy treatments to athletes with misunderstood parameters. Further clinical understanding and conclusive research of interval cryotherapy and the effects of delaying muscular fatigue need to be addressed. Neglecting the possibility of delayed fatigue from interval cryotherapy treatment between endurance exercise bouts cannot be ignored from future research and evidence based practice.

Physiologically interval cryotherapy causes conductive heat loss in muscles, allowing muscle temperatures to remain at more appropriate levels throughout exercise, which may allow healthy adults to achieve more total work before reaching muscular fatigue.[2] Decreases in cell metabolism caused by cryotherapy application occur in treating acute musculoskeletal injuries. However, limited research on decreasing intramuscular temperature to more suitable levels has been conducted to assess the effects of delaying fatigue during endurance resistance exercise.

PURPOSE OF THE STUDY

The purpose of this study is to determine if short duration cryotherapy or thermotherapy applied intermittently between fatiguing muscle contractions can benefit a healthy, athletic population by delaying the onset of musculoskeletal fatigue and maintaining higher force outputs during endurance exercise.

HYPOTHESES

It was hypothesized that:

H 1: The cryotherapy condition will result in a slower onset of fatigue when compared to the control and thermal resting periods.

H 2: The cryotherapy treatment during resting periods will result in an increase of total repetitions and work completed when compared to the control and thermal conditions.

H 3: The thermotherapy condition will not cause a difference in onset of fatigue, total repetitions, and work completed when compared to the control.

INDEPENDENT VARIABLES

The independent variables were the type of treatment, control (normal muscle temperature), cryotherapy (ice bag treatment) and thermotherapy (moist heat packs). A secondary independent variable was gender, male or female. Gender was a between-subjects variable, while the type of treatment was a within-subjects (repeated) variable.

DEPENDENT VARIABLES

The dependent variables were active range of motion (AROM), internal rotation (IR) peak torque, external rotation (ER) peak torque, number of repetitions to 70% max, number of repetitions to 50% max, total work to 70% max, total work to 50% max.

DELIMITATIONS

1) Only healthy, physically active adults between ages 18-35 participated in this study.
2) Only subjects who performed resistance training two or more days each week within the ACSM guidelines for resistance training frequency.
3) Only subjects with no past history of dominant shoulder surgery, acute shoulder injuries within the past 6 months, or current chronic injuries participated in this study.
4) Cryotherapy parameters included an application of four minutes as the period of treatment.
5) The thermotherapy parameters consisted of an application of four minutes as the period of treatment.

6) Only physically active adults within central Texas participated in this study.

LIMITATIONS

The limitations of this study reflect the effect of the delimitations on the collection and interpretation of the data as well as the ability to expand the scope of influence beyond the sample population. Generalizations made from the results were compromised by the following limitations:

1) The results of this investigation cannot infer to an unhealthy, adolescent or geriatric populations.
2) The results from this research study cannot infer to a population who do not routinely perform a form of resistance training according to the ACSM guidelines for resistance training frequency.
3) Generalization from the results should not be made on subjects with an acute or chronic shoulder injury or surgeries participated in this study.
4) The results of this research study cannot infer to cryotherapy treatment times shorter or longer than four minutes was not concluded.
5) Due to subject availability, subjects outside central Texas was not inferred.

ASSUMPTIONS

Several assumptions can be made throughout the study, such as:

1) Endurance training experience and training status among subjects was similar.
2) Subjects discontinued an upper extremity resistance-training program between testing sessions.

3) The learning effect among subjects during the crossover study design was similar.
4) Subjects spoke truthfully on the written inclusion questionnaire.
5) Subjects understood the verbal commands during the testing.
6) Intramuscular temperature change was equal among subjects.
7) To the best of their ability, all subjects performed maximal contractions until muscular fatigue is reached.
8) Verbal reinforcement was consistent among all subjects.
9) Coherent levels of mental coping to experiencing physical muscle fatigue.

SIGNIFICANCE OF THE STUDY

In this study, I intended to provide evidence that interval cryotherapy application delays the onset of muscular fatigue due to decreases in intramuscular temperature. The rationale for this study was to determine if either cryotherapy or thermotherapy will aid in delaying the onset of muscular endurance fatigue, and if more physical work can be accomplished during each training session. Understanding proper muscle temperature during exercise is an important factor to consider when training athletes to perform at their highest, safest level possible.

Strength training is not the only component of fitness that should be addressed in exercise training programs. Local muscular endurance plays a vital role in athletics and the athlete’s ability to perform maximal muscular contractions on a very repeated basis. Increasing the time before the onset of fatigue may allow athletes to achieve an increased amount of maximal muscular work prior to achieving muscular fatigue. This study has provided answers to understanding if muscle endurance can be prolonged through the use of interval cryotherapy.

Cryotherapy treatments are being used as the framework to shorten recovery time between exercise sessions. With evidence-based research becoming more widely used throughout all health care professions, athletic trainers need to understand the physiological effects of interval cryotherapy between bouts of exercise. Developing research protocols for interval cryotherapy treatments are essential to maximizing an athlete's muscular performance. If interval cryotherapy decreases muscular temperature during exercise, it could be useful for athletes to delay endurance muscular fatigue. This treatment may be used to help safely enhance an athlete's physical performance and decrease risk of injury due to the early onset of fatigue.

OPERATIONAL DEFINITIONS

Modality – A therapeutic tool used in sports medicine protocols to manage pain, return full range of motion, maintenance and recovery of strength, and regaining neuromuscular control.

Interval Cryotherapy – External application of cold therapy applied for a short duration in between repeated bouts of endurance exercise.

Thermotherapy – External application of moist heat packs applied for a four minute treatment time in between repeated bouts of endurance exercise.

Fatigue – Physical muscular exhaustion caused by resistance training stressors resulting in less than 50% of initial maximal contractile force.

Muscular Endurance – The ability of a muscle to repeatedly apply force against isokinetic resistance forces.

Peak Torque – The highest muscular force output during a one repetition maximum isokinetic effort at 300° per second.

Accessory Motion – Motions within a joint and surrounding tissue that are necessary to complete a joints full range of motion, but are motions that are not able to be completed actively.

Isokinetic Testing – An exercise providing variable resistance while maintaining a constant velocity, with assistance of specialized equipment.

Concentric Contraction – A dynamic muscular contraction that produces force while shortening the contracted muscle.

Delayed Onset Muscle Soreness (DOMS) – Muscular soreness that occurs after 24 hours of muscular exercise. Soreness often peaks at 24-48 hours post exercise and declines over the next 5-7 days.

CHAPTER II

REVIEW OF LITERATURE

INTRODUCTION

Medical uses for cryotherapy have been dated back to ancient times when Greeks and Romans used snow and natural ice for injuries.[1] During the 1800's scholarly articles were introduced the use of cold compresses for therapeutic benefits of inflamed wounds.[1,5] As time went on, immense advances in human medicine directed sports medicine practitioners to apply cryotherapy immediately to acute injuries. Health providers questioned the theoretical foundations of the effects of cryotherapy until the secondary hypoxic injury theory was introduced in 1976.[1] The introduction of this theory provided sports medicine professionals a stable basis of understanding the use of cryotherapy. Most often, sports medicine professionals continue to use cryotherapy as a treatment for acute injuries seen during exercise.

Every year, millions of U.S. adults participate in exercise activities on a normal basis.[9] Exercise causes increases in muscular temperature which in turn has a impact on the mechanical and metabolic stresses on the skeletal muscle being targeted.[10] Exercise-induced damage to muscular tissue causes oxidative stress and inflammation to the injured tissue.[11] The accumulation of inflammation within the muscle cell caused by metabolic change is one cause for muscular fatigue.[11] Fatigue often causes a decrease in muscular strength, power, and work output.[12] The decrease of muscular performance can be indirectly attributed to the increases in muscular tissue temperature during exercise.

Researchers have studied the effects of cryotherapy use after exercise on aiding in the recovery of acute injuries. The majority of cryotherapy studies indicate a decrease in metabolism of the tissues being treated to be a positive effect for muscle recovery after exercise.[1,3-8] However, a lack of research exists to see determine if interval cryotherapy will produce the same benefits of slowed muscle metabolism when applied in between repeated bouts of exercise. By slightly slowing muscle metabolism and decreasing already increased muscle temperatures through short duration cryotherapy treatments, it seems evident that certain factors contributing to fatigue are also affected.

Through this literature review provides an overview of cryotherapy application with an emphasis in the physiological effects, common treatment parameters, and overall effectiveness. I describe the components of shoulder muscular anatomy and how it relates to endurance exercise. Finally, I explain the importance of muscular fatigue and how delaying the onset of this response can alter athletic performance.

CRYOTHERAPY

Background

Cryotherapy within sports medicine treatment strategies is the application of external cold sources on the body to achieve physiological changes to human tissue. Cryotherapy has become the most commonly used modality in the management of acute musculoskeletal injuries.[13] Numerous theories on the positive effects of cryotherapy as a treatment for acute injuries have been developed in past years. The first theorized beneficial effect of cryotherapy believed cold therapy providing a reduction in blood flow and decrease in hemorrhage and edema formation.[5] Without conclusive research supporting this theory, a secondary hypoxic theory was introduced. Sports medicine providers now believe cryotherapy application reduces metabolic rate, reducing the effect of secondary hypoxic injury.[1,5,6,8,13-15] Cold application to localized skin areas provide a lowering of tissue temperature primarily through conduction.[13] The decline of skin and intramuscular temperature during cryotherapy reduces the need of oxygen in the cells in order to survive. By decreasing the muscles need for oxygen, secondary tissue death from oxygen deprivation is diminished.[1,5,14] Limiting secondary tissue death decreases the muscular damage causing a direct decrease in recovery time needed between exercise sessions.

Effectiveness of Cryotherapy

The efficacy of cryotherapy highly depends on many factors such as, duration of cold application, the use of compression, type of cryotherapy mode used, the anatomical location of treatment and muscle temperature prior to application.[13] The widespread of factors that influence the effectiveness of cryotherapy challenge sports medicine professionals in determining the proper parameters that cause the necessary physiological change. Cryotherapy application after exercise provides several other physiological responses such as, anesthesia, reduced muscle spasm, stimulates muscle relaxation resulting in decreased muscle tension, decreased circulation, and inhibition of inflammation.[14] Although cryotherapy application provides an abundance of physiological effects, very few studies provide evidence to the necessary duration in order to achieve these changes.

Determining the proper duration of cryotherapy treatments depends on the desired change in intramuscular temperature. Factors that heavily influence the necessary treatment duration are the use of compression, type of ice mode, and amount of adipose tissue. Compression is commonly used along with cryotherapy to increase external pressure to decrease the formation of edema.[6] Research is scarce on the effect of intramuscular temperature with the use of compression along with cryotherapy application. One study found the use of a four minute cryotherapy and compression treatment to decrease intramuscular temperatures at 1cm and 2cm from 36.28°C to 23.54°C and 26.46°C, respectively.[6] The decrease in tissue temperature was significantly lower than the control group using only ice.[6] During another study, a 5-minute cryotherapy treatment at a depth of 2cm, produced a tissue temperature decrease of 0.40°C with ice only and 0.99°C with ice and compression.[16] It is evident the use of compression during cryotherapy treatments significantly increases the amount of tissue temperature change.

Cryotherapy treatment can be performed with various modes of application. Each mode of cryotherapy possesses different thermodynamic properties, which results in varied levels of effectiveness.[4,13] Several types of cryotherapy modes include ice cubes, frozen gel packs, cold water immersion, Cryo-Cuff, and topical sprays and lotions.[4] Sports medicine professionals most commonly use ice cubes as the mode of cryotherapy.[15] Frozen gel packs, although much colder than ice, was found to provide less of a cooling effect to intramuscular tissue, most likely due to the lack of heat conduction compared to that of normal ice.[4,13] This study provides evidence that a crushed ice bag application reduces sub-adipose intramuscular temperature at 1cm by nearly 2.0°C at four minutes of treatment.[13] Current literature indicates that there is more potential to extract heat energy from the body when using solid crushed ice because of its ability to undergo a change in state, from a solid to a liquid.[4]

Anatomical areas of cryotherapy application alter the necessary duration in order to achieve the specific amount of tissue cooling. Depending on the location of the intended cryotherapy treatment, overlying superficial tissue can delay the physiological response of cold to intramuscular layers due to increased depth. During a cryotherapy treatment, surface skin tissue experience conductive heat loss immediately, then the lowering of those superficial tissues extract heat from direct underlying tissues.[6] This form of conductive heat loss results in underlying tissues cooling and rewarming slower than that of superficial tissue.

The effectiveness of cryotherapy application relies heavily on the duration of the treatment. In order to determine the appropriate cryotherapy duration, it seems obvious that clinicians should measure the amount of adipose tissues. Based on previous literature, skinfold measures have been proven to be an effective testing procedure to determine the thickness of adipose tissue that lie more superficial to intramuscular layers.[17] A variety of skinfold thicknesses have been shown to greatly alter appropriate treatment times in physically active adults due to the thermodynamic properties of overlying adipose tissue.[8,17] Middle deltoid skinfold measurements were taken to determine the average adipose thickness among active adults in the shoulder.[17] In recreationally active collegiate athletes, deltoid skinfold measurements were found to an average of 17.9mm. [17]

Intramuscular temperature was examined in adults with varying levels of adipose thickness to determine the proper duration for cryotherapy treatments.[8] Subjects within the 11-20mm skinfold group were found to have decreases in intramuscular temperature of 1.00°C at 4 minutes of treatment.[8] Subjects with less than 20mm of adipose thickness proved a 25-minute cryotherapy treatment was adequate to decrease intramuscular tissue by 7°C of their respective baseline intramuscular temperature.[8] Adipose thickness of greater than 20mm requires a 38-minute treatment application to attain the same benefits, providing a basis that adipose thickness alters levels of intramuscular cooling.[8] Understanding the importance of targeted tissue depth, clinicians can provide more appropriate durations of cryotherapy treatments in order to achieve the physiologic effects of cold therapy.

Interval Cryotherapy

Cryokinetics, a cold application developed in the 1960's, combines cold and exercise to achieve quicker rehabilitation through decreased pain and early motion.[1] Cryokinetics was locally applied between 3 to 20 minutes until patient numbness was reported, acting as a local anesthetic.[1] This length of treatment was later found to depress blood flow during the treatment and after the treatment had been withdrawn.[1] Although cryokinetics decreases blood flow in injured tissues, this form of treatment continues to be used today to aid in early rehabilitation of musculoskeletal injuries.

Interval cryotherapy treatments are characterized by numerous short duration local applications in between subsequent treatments or exercises. The thought of interval cryotherapy can be contributed to the use of cryokinetics, but mainly administered to active healthy subjects. Cryotherapy treatment is known to decrease cell metabolism, blood flow, nerve conduction velocity, muscle extensibility, and delivery of leukocytes to the treatment area.[3] Additionally, the effect of cooling muscles decreases muscle strength, isokinetic and isometric force production, velocity, and muscular power.[1,14] Even though the consequences of prolonged cryotherapy treatments seem detrimental to athletic performance, the effects of short duration cryotherapy remain unknown.

Limited research has found that short duration cryotherapy treatments slightly lower muscle temperature and have an effect on delaying muscular fatigue.[2] Slightly colder muscles have been shown to last significantly longer work periods during endurance exercise.[2] On the contrary, higher muscular temperatures revealed a significantly quicker onset to fatigue when compared to muscle temperatures slightly below normal ranges.[2] The slight decrease in intramuscular temperature however does not effect isokinetic strength.[14] Another study demonstrates that short duration ice application has no effect on functional performance components, such as muscle power, speed, and agility.[4,14] A cryotherapy treatment of 10 minutes applied to the biceps brachii resulted in no significant effect on concentric and isokinetic strength at the elbow.[18] Knowing limited research concludes the benefits of short duration cryotherapy; it seems evident that interval cryotherapy applications need to become better understood in athletic populations.

THERMOTHERAPY

Background

Thermotherapy has been used in medicine practices for over 2000 years.[19] Thermotherapy is the external application of thermal modalities within sports medicine protocols to achieve a desired increase in human tissue temperature. Heat applied to the external surface of the skin is transferred from superficial to deep layers of tissue to help promote healing.[19] The levels of increased tissue temperature are often how the effectiveness of a thermotherapy agent is described.[20] A minimal tissue temperature increase of 1.0°C suggests a mild heating effect, whereas 2.0°C to 3.0°C is moderate heating, and 4.0°C or more is a vigorous heating treatment.[20]

Heating examples in medicine practices used today are ultrasound, diathermy, moist heat packs, paraffin wax, hot whirlpools, and infrared radiation.[19,21] Different levels of tissue heating result in different physiological effects; such as vasodilation, nerve endings sending impulses of temperature change to hypothalamus, increased capillary permeability, increased blood flow, and increased tissue elongation.[22] Therapeutic effects of thermotherapy include increased blood flow, increased metabolism, decreased pain, increased joint range of motion, muscle relaxation, decreased joint stiffness, and decreased muscle contractions.[20,22]

Effectiveness of Thermal Application

Similar to cryotherapy, the effectiveness of thermotherapy greatly depends on several factors related to mode of thermotherapy used, anatomical location of treatment, and duration of thermal application.[13] In order to determine the proper duration and treatment for a patient highly depends on the desired change in intramuscular temperature. Considering the comprehensive factors that influence the effectiveness of thermotherapy, sports medicine professionals face difficulty when determining the proper treatment and parameters. Important factors that profoundly influence the necessary duration of treatments are adipose tissue thickness and mode of thermotherapy treatment.[19]

In the clinical setting, moist heat packs are the most commonly used thermotherapy modality used for superficial heating.[20] Moist heat packs were found to increase tissue temperature by 2.2°C to 3.8°C from baseline at 1cm subadipose depth.[20] In this same study, a 5-minute moist hot pack treatment increased tissue temperature from 34.7°C to 35.6°C.[20] In a study examining the tissue temperature change among subjects with varying adipose thickness, moist heat packs were found to cause a rise in muscle temperature at a rate of 0.06°C per minute at an intramuscular depth of 2.5cm.[19] Demonstrating that even though moist hot packs increase tissue temperature at deeper depths, the heating is very minimal. Understanding that moist hot packs mainly heat superficial layers in short durations may result in minimal tissue temperature change at more significant intramuscular depths.

Comparing modes of thermotherapy treatments becomes extremely important when requiring a short duration treatment to cause an increase in deep intramuscular layers. Researchers have found moist heat and water modalities to provide a much quicker change in deep muscle temperature caused by a higher transfer of calories due to convection and conduction.[19] However, shortwave diathermy was found to cause a greater increase in intramuscular tissue temperature, but only after 20 minutes of treatment.[20] Therefore, in short duration treatments, moist hot packs produce a greater level of increased tissue temperature when compared to shortwave diathermy treatments.[20] The fastest rise in intramuscular temperature was found with use of a warm whirlpool treatment, followed by moist hot packs.[19] Although a warm whirlpool treatment provides the greatest increase in intramuscular temperature, this treatment is very impractical for use outside the clinic. Moist hot packs are the most convenient superficial heating modality for immediate field use.

EXERCISE SCIENCE

Muscular System

The muscular system functions in the human body to create movement of the skeletal system. In order for proper movement, the nervous system works in harmony with the muscular system.[23] The nervous system is the control center for all voluntary human movement, which allows various joints to move from generated muscle force.[23] More specifically, skeletal muscle is a collection of individual muscle fibers that collectively produce voluntary force. Muscle contraction, through interaction of various contractile and regulatory proteins, allows for an endless amount of functions to be performed.[23]

Although singular muscle fibers work together throughout the body, they are composed of different types of fibers, which have diverse characteristics when related to exercise. Skeletal muscle is mainly named based on the fiber type and its metabolic composition.[23] Muscle fiber types consist of type I slow oxidative, type IIa fast oxidative, and type IIx fast glycolytic.[23] Each fiber type has different metabolic characteristics that allow these muscles to achieve different tasks. Metabolic differences among these muscle fiber types include, speed of contractions, resistance to fatigue, myosin ATPase activity, oxidative capacity, non-oxidative energy capacity, and fiber color.[23] Type I slow oxidative muscle fibers characteristically are highly resistant to fatigue, but contract at slower speeds than other muscle types. Type IIa and IIx fibers are similar in that these fibers have fast contraction speeds, however type IIx fibers are less resistant to fatigue than type IIa.[23] The fiber types resistance to fatigue is determined by the fibers capacity to oxidative energy. Type I muscle fibers having a higher capacity of oxygen as an energy source allows for longer periods of excitation before fatigue sets in. With this in mind, muscles possess a mixed composition of fiber types to allow for both speeds of contraction with varying levels of fatigue resistance.[24]

Shoulder Anatomy

The shoulder is an extremely complex combination of articulations that allow a widespread of range of motion (ROM) in all anatomical planes.[25] This multi-joint complex heavily relies on muscular stabilization due to the lack of ligamentous stabilizers.[25] The glenohumeral (GH) joint is comprised of the head of the humerus and glenoid fossa of the scapula. This joint articulation provides a vast amount of mobility, but sacrifices stability. Considering the lack of boney and ligamentous stability, several muscles are needed to provide stability throughout functional movements. A group of muscles known as the rotator cuff includes, the supraspinatus, infraspinatus, teres minor, and subscapularis. These muscles work together to provide stabilization of the GH joint during functional movements, especially overhead motions.[25] Not only do these muscles stabilize, the supraspinatus, infraspinatus, and teres minor are prime movers of glenohumeral external rotation.[25] The subscapularis is the only rotator cuff muscle responsible for providing internal rotation of the GH joint.[25] For instance during an overhead throwing motion, the rotator cuff group is not only responsible for providing major forces for internal and external rotation of the GH joint, but also eccentrically decelerating the arm upon throwing.[26] This particular muscle group plays a vital role in the strength, velocity, and stabilization of an overhead athlete.

Rotator Cuff Fiber Type

The rotator cuff muscle group is extremely important for completion of overhead activities. Considering the need for rotator cuff musculature to provide GH joint stability, it is important to understand the composition of these muscles. As mentioned before, all muscles have certain percentages of mixed fiber types, depending on the demand of the muscle.[24] Not only are all the muscle of the rotator cuff mixed fiber types, but interestingly enough, different percentages exist between this muscle group.[24]

Recent research of human cadaver rotator cuff muscles, the external rotators, supraspinatus, infraspinatus, and teres minor, all revealed slow oxidative percentages of 54%, 41%, and 49%, respectively.[24] Another study confirms the external rotators being composed of slow oxidative fibers with the supraspinatus, infraspinatus, and teres minor values at 50%, 48%, and 49%, respectively.[27] A more recent study examining the subscapularis, the only GH internal rotator of the rotator cuff, was analyzed to be comprised of only 38% slow oxidative fibers.[24] A study analyzing the proportions of fiber type composition among shoulder muscles supports subsequent research by finding the subscapularis to have an equal proportion of type I and type IIx fibers.[27] Understanding the proportion of fiber type in these essential shoulder muscles becomes increasingly more important when selecting the correct demands to impose to achieve maximum effectiveness.

Endurance Exercise

Muscles are capable of producing extremely large forces when maximally contracted. A common measure of strength is accomplished by completing maximal resistance loads, normally over a short period of time.[12] Endurance exercise however, is defined as a muscles ability to sustain its function throughout numerous contractions.[12] Normally endurance exercise combines a light resistance with a high number of repetitions. Improving a muscles endurance capabilities may be more beneficial through multiple contractions of muscles composed of type I slow oxidative fibers.[12] Most commonly, endurance exercise parameters focus on a high volume of repetitions, lower intensity, and short recovery durations.[28] Knowing strength training programs normally strengthen type I slow oxidative muscles using these parameters, it seems evident that testing a muscles endurance should be tested in the same way.

Past literature has discovered the most effective way to test type I muscles, such as the rotator cuff muscle group. First off, the most effective way to properly determine the endurance properties of a muscle is to conduct testing on an isokinetic dynamometer.[29,30] Most commonly the rotator cuff muscles are functionally used during a throwing motion. When testing isokinetic strength, it is essential to test in the most functional position possible. However, when testing the internal and external rotators of the GH joint, the most accepted patient position is seated with the shoulder abducted to 90°, elbow flexed to 90°, and forearm in a neutral position.[29,30] This position optimizes length-tension relationships of the internal and external rotators.[30] With this in mind, this position not only intends to isolate the GH internal and external rotators, but closely mimic the cocking and acceleration phase in throwing.[30]

Consistent patient positioning is not the only standardization recent literature has evaluated. A study reports 15 isokinetic repetitions properly produces ideal training effects for peak torque and power testing of the internal and external rotators of the GH joint.[30] A more recent study suggests completing 20 maximal contractions of internal and external GH rotation.[31] As closely resembling isokinetic testing to functional throwing volume, pitchers during the 2013 Major League Baseball (MLB) season threw approximately 16 pitches per inning.[32] With all the repetition parameter literature presented falling between accepted endurance exercise ranges, it seems evident that several repetition parameters can be used to appropriately test peak torque and power.

The shoulder is capable of enormous amounts of angular velocity during the throwing motion. Researchers have found that shoulder angular velocities can reach up to 9,000°/s during the acceleration phase of throwing.[26] Knowing the capability of the shoulder to move so quickly, testing isokinetic strength at slow speeds is not only impractical to functional movement, but could also stimulate unwanted musculature.[30] Current literature reports isokinetic testing should replicate a functional throwing velocity, therefore testing should be performed at 300°/s.[26,30,31] Proper endurance assessments for the throwing shoulder should consist of 15 repetitions at 300°/s.[30,31,33] Knowing our understanding of proper repetitions to achieve endurance benefits, isokinetic testing for endurance of the GH internal and external rotators should replicate both patient positioning and isokinetic velocity.

FATIGUE

Onset of Fatigue

Although an abundance of literature has dedicated its efforts to determine muscle fatigue, no one mechanism for the development of muscle fatigue is known to be a main contributor.[34] Several factors are known to influence the onset of muscular fatigue, varying from an accumulation of lactate, a decreased motor command in the motor cortex or even a decline in mental function.[34,35] The development of these numerous factors during prolonged muscular contractions have eventually resulted in fatigue, which is measured by a decrease in maximal muscle force and power capacity.[12,34] Even after clinical muscular fatigue has been reached, submaximal contractions are still able to be sustained.[34] Clinically muscles are commonly considered fatigued after they reach a decrease in a certain percentage of peak torque, however even after this level of fatigue is reached, muscles are still capable of submaximal contractions.

The quickness of fatigue onset differs among people depending on various elements. Considering there is no single cause of muscle fatigue, the onset of fatigue becomes specific to those factors being stressed through exercise.[34] Depending on the muscles being stressed, fiber type plays a role in how quickly a muscle decreases in maximal power and force. Differences of contractile proteins of red and white muscle determine the endurance capacity of a muscle.[34] Type I slow-twitch muscle fibers have a higher capacity for endurance exercise than type IIa and IIx due to it’s increased capacity for oxygen as an energy source.[23] The percentage of fiber type in muscle is determined by anatomical muscle function and physical stresses placed on a specific muscle through exercise.

Even considering muscle fatigue begins at the moment of any deficit in muscular power or force, researchers have determined a proper shoulder internal and external rotation protocol in order to be considered clinically fatigued. A decreased force output of any muscle being stressed demonstrates the onset of fatigue factors limiting a maximal contraction.[12] During isokinetic testing of the GH internal and external rotators, one way to measure fatigue is by having peak torque output decline by 50% when compared to initial baseline peak torque values.[29,31] A reduction of peak torque to this level could link muscular fatigue with decreased performance.

After intense exercise, a considerable decrease in muscular power and force also occurs. Although the decline in performance resembles fatigue, this physiological response is known as delayed onset muscle soreness (DOMS).[5,36,37] The DOMS response has been considered an indicator of muscular training effectiveness.[36] The occurrence of DOMS develops from an accumulation of inflammation within the muscle caused by microscopic tears in connective tissue.[36] The inflammation causes a heightened awareness to nociceptors resulting in an increased sensation of pain.[36] Generally, DOMS becomes most apparent within the initial 6-8 hours after training, but performance decrements often peak between 24-48 hours post-exercise. With this in mind, training regimens need to consider the substantial decline in power and force results in decreased performance after vigorous exercise.

CONCLUSION

With the increasing needs of athletes in order to perform at their highest ability possible, it is important to consider interval cryotherapy as a method to delay the onset of fatigue. Cryotherapy is commonly only used to improve the recovery from muscle damage after exercise.[1] Sports medicine professionals could better treat athletes by having a better understanding of interval cryotherapy use during repeated bouts of endurance exercise.

Cryotherapy use in sports medicine protocols continues to be one of the most effective and widely used modalities. Even though cryotherapy use is so abundant in sports medicine practice, methodological flaws still exist in research on the effects of short duration applications on performance. A valid measure of muscle endurance testing has been researched heavily when using an isokinetic dynamometer. With this in mind, sports medicine professionals need to continue its research in the combination of short duration cryotherapy and the effects of muscle performance.

CHAPTER III

METHODS

INTRODUCTION

This study was designed to investigate if the use of short duration cryotherapy delays the onset of muscular fatigue during repeated bouts of endurance exercise. In random order, subjects were selected to perform crossover testing in both the control and experimental conditions. The cryotherapy experimental intervention during the study received interval cryotherapy treatments. The study includes another experimental condition where subjects received a thermal treatment application. Both the interval cryotherapy and thermal conditions were repeated applications in between endurance exercise bouts of glenohumeral internal and external rotation.

PARTICIPANTS

The participants in this study were healthy adults of any ethnic background between 18-35 years of age. Both sexes are involved in this study, however; only English speaking adults were included to ensure comprehension of the testing protocol. Due to the previous researched effectiveness of cryotherapy, only subjects with a dominant arm middle deltoid skinfold measure of 0-20mm were included in the study.[1,17] Skinfold measures were taken to determine overlying adipose tissue in the area of cryotherapy application. Physically active adults meeting American Heart Association physical activity recommendations with overall good health were recruited throughout the Texas State University campus and community to participate in this study.[38] In order to control for training status among participants, each subject must have completed two or more sessions of resistance training on major muscle groups per week according to the ACSM's guidelines for resistance training frequency.[23]

Subjects with a current dominant shoulder injury, incurred an acute injury within the last six months, or underwent any shoulder surgery were excluded from this study. Any subjects suffering from cardiovascular disease, neurological disorders, or respiratory disease were not included in this study. Subjects were instructed to discontinue upper body lifting exercises three days prior to the initial testing session and between testing sessions.

INFORMATIVE PROTOCOL

This study used a repeated measures crossover design in which participants performed the control and both the experimental conditions. Subjects randomly were chosen to receive either an experimental treatment or control first. Experimental conditions included interval cryotherapy treatments and interval thermal applications in between bouts of endurance exercise for glenohumeral internal and external rotation. The control received no treatment in between identical bouts of endurance exercise. Subjects who completed testing sessions received another randomized treatment condition three or more days following the previous testing session.

All participants were required to come to the laboratory on one occasion before the start of the study. At this time, potential subjects were given a health history questionnaire (Appendix A) in order to determine if they fit all inclusion criteria. Potential participants had vertical skinfold measurements taken directly over the deltoid muscle half the distance from the acromioclavicular joint and the deltoid tubercle.[17] Investigators took three consecutive middle deltoid skinfold measurements by grasping the skin of the participant between the thumb and forefinger and placing the Lafayette Skinfold II (Lafayette Instrument Company, Lafayette, IN) approximately one cm from the thumb and forefinger.[17] The average of the three measurements was recorded and used as the participant's skinfold measurement. In order to achieve higher intra-rater reliability; three measurements were taken, all within one millimeter of each other. In the event a measurement was not within one millimeter, the investigator waited five minutes in order to obtain a measurement again. Once potential subjects met all the inclusion criteria, they were asked to sign an informed consent (Appendix B) before participation in the study. Each subject was then familiarized with the experimental design and isokinetic testing through physical and verbal explanation of glenohumeral internal and external rotation. During this familiarization period, subjects were seated in the testing position and properly aligned in the isokinetic dynamometer. At this time during the informational meeting, subjects completed resistant free repetitions of glenohumeral internal and external rotation while being instructed on proper form when using the isokinetic dynamometer.

Using the Research Randomizer software, subjects were randomly assigned to perform either the treatment or control group first.[39] Each subject was then given an identification number to be inputted in the Biodex Isokinetic Dynamometer (Biodex Medical Services, Shirley, NY) in order for collected data to remain confidential and unbiased. Collected demographic data from the health history questionnaire included age, height, weight, recorded averages of middle deltoid skinfold measurements, and history of previous upper body injuries. All information remained confidential and locked in a designated cabinet in the thesis chair's faculty office within the Jowers Building, room A112. All subjects were blinded from the research hypotheses throughout testing.

EXPERIMENTAL DESIGN

At least three days after the initial informational meeting, subjects returned to the laboratory to perform their respective randomly assigned treatment. Subjects were instructed to discontinue any upper body exercise program between testing sessions. The three days of inactivity between testing sessions was chosen to allow subjects adequate recovery between fatigue tests in order to control for a decline in performance due to delayed onset muscle soreness (DOMS).[5,36,37,40] The dependent variables measured were glenohumeral IR and ER AROM, glenohumeral IR peak torque, glenohumeral ER peak torque, repetitions to 70% max, repetitions to 50% max, total work to 70% max, total work to 50% max.

TESTING PROTOCOL

Subjects were instructed to properly warm-up upper extremities for five minutes using an upper body stationary bicycle. (Figure 1).[26,30,33] Subject's identification number was inputted in the Biodex Isokinetic Dynamometer for later identification in program (Figure 2). Immediately following warm-up, participants were seated and stabilized in the seat of the isokinetic dynamometer with a seat belt across their chest.[30,33] An additional seat belt was also used to stabilize the dominant shoulder to the chair during testing (Figure 3). An ace wrap was wrapped around the elbow while in the armrest of the isokinetic dynamometer for elbow stabilization. The dominant arm was positioned in 90° glenohumeral abduction, elbow fixed at 90° flexion and forearm and wrist in a neutral position. (Figure 3)[26,30,33] Total glenohumeral internal and external rotation active range of motion (AROM) was recorded using the Biodex Isokinetic Dynamometer and used for statistical analysis. Testing was performed with a range of motion of 0-90° of external rotation and 0-65° of internal rotation.[26] During all testing procedures on the isokinetic dynamometer, participants were instructed to keep their back in contact with the seat in order to minimize accessory motion and strength from the trunk. Participants were given consistent verbal explanation and three resistant-free repetitions in order to re-familiarize themselves with the movement being tested.

After subjects were accustomed to the internal and external rotation movements, they were reminded the exercise testing is to be a maximal shoulder internal and external rotation contraction throughout the entire set (Appendix C). Before any treatment was applied, subjects underwent an initial set of 20 repetitions of glenohumeral internal and external rotation. From this initial set, the peak torque of internal rotation was recorded to later determine what torque measurement indicated muscular fatigue.

Subjects randomly selected to receive the control condition first were given four minutes of rest time between sets. Randomized participants receiving interval cryotherapy treatment received a four-minute cryotherapy treatment.[2,6,8,13,16,41,42] Interval cryotherapy treatment consisted of applying 2 plastic bags (17 x 9 in) one-third filled with ice cubes (1/4 x 1/4 x ¼ in). The ice bags were applied to both the anterior and posterior aspect of the shoulder. Ice bag application also included compression from

Chattanooga Nylatex Wraps (Chattanooga Group, Chattanooga, TN). To assure similar ice bag temperature, new ice bags were used every three sets. Participants completing the thermal condition first received a four-minute thermal treatment consisting of a moist hot pack. Fully heated moist hot packs were used after each set. Consistent with all the treatment conditions, once participants completed their respective resting periods, the subject immediately completed additional sets of identical endurance testing.

Sets and interventions continued in identical sequencing until three consecutive repetitions of shoulder internal rotation fall below 50% of peak torque obtained during the first set.[29,31] Since peak torque values are less achievable in the initial two repetitions of each set, the three consecutive repetitions below 50% of initial peak torque values must occur after the two initial repetitions of each set.[30] Once muscular fatigue was reached, the subject was completed with the testing protocol. Three or more days after participants completed the first randomized condition protocol, they returned to the Biomechanics Lab to undergo the next randomized protocol.

Data collection was completed by using the Biodex Isokinetic Dynamometer system. The Biodex system immediately provided data for peak torque and total work on the biofeedback screen. After completion of the fatigue testing, the Biodex system generated a general evaluation specifying total repetitions completed and total work completed within each set. AROM was measured using the Biodex Isokinetic Dynamometer and recorded prior to the initial set of repetitions. Comprehensive evaluations were printed following fatigue testing and AROM values were recorded on a separate subject data collection sheet (Appendix D).

STATISTICAL DESIGN AND ANALYSIS

The physical onset of muscular fatigue during endurance exercise data was tested using a randomized experimental design. Prior to the initial set of endurance testing, no treatment was applied to subjects, therefore there was no influence to peak torque measures. An analysis of variance was used to determine if a difference existed in peak torque measures between subjects prior to receiving treatment.

A two-way repeated measures ANOVA was used to determine the differences among the type of treatments as well as differences between males and females. The dependent variables were AROM, IR peak torque, ER peak torque, number of repetitions to 70% max (Reps70%), number of repetitions to 50% max (Reps50%), total work to 70% max (TW70%), and total work to 50%max (TW50%). The two independent variables were: 1) the type of treatment, either control (normal muscle temperature), cryotherapy (ice bags), or thermotherapy (moist heat packs); and 2) gender. Gender is a between-subjects variable, while the type of treatment is a within-subjects (repeated) variable.

Greenhouse-Geisser epsilon was used to adjust probability values for any variation in sphericity among the treatments. Partial eta^2 was used to determine effect size for each statistical test. Overall statistical significance was defined as $p < .05$, and the Boneferroni adjustment was used to correct the overall alpha level for each post-hoc test.

CHAPTER IV

MANUSCRIPT

Context: Sports medicine professionals typically apply cryotherapy to athletes after exercise for acute injury management and recovery strategies. Interval cryotherapy is reported to slightly decrease muscle temperatures without causing a decrease in muscle performance. Previous authors have primarily investigated small samples of male athletes self-reporting fatigue, without considering measuring fatigue through decreasing torque measurements.

Objective: To determine if interval cryotherapy or interval thermotherapy in between maximal bouts of endurance exercise affects the onset of muscular fatigue or total work performed.

Design: Randomized crossover study.

Setting: Research laboratory.

Patients or Other Participants: A total of 32 healthy physically active adults (age = 21.65 ± 1.69 years, height = 174.70 ± 8.96 cm, mass = 72.05 ± 15.24 kg).

Interventions: Participants performed multiple sets of 20 repetitions of glenohumeral internal rotation (IR) and external rotation (ER) on the Biodex Isokinetic Dynamometer until reaching fatigue. After each set of IR and ER, an interval cryotherapy treatment, thermotherapy treatment, or control was applied for the entire resting period of four-minutes. Participants continued until reaching less than 50% of their baseline peak torque measured in the initial set.

Main Outcomes Measure(s): The dependent variables were AROM, IR peak torque, ER peak torque, number of repetitions to 70% max (Reps70%), number of repetitions to 50% max (Reps50%), total work to 70% max (TW70%), and total work to 50% max (TW50%).

Results: During the interval cryotherapy treatment, the Reps70%, Reps50%, TW70%, and TW50% were significantly higher when compared to both the thermotherapy and control conditions.

Conclusions: Applying interval cryotherapy between bouts of endurance exercise will delay the onset of muscular fatigue and allow for completing more total work at both 70% and 50% levels of fatigue. Additional research on muscular fatigue responses to specific intramuscular temperature change is needed.

Key Words: thermotherapy, isokinetic, torque, work, velocity, shoulder, baseball

Cryotherapy use within sports medicine injury management protocols have been widely used since the early 1950's.[1] Management of acute orthopedic injuries is most the common use of cryotherapy treatments.[1] The recommendation of cryotherapy application by sports medicine professionals are based off of a secondary hypoxic injury theory.[1] This theory demonstrates that cryotherapy decreases the target tissues need for oxygen in order to survive. By decreasing the need for oxygen of the primary tissue injured, the periphery tissues are not required to give up as much oxygen in order to begin the healing process of the primary injury.[1] As a result, the chance of an oxygen deficiency is decreased.[1] Even though the oxygen supply within the target tissue is decreased due to injury, the application of cryotherapy will reduce secondary injury and result in a quicker recovery.[1]

Athletes also sustain microtrauma in anatomical muscle and connective tissue during training, practice, and competition. Most commonly athletes rely on cryotherapy treatments for a recovery strategy between training sessions.[1,3-8] Microtrauma occurs after stress is placed on muscle tissue, so based on the secondary hypoxic injury theory short duration cryotherapy treatments in between exercise bouts seem plausible in aiding in the immediate recovery of muscle. However, due to misunderstood concepts of cryotherapy in research, the most effective cryotherapy parameters and uses are still undefined. It is important to understand the most beneficial parameters and practical uses for cryotherapy in athletics.

Athletes are constantly training, practicing, and competing at high levels of intensity, which result in increases in muscle temperature.[10] Increases in muscle temperature trigger metabolic changes within the muscle causing an accumulation of inflammation and metabolites.[11] The accumulation of inflammation, caused partly by increases in muscle temperature, is one cause for muscle fatigue.[11,34,35] Muscle fatigue, measured by a decrease in muscle force and power capacity, often causes decreases in overall performance including, endurance, strength, speed, and agility.[12,34] Clinically, muscle fatigue is often measured by a decrease in force output below 50% of initial peak torque values, however even after muscular fatigue is reached, muscles are still capable of submaximal contractions.[29,31] Even after intense exercise, deficits in muscular power and force output occur from a physiological response known as DOMS.[5,36,37] Delayed onset muscle soreness develops in muscle cells from an accumulation of inflammation caused by microscopic tears in connective tissue.[36] The increased inflammation causes a heightened awareness to nociceptors resulting in an increased sensation of pain, delaying muscle recovering.

One method for decreasing recovery time between exercise sessions is to perform cryotherapy treatments to aid in the decrease of inflammation accumulation. Cryotherapy treatment lowers tissue temperature predominantly through conduction.[13] Cold application to localized skin results in a reduction of blood flow, accumulation of inflammation, and a reduction in the muscle cells need for oxygen to survive.[1,5,14] Decreasing the muscles need for oxygen resulted in diminished secondary tissue death caused from oxygen deprivation.[1,5,14] Limiting secondary tissue death decreased the muscular damage causing a direct decrease in recovery time needed between exercise sessions. Even though the physiological effects of cryotherapy are well understood, very few studies provide evidence to the necessary duration in order to achieve these physiological changes. [4,6,8,13,16]

In order to determine the proper duration of cryotherapy treatments, the desired change in intramuscular temperature must be known. Several factors that influence the necessary treatment duration are the use of compression, type of cryotherapy mode, and thickness of adipose tissue. The most effective combination of cryotherapy treatment includes use of compression, ice cubes, and areas of minimal adipose tissue.[4,6,8,13,16] Compression during cryotherapy treatments limits the formation of edema due to an increase in external pressure.[6] Ice cubes, although not the coldest mode of cryotherapy, provide more of a cooling effect to intramuscular tissue due to an abundance of heat conduction compared to that of colder chemical forms of cryotherapy.[4,13] Areas with skinfold measurements of 20mm or less are shown to decrease muscle temperature at the same speed when using consistent modes of cryotherapy treatments.[8]

Researchers have provided evidence that prolonged applications of cryotherapy reduce the secondary hypoxic injury by causing several physiological responses in muscle connective tissue.[1,5,6,8,13-15] Long duration cryotherapy treatments has been shown to be beneficial to the decrease in recovery time, the same treatments are also proven to decrease cell metabolism, blood flow, and nerve conduction velocity, resulting in decreased muscle strength, muscle force production, velocity, and power.[1,5,14] Even though prolonged cryotherapy treatments limit the accumulation of inflammation, at the cost of decreased performance, very few studies provide evidence in the effectiveness of interval cryotherapy.

Interval cryotherapy is characterized by frequent short duration applications in between subsequent bouts of exercise. Limited research has concluded short duration applications of cryotherapy can slightly lower muscle temperature and have an effect on delaying muscular fatigue.[2] Verducci found slightly colder muscle temperatures last significantly longer work periods when compared to higher muscular temperatures.[2] Decreased muscle temperatures and performance variables creates a slight decrease in intramuscular temperature has no effect on isokinetic strength or performance components such as muscle power, speed, and agility.[4,14]

In contradiction to the idea of using cryotherapy in between exercise, today's athletes most commonly apply heat as a modality in between bouts of exercise. For example, a baseball pitcher commonly applies moist hot packs between innings. The belief that a mild heating effect increases a muscles ability to optimally perform may be why athletes routinely use this type of thermal therapy. The use of heat is most commonly used before and during exercise in attempts to maintain an increased temperature of muscular tissue. Knowing substantial increases in muscle temperature will result in decreased muscle endurance performance; it brings up a controversial question to which modality may actually benefit our athletes the most. Therefore, the purpose of this study was to examine whether interval cryotherapy or interval thermotherapy treatments delay the onset of muscular fatigue and maintain higher force outputs in between maximal endurance bouts of internal and external glenohumeral rotation.

METHODS

Experimental Design to the Approach

Using a Research Randomizer[39] program, subjects were randomly assigned to a subject number, which was associated with a randomized treatment order including interval cryotherapy, interval thermotherapy, and control. Subjects completed their respective treatment order with at least 72 hours between each testing session. The two independent variables were: 1) the type of treatments, cryotherapy, thermotherapy, and control and 2) gender. The dependent variables were AROM, IR peak torque, ER peak torque, repetitions to 70% max, repetitions to 50% max, total work to 70% max, and total work to 50% max. It was hypothesized that interval cryotherapy treatments would result in significantly more repetitions until fatigue and a significantly greater amount of work completed when compared to both the control and thermotherapy treatment.

Participants

Forty-one healthy participants were screened from the student population at Texas State University, and thirty-two met the inclusion criteria to participate in this study. We examined all n=32 (men = 16, women = 16; age = 21.65 ± 1.69 years, height = 174.70 ± 8.96 cm, mass = 72.05 ± 15.24 kg of the eligible participants. Descriptive statistics are presented in (Table 1). Participants were college aged subjects with experience in resistance training by meeting ACSM guidelines of resistance training major muscle groups two or more times each week.[23] All participants voluntarily joined the study and completed all testing procedures. Any subject that sustained an injury throughout the study were dropped from the data collection. Subjects were randomly assigned to different treatment orders to limit a learning effect from one testing session to another and eliminate bias. Each subject was in good overall health and capable of completing glenohumeral IR and ER isokinetic testing at 300°/s, which was based on an inclusion survey (Appendix A) and a short familiarization session prior to testing.

Table 1. Participants Demographics

Variable	*Subjects*	*Mean*	*Std. Dev.*	*Min*	*Max*
AGE (years)	32	21.65	1.70	19	26
HEIGHT (cm)	32	1.747	.089	1.574	1.981
MASS (kg)	32	72.06	15.24	49.83	106.46
SKINFOLD (mm)	32	12.98	3.29	5	19
AROM (degrees) CONTROL	32	202.41	16.84	156	232
AROM (degrees) CRYOTHERAPY	32	201.06	15.77	162	230
AROM (degrees) THERMAL	32	203.78	14.33	165	227

Figure 1. Upper Body Stationary Bicycle

Participants were recruited through mass e-mails, flyers placed around campus, athletic training classes, exercise and sports science classes and the student recreational center. Volunteers were included if they were physically active according to the American Heart Association, regularly participated in resistance training, were willing to discontinue upper body resistance training throughout testing, and experience no known contraindications to cryotherapy, thermotherapy, or intense exercise.[38] Volunteers were excluded if they have had underwent a dominant-arm shoulder surgery, experienced a dominant-arm shoulder injury within the past six months, had a dominant-arm middle deltoid skinfold greater than 20mm, or suffered from any cardiovascular, neurological, or respiratory disorders. The dominant upper extremity, which was defined as the extremity with which the participant would throw a ball, was tested for each participant. All participants provided written informed consent, and the Texas State University Institutional Review Board (IRB) approved this study.

Testing Procedures

Subjects were instructed to properly complete an upper extremity warm-up for five minutes using an upper body stationary bicycle (Figure 1).[26,30,33] The warm-up was completed with at 50% maximum resistance at a speed between 60-70 repetitions per minute. Following the warm-up, participants were instructed to sit in the seat of the

Figure 2. Biodex Isokinetic Dynamometer

Biodex Isokinetic Dynamometer (Biodex Medical Services, Shirley, NY) and were then stabilized in the seat using two seat belts across each shoulder and one across their waist (Figures 2 and 3).[30,33] The dominant arm was positioned in 90° glenohumeral abduction, elbow fixed at 90° flexion and forearm and wrist in a neutral position (Figure 3).[26,30,33] To ensure the dominant arm remained stabilized and secure throughout testing, an ace wrap was wrapped around the elbow and armrest of the isokinetic dynamometer. Prior to each experimental testing, AROM was measured using the Biodex Isokinetic Dynamometer and used for statistical analysis.

Figure 3. Shoulder Testing Position/Stabilization

After AROM measurements were taken, the ROM limits for each testing session were set to 0-90° of external rotation and 0-65° of internal rotation.[26] Subjects were instructed to reach the ROM limit throughout testing as well remain in contact with the back of the seat and minimize trunk and accessory motion during testing procedure.

After subjects were accustomed to the isokinetic glenohumeral IR and ER movements at 300°/s, they were reminded the exercise testing is to be a maximal contraction for every repetition within the entire set (Appendix C). Before any treatment was applied, subjects performed an initial set of 20 repetitions of glenohumeral IR and ER at 300°/s through a ROM limit set at 0-90° ER and 0-65° IR in order to record their respective IR and ER peak torque. The peak torque measure was used to later determine what torque measure defined fatigue. Each subject received the same verbal encouragement for each condition throughout the entire isokinetic testing (Appendix C). Subjects were reminded every repetition was a maximal effort prior to beginning the testing. At repetitions 10 and 15, subjects received specific verbal cues to continue giving maximal effort for each repetition. Immediate visual feedback was provided for each subject in all conditions, as they were able to watch the Biodex computer screen revealing the torque for each repetition completed.

After the initial baseline set of IR and ER repetitions, each subject was given four minutes of resting time before completing additional sets of the exact same parameters. In between sets of the maximal effort isokinetic glenohumeral IR and ER repetitions, subjects received their respective random condition. Control groups received no treatment during the four minutes of rest time between sets. The interval cryotherapy and thermotherapy treatments both received a four minute application of their respective treatment during the resting time.[2,6,8,13,16,41,42]

Interval cryotherapy treatments consisted of applying 2 plastic bags (17 x 9 in) one-third filled with ice cubes (¼ x ¼ ¼ in). The ice bag application was applied to both the anterior and posterior aspect of the shoulder. Compression was applied to ice bags using Chattanooga Nylatex Wraps (Chattanooga Group, Chattanooga, TN). To assure ice bag temperature remained consistent, new ice bags were used every third set. The thermotherapy condition received a moist hot pack during the four-minute resting period. Fully heated moist hot packs were used after each set to ensure consistent temperature.

For all conditions, after the four-minute resting period, subjects immediately returned to completing additional sets of isokinetic testing with identical parameters to the initial set completed. After each set of IR and ER, subjects continued to receive their respective treatment, followed by additional sets of endurance exercise until the subject reached muscular fatigue. Muscular fatigue was defined at reaching three consecutive repetitions below 50% of the initial peak torque measure.[29,31] Due to a delay in maximal muscle contractions, the three consecutive repetitions below 50% of the initial peak torque must take place after the first two repetitions of each set. Once each subject reached muscular fatigue, that respective testing condition was complete. Participants were scheduled to complete their next randomized treatment 72 hours or more after completing their last testing session.

Data collection was accomplished by using an evaluation tool within the Biodex Isokinetic Dynamometer system. This system provides immediate measurements on peak torque and total work completed on the biofeedback screen. Each subject had their respective number of repetitions recorded when they reached two different levels of fatigue based off of their respective peak torque from the baseline set. The repetitions completed were recorded when the subject reached a level of 70% and 50% of their baseline peak torque measure. After completion of each fatigue testing, the Biodex system generates a comprehensive evaluation specifying total work completed within each set. At this time, total work was recorded by calculating work completed in every repetition until reaching both the 70% and 50% fatigue levels. AROM values were recorded on subject data collection sheets and comprehensive evaluations were printed for each set completed (Appendix D).

Statistical Design and Analysis

The physical onset of muscular fatigue during endurance exercise data was tested using a randomized experimental design. Prior to the initial set of endurance testing, no treatment was applied to subjects, therefore there was no influence to peak torque measures. An analysis of variance was used to determine if a difference existed in peak torque measures between subjects prior to receiving treatment.

A two-way repeated measures ANOVA was used to determine the differences among the type of treatments as well as differences between males and females. The dependent variables were AROM, IR peak torque, ER peak torque, number of repetitions to 70% max (Reps70%), number of repetitions to 50% max (Reps50%), total work to 70% max (TW70%), and total work to 50% max (TW50%). The two independent variables were: 1) the type of treatment, either control (normal muscle temperature), cryotherapy (ice bags), or thermotherapy (moist heat packs); and 2) gender. Gender is a between-subjects variable, while the type of treatment is a within-subjects (repeated) variable. Greenhouse-Geisser epsilon was used to adjust probability values for any variation in sphericity among the treatments. Partial eta^2 was used to determine effect size for each statistical test. Overall statistical significance was defined as $p < .05$, and the Boneferroni adjustment was used to correct the overall alpha level for each post-hoc test.

RESULTS

Table 2 reports the descriptive values across treatments, both overall and for each gender. For AROM, repeated measures ANOVA indicated no significant differences among treatments, Greenhouse-Geisser epsilon = 0.93, $F(2, 60) = 0.8$, $p = 0.44$, partial eta^2 = 0.026, a small effect. There was no significant differences in AROM between males and females, $F(1,30) = 1.7$, $p = 0.20$, and no interaction between gender and treatment, $F(2, 60) = 0.3$, $p = 0.73$, partial eta^2 = 0.010, another small effect.

Table 2. Sample Means and Standard Deviations

Variable	*Subjects*	*Mean*	*Std. Dev.*	*Min*	*Max*
IR PEAK TORQUE (nm) CONTROL	32	50.75	16.46	13	86
IR PEAK TORQUE (nm) CRYOTHERAPY	32	48.72	13.73	16	81
IR PEAK TORQUE (nm) THERMAL	32	49.13	16.68	14	81
ER PEAK TORQUE (nm) CONTROL	32	39.47	10.74	12	60
ER PEAK TORQUE (nm) CRYOTHERAPY	32	37.97	10.71	13	69
ER PEAK TORQUE (nm) THERMAL	32	35.81	12.47	5	59
REPS 70% FATIGUE CONTROL	32	93.41	58.25	26	209
REPS 70% FATIGUE CRYOTHERAPY	32	142.72	101.56	26	460
REPS 70% FATIGUE THERMAL	32	85.19	70.49	26	359
REPS 50% FATIGUE CONTROL	31	174.42	112.63	27	497
REPS 50% FATIGUE CRYOTHERAPY	32	262.88	147.28	93	600
REPS 50% FATIGUE THERMAL	32	161.97	121.11	26	477
WORK 70% (J) CONTROL	32	9611.01	7782.04	1187.50	27002.50
WORK 70% (J) CRYOTHERAPY	32	14697.11	15120.62	914.90	57693.10
WORK 70% (J) THERMAL	32	8899.90	9921.19	531.70	41705.50
WORK 50% (J) CONTROL	31	16271.15	14164.05	1385.00	54832.10
WORK 50% (J) CRYOTHERAPY	32	24760.30	22252.26	2891.70	82529.90
WORK 50% (J) THERMAL	32	15817.10	16343.00	531.70	54321.40

Peak Torque

For IR peak torque, no significant differences among treatments were observed, Greenhouse-Geisser epsilon = 0.97, $F(2, 60) = 2.6$, $p = 0.08$, partial $eta^2 = 0.080$, a moderate effect. There was a significant difference in IR peak torque between males and females, $F(1,30) = 41.8$, $p < .0001$, but no interaction between gender and treatment, $F(2, 60) = 2.7$, $p = 0.08$, partial $eta^2 = 0.046$, a moderately small effect. Males had significantly higher IR peak torque values than females for each of the three treatments, but there were no significant treatment differences between males and females.

For ER peak torque, no significant differences among treatments were observed, Greenhouse-Geisser epsilon = 0.81, $F(2, 60) = 2.0$, $p = 0.15$, partial $eta^2 = 0.063$, a moderate effect. There was a significant difference in ER peak torque between males and females, $F(1,30) = 18.8$, $p = 0.0002$, but no interaction between gender and treatment, $F(2, 60) = 0.8$, $p = 0.45$, partial $eta^2 = 0.025$, a small effect. Again, males had significantly higher ER peak torque values than females for each of the three treatments, but there were no significant treatment differences between males and females.

Muscle Fatigue

For Reps70%, a significant difference among treatments was observed, Greenhouse-Geisser epsilon = 0.96, $F(2, 60) = 16.1$, $p < .0001$, partial $eta^2 = 0.349$, a very large effect. Post-hoc tests indicated that the cryotherapy treatment (142.7 ± 18.0 reps) resulted in a significantly greater number of repetitions compared to the thermal treatment (85.2 ± 12.5 reps). Post-hoc tests indicated that the cryotherapy treatment also resulted in a significantly greater number of repetitions compared to the control (93.4 ±

10.3 reps), t(31)= -4.1, $p < .0001$, but the control did not differ significantly from the thermal treatment, t(31)= 0.8, p =0.22. This effect is demonstrated in (Figure 4). There was also a significant difference in Reps70% between males and females, $F(1,30) = 24.9$, $p < .0001$, but no interaction between gender and treatment, $F(2, 60) = 2.2$, $p = 0.12$, partial $eta^2 = 0.068$, a moderate effect. Males had significantly more repetitions to 70% max than females for each of the three treatments, but there were no significant treatment differences between males and females.

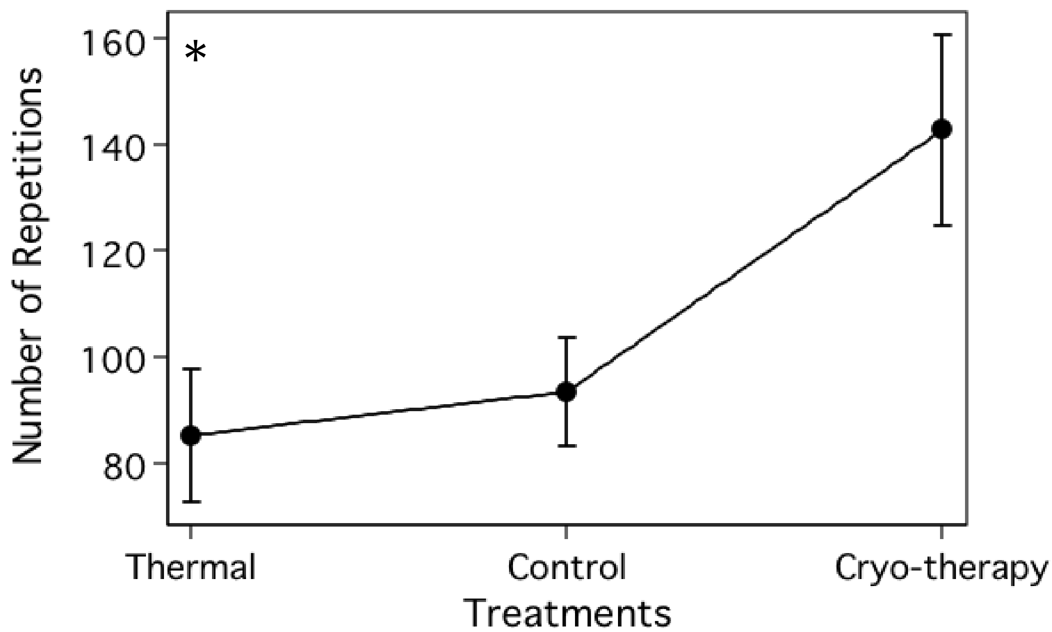

Figure 4. Treatment Effect for Repetitions to 70% max

For Reps50%, a significant difference among treatments was observed, Greenhouse-Geisser epsilon = 0.91, $F(2, 59) = 37.4$, $p < .0001$, partial $eta^2 = 0.559$, another very large effect. The sample means again indicate that the cryotherapy treatment (255.2 ± 25.7 reps) resulted in a significantly greater number of repetitions compared to the thermal treatment (153.6 ± 20.4 reps). Post-hoc tests indicated that the cryotherapy treatment also resulted in a significantly greater number of repetitions compared to the control (174.4 ± 20.2 reps), $t(30) = -5.4$, $p < .0001$, but the control did not differ significantly from the thermal treatment, $t(30) = 1.96$, $p = 0.029$ after adjusting the individual alpha level to 0.025. This effect is demonstrated in (Figure 5). There was a significant difference in Reps50% between males and females, $F(1,30) = 28.2$, $p < .0001$, but no interaction between gender and treatment, $F(2, 59) = 3.2$, $p = 0.06$, partial $eta^2 = 0.098$, a moderate effect. Again, males had significantly more repetitions to 50% max than females for each of the three treatments, but there were no significant treatment differences between males and females. This effect is demonstrated in (Figure 5).

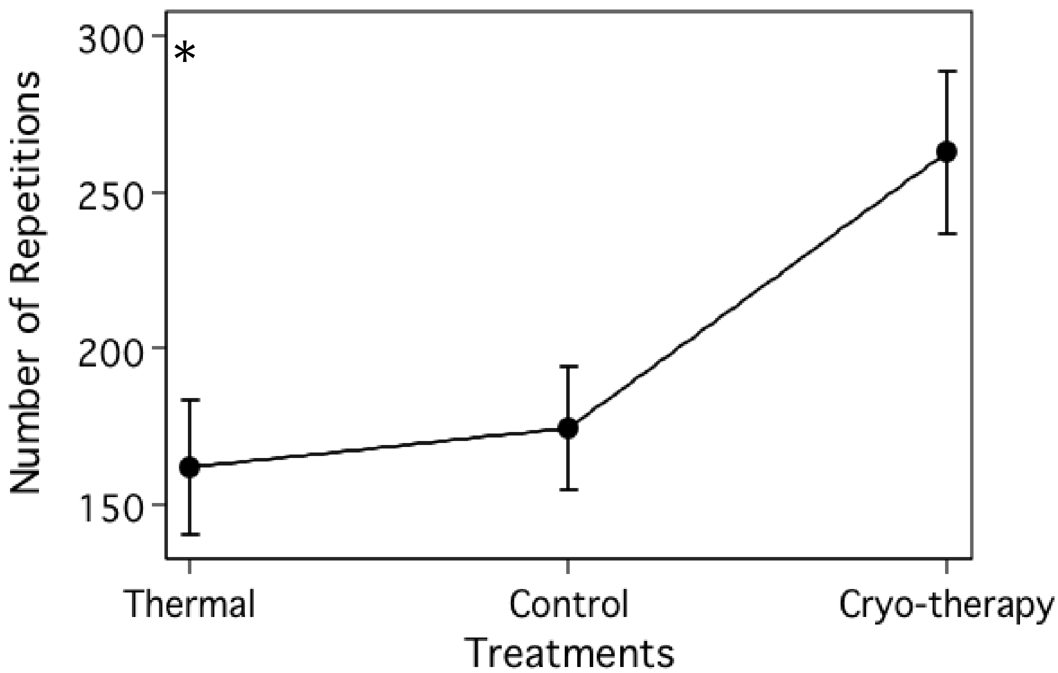

Figure 5. Treatment Effect for Repetitions to 50% max

Force Output

For TW70%, another significant difference among treatments was observed, Greenhouse-Geisser epsilon = 0.82, $F(2, 60) = 11.7$, $p = 0.001$, partial $eta^2 = 0.280$, a large effect. The sample means indicate that the cryotherapy treatment (14697.1 ± 2673.0 Joules) resulted in a significantly greater total work to 70% max compared to the thermal treatment (8899.9 ± 1753.8 J). Post-hoc tests indicated that the cryotherapy treatment also resulted in a significantly greater TW70% compared to the control (9611.0 ± 1375.7 J), $t(31) = -3.0$, $p = 0.003$, but the control did not differ significantly from the thermal treatment, $t(31) = 0.7$, $p = 0.26$. There was a significant difference in TW70% between males and females, $F(1,30) = 41.0$, $p < .0001$, and also a significant interaction between gender and treatment, $F(2, 60) = 5.6$, $p = 0.01$, partial $eta^2 = 0.157$, a large effect. This effect is validated in (Figure 6).

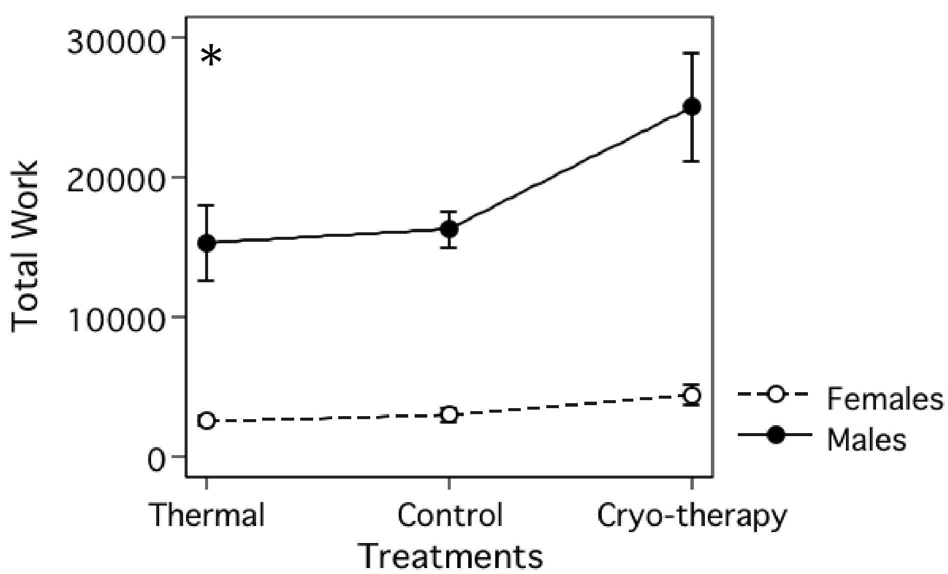

Figure 6. Gender Effect Across Treatments for Total Work to 70% max

Figure 6 also demonstrates that males had significantly greater TW70% values than females, but there was also a significant treatment difference between males and females. Post-hoc tests indicate that there was no significant gender effect in the difference between the control versus thermal treatments, $t(30) = 0.24$, $p = 0.80$, nor in the difference between the control versus cryotherapy treatments, $t(30) = 2.3$, $p = 0.028$ when the individual alpha level was adjusted to 0.0167. However, there was a significant gender effect in the difference between the cryotherapy and thermal treatments $t(30) = 3.25$, $p = 0.003$. There was a significantly greater difference between the cryotherapy (24999.8 ± 15418.3 J) and thermal (15281.9 ± 10707.5 J) treatments in males, a difference of 9717.9 Joules, than the difference between the cryotherapy (4394.4 ± 2887.9 J) and thermal (2517.9 ± 1371.3 J) treatments in females, a difference of only 1876.5 Joules.

For TW50%, a significant difference among treatments was observed, Greenhouse-Geisser epsilon = 0.75, $F(2, 59) = 17.4$, $p < .0001$, partial $eta^2 = 0.371$, a very large effect. The sample means indicate that the cryotherapy treatment (23504.5 ± 3850.1 J) resulted in a significantly greater total work to 50% max compared to the thermal treatment (14575.0 ± 2694.0 J). Post-hoc tests indicated that the cryotherapy treatment also resulted in significantly greater TW50% compared to the control (16271.1 ± 2543.9 J), $t(30)= -3.3$, $p = 0.001$, but the control did not differ significantly from the thermal treatment, $t(30)= 1.4$, $p = 0.08$. There was a significant difference in TW50% between males and females, $F(1,30) = 46.7$, $p < .0001$, and also another significant interaction between gender and treatment, $F(2, 59) = 7.0$, $p = 0.005$, partial $eta^2 = 0.192$, a large effect. Males had significantly greater TW50% values than females, but there was also another significant treatment difference between males and females. Post-hoc tests indicate that there was no significant gender effect in the difference between the control versus thermal treatments, $t(29) = 0.41$, $p = 0.68$, nor in the difference between the control versus cryotherapy treatments, $t(29) = 2.51$, $p = 0.018$ when the individual alpha level was adjusted to 0.0167. However, there was a significant gender effect in the difference between the cryotherapy and thermal treatments $t(29) = 3.48$, $p = 0.002$. It appears that there was a significantly greater difference between the cryotherapy (41455.1 ± 20434.9 J) and thermal (27080.6 ± 16522.8 J) treatments in males, a difference of 14374.5 units, than the difference between the cryotherapy (8065.5 ± 3339.9 J) and thermal (4553.6 ± 2888.8 J) treatments in females, a difference of only 3511.9 units. This effect is demonstrated in (Figure 7).

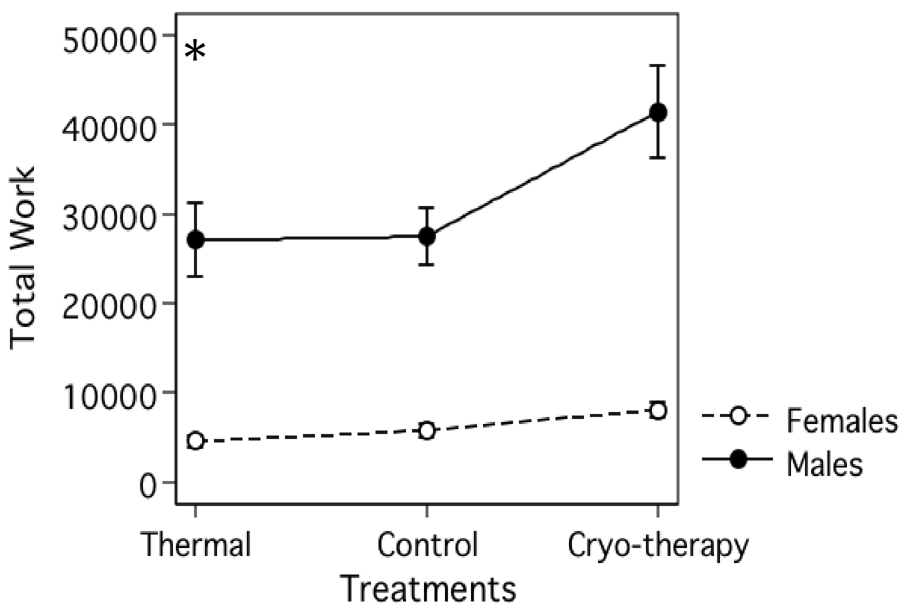

Figure 7. Gender Effect Across Treatments for Total Work to 50% max

DISCUSSION

The justification for this study was that exercise rapidly increases muscular temperature through increased metabolic reactions.[1,2] The results of this study suggest that eventually, this increased muscular temperature will hinder the capacity to maintain constant work loads. Heat production throughout exercise is capable of increasing a normal resting muscle temperature of 35 ± 2.0°C to as high as 45°C.[10.43] In order to maintain homeostasis, the body must rapidly adjust to the increases of heat by increasing overall heat loss.[44] Evaporation, convection, and radiation are the major pathways of heat loss in the body during exercise, as conduction results in an extremely small amount of heat loss.[1,45,46] Cryotherapy creates conductive heat loss, so allowing the body another mechanism of heat loss may aid other therapeutic methods of overall reduction to decrease muscle temperatures to more appropriate levels during exercise.

Prior to applying any treatment, IR and ER peak torque values were taken by completing the first initial set of isokinetic testing. IR and ER peak torque values were consistent among all treatment conditions, as no significant difference existed between each condition regardless of testing order. This indicates each subject performed a consistent maximal effort for each condition in which they were tested. Having no significant difference among initial peak torque values between each condition suggests that 72 hours between testing sessions was enough time to limit decreases in peak torque caused by DOMS.

Thermotherapy treatment between sets of isokinetic glenohumeral IR and ER on the Biodex Isokinetic Dynamometer produced the least amount of repetitions and total work at both 70% and 50% levels of fatigue, but was not significantly different as compared to the control trials. Moist hot packs were considered a superficial heat source, which may be the rationale for no significant differences in total repetitions and total work occurring between the thermotherapy and control condition. Since the moist heat packs are considered a superficial heating source, the thermotherapy treatment duration may not have been to short to see increases in muscle temperatures that would effect total repetitions and total work performed. In contrast, previous research on the effectiveness and depth of cryotherapy treatments were correct in assuming the four-minute duration of cryotherapy would reach the depth of the rotator cuff muscles. This logic can be seen in our study by the interval cryotherapy application resulting in a significant increase in both repetitions until fatigue and total work completed when compared to the control and thermotherapy conditions.

Cryotherapy treatments between isokinetic exercise did significantly increase the number of repetitions completed when compared to both the control and thermotherapy treatments. This is in agreement with the hypothesis and suggests that slightly decreased muscle temperatures create a better working environment for muscles to work for longer durations during endurance exercise than normal or increased muscle temperatures. As previous research agrees, short duration cryotherapy treatments were effective at decreasing intramuscular temperature to aid in recovery between sets of maximal effort endurance exercise.[1,2,5,6,14,16,42]

When comparing cryotherapy to the control and thermotherapy treatments, cryotherapy application had significant increases in both total repetitions to 70% and 50% fatigue for both genders, as well as having no significant gender effect between all the treatments. This suggests that males and females were both alike with receiving the benefits of cryotherapy between sets of exercise. This indicates the benefits of cryotherapy on reducing fatigue is not effected by the endurance capability of the athlete, considering males had a significantly higher amount of completed repetitions compared to females for both 70% and 50% levels of fatigue. No matter how many sets of endurance exercise an athlete can complete, our study has demonstrated cryotherapy to delay the onset of muscle fatigue when compared to normal and increased muscle temperatures.

The cryotherapy treatment was significantly effective for both levels of fatigue, 70% and 50%, since subjects performed more work when compared to the control and thermotherapy treatments. This indicates that interval cryotherapy allows athletes to maintain higher levels of force output. Cryotherapy treatments were shown to have higher work outputs over the course of a maximal effort isokinetic endurance exercise. This result demonstrates that not only has cryotherapy delayed the onset of fatigue through increased repetitions completed, but also each repetitions maintained higher force outputs throughout the duration of the exercise until fatigue is reached.

Both male and female subjects did significantly perform more total work during the cryotherapy treatment when compared to the control and thermotherapy conditions. Male participants however, demonstrated significantly higher values for total work at both 70% and 50% levels of fatigue when compared to female subjects. Even though both genders seen statistically significant increases in total work output from the cryotherapy condition, compared to the control and thermotherapy conditions, a significant treatment difference between males and females existed. There was no significant gender effect in the difference between the control and thermotherapy nor the control versus cryotherapy treatments. However, the significant gender difference existed between the cryotherapy and thermotherapy treatments. Cryotherapy had a greater effect on male participants in total work performed than female participants. Based off of prior knowledge of average female athlete's endurance levels being higher than males, this suggests that the males in this study may have had higher endurance capacities than the females. This could have been due to the sample size within this study that resulted in a greater percentage of males who had better initial training statuses.

Even though males, who performed more sets and repetitions, saw a greater benefit of cryotherapy treatments due more applications prior to reaching fatigue, total work is based off of total repetitions and torque applied for each repetition, so naturally males who have more strength will out perform female subjects. Female subjects, who performed less total repetitions, however still benefitted from cryotherapy treatments when compared to all other conditions. This raises the question that if an athlete were able to perform longer durations of maximal effort endurance exercise, if they would continue to see greater benefits from the cryotherapy treatment in performing more total work.

Theoretically the slight decrease in muscle temperature caused a decrease in the inflammatory response associated with increased muscle temperature caused by exercise.[1] As muscle tissue is stressed through exercise, microtrauma within the muscle occurs resulting in an increase in inflammatory responses in order to supply more oxygen to the micro tears.[1] When they cryotherapy is applied, the muscles decrease demand for oxygen limits an oxygen deficiency within the injured cells.[1] This decreased inflammatory response may immediately aid in the muscles ability to recover more quickly, resulting in a delayed onset of muscular fatigue.[1]

CONCLUSIONS

Practical Applications

This study demonstrated that cryotherapy application in between maximal effort endurance exercise delays the onset of fatigue and maintaining high levels of force output throughout exercise until fatigue is reached. Interval cryotherapy offers the same benefits of acute recovery in between sets of exercise as it would between training sessions. Interval cryotherapy relies on the basis of slightly decreasing muscle temperature to a more appropriate temperature that limits the inflammatory response resulting in delayed fatigue, while still maintaining a proper temperature that does not decrease performance components.

For generations, baseball pitchers were using heat or mild heating effects to keep their arms warm in between innings. In contrast to this belief, interval cryotherapy has been shown to delay the onset of muscular fatigue in between bouts of maximal effort endurance exercise. The concept of interval cryotherapy should be implemented in several areas of athletics, especially baseball. By applying interval cryotherapy, pitchers who perform maximal effort pitches throughout the course of a game could see a benefit of increased repetitions while maintaining torque. The interval cryotherapy parameters seen in this study could easily fit within the game of baseball, as pitchers can perform their repetitions during their pitching performance and complete a cryotherapy treatment during the other half of the inning.

Another practical application for this type of treatment could be seen during training sessions for all athletes. As athletes perform heavy loads of resistance training, they could be applying cryotherapy treatments in between exercises to allow for quicker muscle recovery. By allowing for quicker recovery of a muscle between exercises, athletes may be able to train for longer durations while maintaining a higher torque throughout their workouts. Depending on a specific training goal, athletes who can train muscles for a longer duration at higher intensities, may see quicker and greater gains in muscle strength, power, agility, or speed.

This study only looked at delaying muscle fatigue through decreasing muscles need for oxygen and limiting acute inflammation build up from exercise. Muscle fatigue encompasses numerous other factors that are highly difficult to pinpoint which mechanism is causing the muscle to fatigue. It is important for athletic trainers, strength coaches, and athletes to understand acceptable parameters for interval cryotherapy, and other factors that may impact muscle fatigue during exercise.

CHAPTER V

CONCLUSION AND RECOMMENDATIONS FOR FURTHER STUDY

The purpose of the study was to determine the effect of muscle temperature on the onset of muscular fatigue during maximal effort endurance exercise. The results suggest that interval cryotherapy application in between sets of endurance exercise prolong the onset of muscle fatigue and allow for more muscular torque until muscular fatigue is reached. The benefits of interval cryotherapy were seen in both genders, however male participants significantly benefitted more than females by performing more total work than the control and thermotherapy conditions. This might suggest that the longer duration of exercise, with use of interval cryotherapy, the greater the benefits of performing an increased amount of work. However, the delay in the onset of muscle fatigue does not depend on the duration of exercise as both genders seen very large improvements in total repetitions completed when receiving cryotherapy treatments between exercise sets.

This investigation has enhanced what is already known about cryotherapy treatments and has had an impact on the future research of the use of interval cryotherapy in between sets of endurance exercise. This research allowed advancement of the literature by providing new concepts of thermotherapy being a detriment to delaying muscle fatigue. By incorporating an interval cryotherapy treatment protocol in between sets of endurance exercise, this investigation has furthered any previous knowledge about delaying the onset of fatigue.

For future investigations, measuring actual muscle temperature during exercise could provide additional research information. Knowing the specific rise and decline of muscle temperature during exercise with application of interval cryotherapy treatments could provide additional value to this research. By investigating the most effective ranges of muscle temperature researches can better understand the most appropriate cryotherapy parameters in order to reach these ranges. Additionally, investigating interval cryotherapy use between sport-specific exercises may lead to different findings. Representing the throwing motion on the Biodex through maximal effort IR and ER were beneficial in isolating the rotator cuff, however a sport-specific movement incorporates several joint movements and muscle contractions.

The application of interval cryotherapy during resistance training needs to be addressed in future research as well. Considering maximal effort endurance exercise is not the only exercise performance goal, additional factors need to be investigated. For instance, strength gains usually involve a lower number of repetitions per set, slower exercise speeds, and shorter resting periods, when compared to the testing parameters studied in the current investigation at 20 repetitions per set at a velocity of 300°/s with four minute resting periods. Further research must be conducted to determine if these benefits exist when changing resistance-training parameters.

Even though this study demonstrates that interval cryotherapy delays the onset of muscular fatigue and allows for more total work to be performed, it is uncertain if repeated cryotherapy treatments will effect ROM. Determining if interval cryotherapy application will result in a decrease in ROM during exercise is important to consider. Another important factor to investigate is the risk of injury when applying interval cryotherapy between exercise bouts. Since interval cryotherapy results in an increased number of repetitions before fatigue, it is important to determine if this increase in performance would affect the risk of overuse injuries.

Due to the numerous factors that cause muscle fatigue during exercise, understanding the main cause of fatigue remains extremely unclear. Even after revealing the significance of cryotherapy aiding in delayed muscle fatigue, performances are affected by several other factors, such as initial muscle temperature, proper functioning and biomechanical movements of joints, atmospheric temperature, cryotherapy benefits of pain reduction, substance depletion for suitable muscle contraction, reduction in secondary hypoxic injuries, central nervous system responses, or a combination of any of these. In order to clarify the unknowns of muscle fatigue, researchers need to consider these numerous variables and factors that encompass muscle temperature and fatigue.

APPENDIX SECTION

APPENDIX A

Name:______________________

Date:____________

Cryotherapy Subject Inclusion Survey

1. Have you ever had a shoulder surgery?
   Yes No

2. Have you had a shoulder injury within the past six months?
   Yes No
   If yes, when and what type of injury?

3. Are you currently participating in a regular upper body strength workout?
   Yes No

4. Are you willing to discontinue your regular upper body strength workout for 12 days to participate in this study?
   Yes No

5. Please fill in the demographic information:
   Age:

   Height:

   Weight:

6. Do you experience any contraindications to cryotherapy treatment?
   (Any conditions that does not allow you to apply ice to your skin)
   Yes No

7. Do you experience any balance or proprioception (body awareness) deficiencies?
   Yes No
8. Are you able to perform multiple sets of endurance resistance exercises?
   Yes No

9. Do you suffer from any cardiovascular, neurological, or respiratory diseases?
   Yes No

10. Are you physically active?
    (30min of moderate exercise 5x/week; 20min vigorous activity 3x/week)
    Yes No

-For Office Use Only-
Measured Middle Deltoid Skinfold ______cm ______cm ______cm
Average Middle Deltoid Skinfold ______cm

APPENDIX B

CONSENT FORM

Casey Meyer, graduate assistant athletic trainer at Texas State University is conducting a research study to determine the effectiveness of interval cryotherapy application on fatigue in between endurance exercise bouts. Cryotherapy is a cold therapy commonly used in sports medicine to decrease pain, inflammation, and cell metabolism by causing declining soft-tissue temperature. This research study will not be funded by any outside source. You are being asked to participate in this study.

As part of the study, your participation will be crucial to correctly examining the effect of interval cryotherapy on fatigue in physically active healthy adults. Principle investigators will collect common demographic information, such as age, height, and weight. Subjects will be positioned on the Biodex Isokinetic Dynamometer to complete 20 repetitions per set of endurance exercise bouts of shoulder internal and external rotation. In between exercise sets, either the experimental treatment or control will be completed. During this time, the principle investigator will record peak torque measures from the first set of repetitions completed. Subjects will continue endurance exercise bouts until internal rotation torque levels fall beneath 50% for three consecutive repetitions. Subjects will meet with the principle investigator for three total sessions to complete the interval cryotherapy, thermal intervention, and control groups. Subjects will be randomly assigned to complete either the control or experimental groups first. Participants may only be included in this study if they are capable of completing the experimental protocol.

Participating in this study does pose some minor risks, but they are quite minimal. Risks include, minor pain, joint swelling, bruising, muscle fatigue, possible musculoskeletal injury, possible ligamentous injury, and muscle soreness. The principle investigator is a certified athletic trainer who is educated in the prevention, evaluation, and treatment of orthopedic injuries in addition to being certified first responders. In a rare case a severe injury happens, the subject will be liable for medical expenses. I feel this study poses no psychological or emotional risks to subjects because all subjects are physically active adults with exercise experience.

As a result of your participation in this study, you will also be exposed to some benefits. Benefits of participating in this research study include: knowledge in research studies and endurance strength testing, possible gains in shoulder muscular strength, contributing to general exercise science knowledge, and learning additional information about the health field. Ten points extra credit will be given to students enrolled in AT 3128 Lower Evaluation of Orthopedic Injuries. Students opting to not participate in the study can earn the same extra credit by writing a four-page article critique on the effects of thermal modalities on fatigue.

To maintain confidentiality, numbers will code subjects during testing procedures. All study documents will be securely kept in a locked file cabinet in the thesis chair's faculty office in the Jowers Center until completion of the thesis. No information collected throughout entire study will be released to anyone besides the principle investigator of the study. Participation to the study is completely voluntary and participants have the right to deny their answer to any question given. If you want to withdraw from the study at any time, you may do so without penalty or prejudice. Any information collected on you up to that point would be destroyed.

Once the study is completed, and you are interested in receiving the results from the study or you have any questions in the meantime, please contact:

Casey Meyer
Graduate Assistant Athletic Trainer
Texas State University
casey.j.meyer@txstate.edu or (512-245-9282)

This project 2014B4518 was approved by the Texas State IRB on 3/31/14. Pertinent questions or concerns about the research, research participants' rights, and/or research-related injuries to participants should be directed to the IRB chair, Dr. Jon Lasser (512-245-3413 - lasser@txstate.edu) and to Becky Northcut, Director, Research Integrity & Compliance (512-245-2314 - bnorthcut@txstate.edu).

I have received a complete explanation of the study and I agree to participate.

____
Participant Name (Printed)

____________________________________ ______________________
Signature Date

APPENDIX C

Verbal Feedback Script

Prior to fatigue testing
"Please remember this is a maximal effort test where every repetition is completed as hard as possible."

At repetition 10 of 20 of each testing set
"You're halfway done, push and pull as hard as you can!"

At repetition 15 of 20 of each testing set
"You're almost done, finish with as much effort as possible!"

At beginning of each resting period
"Please relax for four minutes and prepare for next set of maximal muscle testing."

APPENDIX D

Subject Data Collection

First Name: _______________ Last Name:________________

ID Number:________________

Condition Order (circle)

- Condition 1- Control / Cryotherapy / Thermal
- Condition 2- Control / Cryotherapy / Thermal
- Condition 3- Control / Cryotherapy / Thermal

Dominant Arm- R / L

Middle Deltoid Skinfold

Trial #1______mm Trial #2______mm Trial #3______mm

AVERAGE:________mm

	CONTROL	***CRYOTHERAPY***	***THERMAL***
AROM (DGs)			
PEAK TORQUE (nm)			
REPS (70%)			
REPS (50%)			
WORK @ 70% (joules)			
WORK @ 50% (joules)			

APPENDIX E

FIGURE 1. Upper Body Stationary Bicycle

FIGURE 2. Biodex Isokinetic Dynamometer

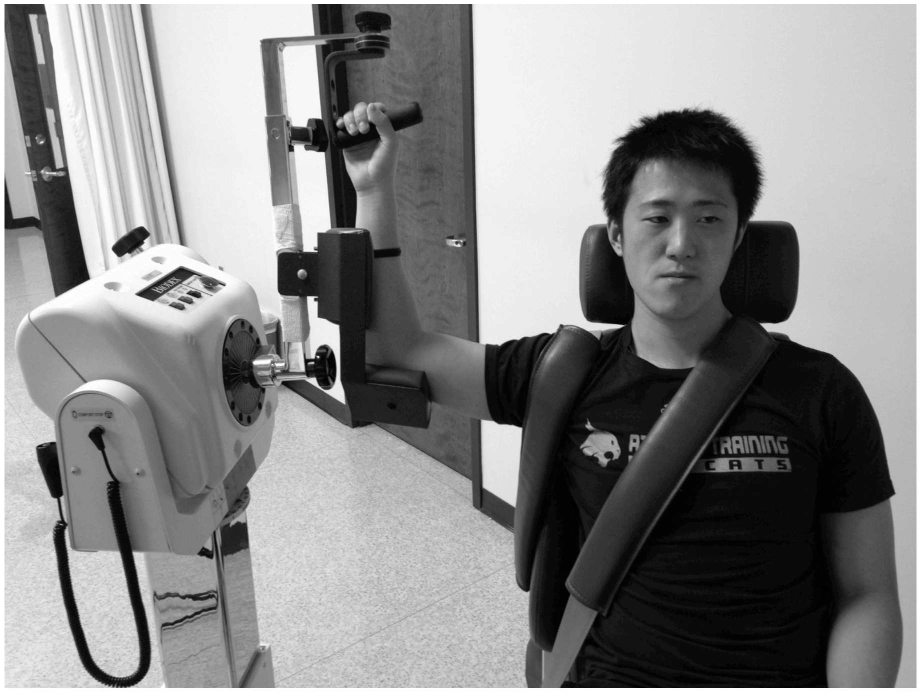

FIGURE 3. Shoulder Testing Position/Stabilization

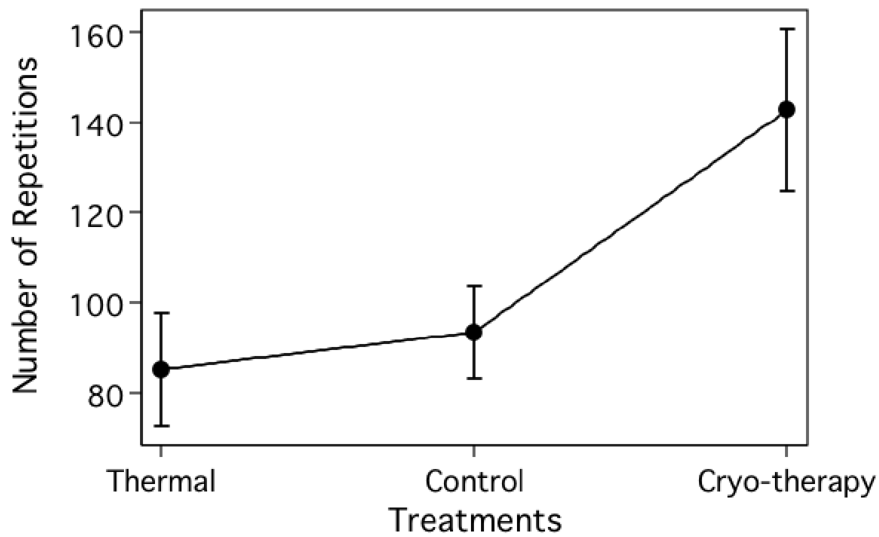

FIGURE 4. Treatment Effect for Repetitions to 70% max

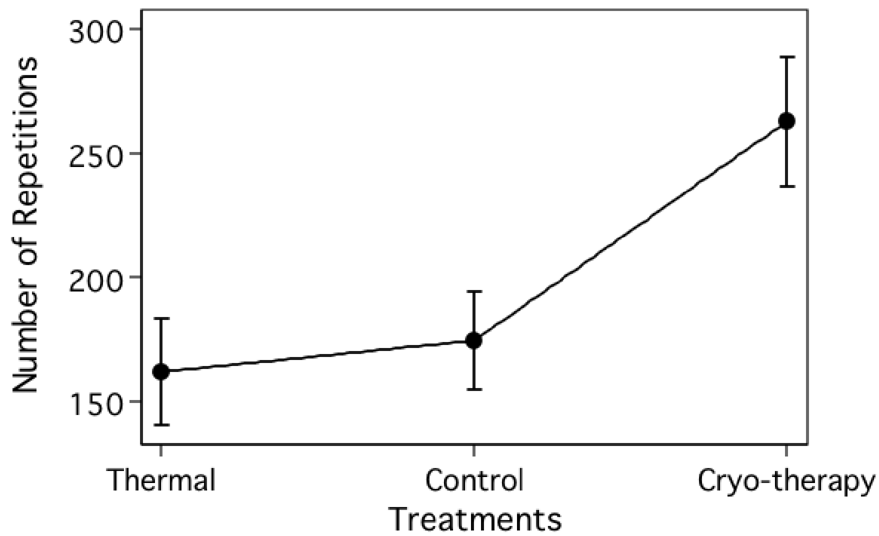

FIGURE 5. Treatment Effect for Repetitions to 50% max

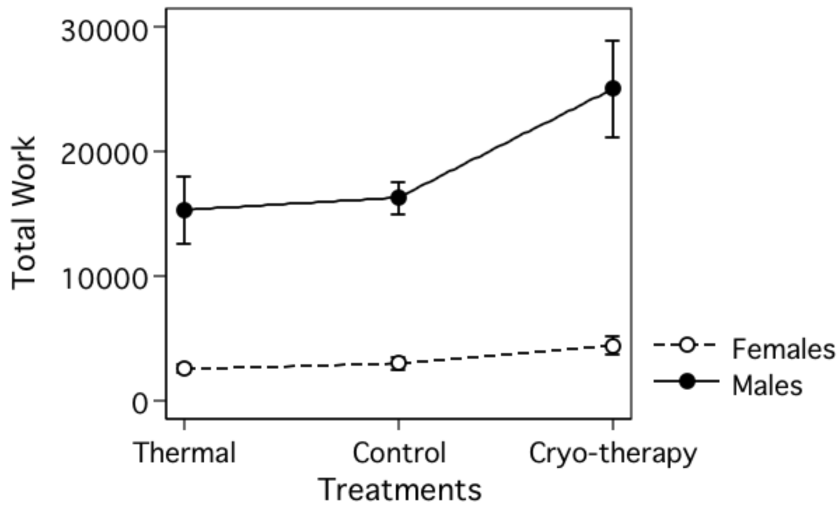

FIGURE 6. Gender Effect Across Treatments for Total Work to 70% max

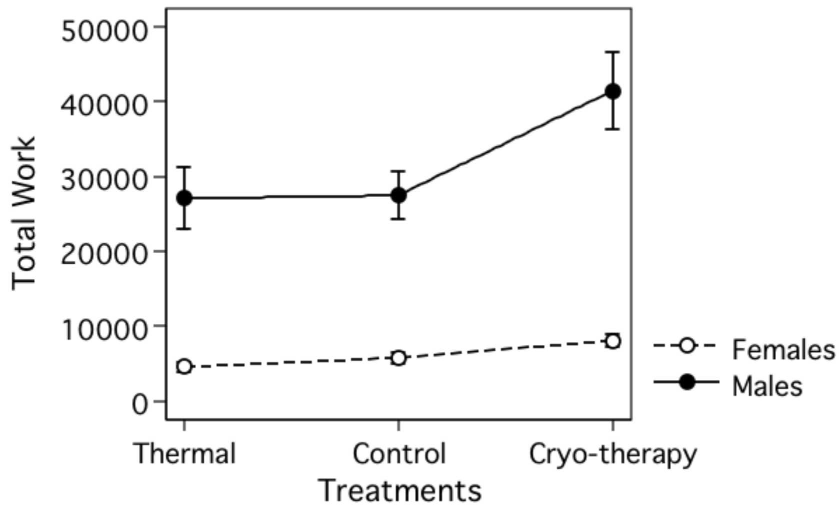

FIGURE 7. Gender Effect Across Treatments for Total Work to 50% max

APPENDIX F

TABLE 1. Participant Demographics

Variable	*Subjects*	*Mean*	*Std. Dev.*	*Min*	*Max*
AGE (years)	32	21.65	1.70	19	26
HEIGHT (m)	32	1.747	.089	1.574	1.981
MASS (kg)	32	72.06	15.24	49.83	106.46
SKINFOLD (mm)	32	12.98	3.29	5	19
AROM (degrees) CONTROL	32	202.41	16.84	156	232
AROM (degrees) CRYOTHERAPY	32	201.06	15.77	162	230
AROM (degrees) THERMAL	32	203.78	14.33	165	227

TABLE 2. Sample Means and Standard Deviations

Variable	*Subjects*	*Mean*	*Std. Dev.*	*Min*	*Max*
IR PEAK TORQUE (nm) CONTROL	16	39.00	7.51	13	47
IR PEAK TORQUE (nm) CRYOTHERAPY	16	38.38	6.26	16	44
IR PEAK TORQUE (nm) THERMAL	16	36.63	8.83	14	44
ER PEAK TORQUE (nm) CONTROL	16	33.81	11.29	12	48
ER PEAK TORQUE (nm) CRYOTHERAPY	16	33.06	9.77	13	46
ER PEAK TORQUE (nm) THERMAL	16	28.69	12.64	5	45
REPS 70% FATIGUE CONTROL	16	50.06	31.38	26	136
REPS 70% FATIGUE CRYOTHERAPY	16	83.63	49.88	26	179
REPS 70% FATIGUE THERMAL	16	48.50	29.29	26	145
REPS 50% FATIGUE CONTROL	16	106.19	57.48	27	207
REPS 50% FATIGUE CRYOTHERAPY	16	161.06	46.63	93	250
REPS 50% FATIGUE THERMAL	16	88.38	56.35	26	229
WORK 70% (J) CONTROL	16	2954.59	1986.67	1187.50	8398.20
WORK 70% (J) CRYOTHERAPY	16	4394.40	2887.87	914.90	11675.80
WORK 70% (J) THERMAL	16	2517.90	1371.27	531.70	5953.30
WORK 50% (J) CONTROL	16	5773.58	3227.00	1385.00	11140.50
WORK 50% (J) CRYOTHERAPY	16	8065.45	3339.85	2891.70	15080.50
WORK 50% (J) THERMAL	16	4553.62	2888.75	531.70	9233.40

REFERENCES

1. Knight KL. *Cryotherapy in Sports Injury Management.* Champaign, IL: Human Kinetics; 1995.
2. Verducci FM. Interval Cryotherapy Decreases Fatigue During Repeated Weight Lifting. *J Athl Train.* 2000;35(4):422-426.
3. Prentice WE. *Therapeutic Modalities in Sports Medicine, Fourth Edition.* Fairfield, PA: McGraw Hill; 1999.
4. Bleakley CM, Hopkins JT. Is it Possible to Achieve Optimal Levels of Tissue Cooling in Cryotherapy? *Phys Ther Rev.* 2010;15(4):344-350.
5. Snyder JG, Ambegaonkar JP, Winchester JB. Cryotherapy for Treatment of Delayed Onset Muscle Soreness. *Int J Athl Ther & Train.* 2011;16(4):28-32.
6. Merrick MA, Knight KL, Ingersoll CD, Potteiger JA. The Effects of Ice and Compression Wraps on Intramuscular Temperatures at Various Depths. *J Athl Train.* 1993;28(3):236-245.
7. Wassinger CA, Myers JB, Gatti JM, Conley KM, Lephart SM. Proprioception and Throwing Accuracy in the Dominant Shoulder After Cryotherapy. *J Athl Train.* 2007;42(1): 84-89.
8. Otte JW, Merrick MA, Ingersoll CD, Cordova ML. Subcutaneous Adipose Tissue Thickness Alters Cooling Time During Cryotherapy. *Am Acad Phys Med Rehab.* 2002;83:1501-1505.

9. Centers for Disease Control and Prevention. *State Indicator Report on Physical Activity, 2010.* Atlanta, GA: U.S. Department of Health and Human Services, 2010.

10. Lionikas A, Li M, Larsson L. Human skeletal muscle myosin function at physiological and non-physiological temperatures. *Acta Physiol Soc*. 2006; 186:151-158.

11. Betts JA, Toone RJ, Stokes KA, et al. Systemic indices of skeletal muscle damage and recovery of muscle function after exercise: effect of combined carbohydrate-protein ingestion. *Appl Physiol Nutr Metab.* 2009;34:773-784.

12. Popadic Gacesa JZ, Klasnja AV, Grujic NG. Changes in Strength, Endurance, and Fatigue During a Resistance-Training Program for the Triceps Brachii Muscle. *J Athl Train.* 2013;(48)6:804-809.

13. Merrick MA, Jutte LS, Smith ME. Cold Modalities With Different Thermodynamic Properties Produce Different Surface and Intramuscular Temperatures. *J Athl Train.* 2003;38(1):28-33.

14. Domingues MP. Cryotherapy and its Correlates to Functional Performance. A Brief Preview. *Sport Sci Rev*. 2013; 22(3):229-254.

15. Rupp KA, Herman DC, Hertel J, Saliba SA. Intramuscular Temperature Changes During and After 2 Different Cryotherapy Interventions in Healthy Individuals. *J Orthop Sports Phys Ther* . 2012;42(8):731-737.

16. Tomchuk D, Rubley MD, Holcomb WR, Guadagnoli M, Tarno JM. The Magnitude of Tissue Cooling During Cryotherapy With Varied Types of Compression. *J Athl Train.* 2010;45(3):230-237.

17. Jutte LS, Hawkins J, Miller KC, Long BC, Knight KL. Skinfold Thickness at 8 Common Cryotherapy Sites in Various Athletic Populations. *J Athl Train.* 2012;47(2):170-177.

18. Bleakley CM, Costell JT, Glasgow PD. Should Athletes Return to Sports After Applying Ice? *Sports Med*. 2012;42(1);69-87.

19. Petrofsky J, Bains G, Prowse M, Gunda S, Berk L. Dry heat, moist heat and body fat: are heating modalities really effective in people who are overweight? *J Med Eng Technol.* 2009;33(5):361-369.

20. Hawkes AR, Draper DO, Johnson AW, Diede MT, Rigby JH. Heating Capacity of ReBound Shortwave Diathermy and Moist Hot Packs at Superficial Depths. *J Athl Train.* 2013;48(4):471-476.

21. Hanson M, Day J. Effects of Different Heating Modalities on Hip Flexion Passive Range of Motion. *Int J Athl Ther Train.* 2012;17(6):27-30.

22. Starkey C. *Therapeutic Modalities for Athletic Trainers.* Philadelphia, PA: F. A. Davis Company; 1993.

23. Potteiger JA. *ACSM's Introduction to Exercise Science.* 1st Ed. Baltimore, MD: Lippincott Williams & Wilkins; 2011.

24. Lovering RM, Russ DW. Fiber Type Composition of Cadaveric Human Rotator Cuff Muscles. *J Orthop Sports Phys Ther.* 2008;38(11):674-680.

25. Starkey C, Brown SD, Ryan J. Shoulder and Upper Arm Pathologies. In: Examination of Orthopedic and Athletic Injuries. 3rd ed. Philadelphia, PA: F.A. Davis Company; 2010:615-705.

26. Ellenbecker TS, Mattalino AJ. Concentric Isokinetic Shoulder Internal and External Rotation Strength in Professional Baseball Pitchers. *J Orthop Sports Phys Ther* . 1997;25(5):323-328.

27. Srinivasan RC, Lungren MP, Langenderfer JE, Hughes RE. Fiber Type Composition and Maximum Shortening Velocity of Muscles Crossing the Human Shoulder. *Clin Anat.* 2007;20:144-149.

28. Baechle TR, Earle RW. *Essentials of Strength Training and Conditioning*. 3rd ed. Champaign, IL: Human Kinetics; 2008.

29. Voight ML, Hardin JA, Blackburn TA, Tippett S, Canner GC. The Effects of Muscle Fatigue on and the Relationship of Arm Dominance to Shoulder Proprioception. *J Orthop Sports Phys Ther* . 1996;23(6):348-352.

30. Wilk KE, Arrigo CA, Andrews JR. Standardized Isokinetic Testing Protocol for the Throwing Shoulder: The Thrower's Series. *Isokin Exerc Sci.* 1991;1(2):63-71.

31. Ellenbecker TS, Roetert EP. Testing Isokinetic Muscular Fatigue of Shoulder Internal and External Rotation in Elite Junior Tennis Players. *J Orthop Sports Phys Ther.* 1999;29(5):275-281.

32. Elias Sports Bureau. MLB Player Pitching Stats 2013. ESPN MLB. 2013. Available at http://espn.go.com/mlb/stats/pitching/_/sort/pitchesPerInning/type/

33. Arrigo CA, Wilk KE, Andrews JR. Peak Torque and Maximum Work Repetition During Isokinetic Testing of the Shoulder Internal and External Rotators. *Isokin Exerc Sci.* 1994;4(4):171-175.

34. Enoka RM, Duchateau J. Muscle Fatigue: what, why and how it influences muscle function. *J Physiol.* 2008;586(1):11-23.

35. Cairns SP. Lactic Acid and Exercise Performance. *J Sports Med.* 2006;36(4):279-291.

36. Schoenfeld BJ, Contreras B. Is Postexercise Muscle Soreness a Valid Indicator of Muscular Adaptations? *Natl Strength Con Assoc.* 2013;35(5):16-21.

37. Olsen O, Sjohaug M, van Beekvelt M, Mork PJ. The Effect of Warm-Up and Cool-Down Exercise on Delayed Onset Muscle Soreness in the Quadriceps Muscle: a Randomized Controlled Trial. *J Hum Kinet.* 2012;35:59-68.

38. American Heart Association. American Heart Association Recommendations for Physical Activity in Adults Website. http://www.heart.org/HEARTORG/GettingHealthy/PhysicalActivity. Updated March 22, 2013. Accessed September 19, 2013.

39. Urbaniak, G. C., & Plous, S. (2013). Research Randomizer (Version 4.0) [Computer software]. Retrieved on June 22, 2013, from http://www.randomizer.org/

40. Bottas R, Miettunen K, Komi P, Linnamo V. Acute and Delayed Effects of Exercise-Induced Muscle Damage and Soreness on Elbow Target Movements. *Motor Control.* 2011;15:525-549.

41. Bender AL, Kramer EE, Brucker JB, Demchak TJ, Cordova ML, Stone MB. Local Ice-Bag Application and Triceps Surae Muscle Temperature During Treadmill Walking. *J Athl Train.* 2005;40(4):271-275.

42. Verducci FM. Interval cryotherapy and fatigue in university baseball pitchers. *Res Q Exerc Sport.* 2001;72(3):280-287.

43. Salo DC, Donovan CM, Davies KJ. HSP7O and other possible heat shock or oxidative stress proteins are induced in skeletal muscle, heart, and liver during exercise. *Free Radic Biol Med.* 1991;1(1):239-246.

44. Bazett HC. The regulation of body temperature. *Physiology of Heat Regulation and Science of Clothing.* Philadelpha, PA: WB Saunders; 1949:109-122.

45. Stitt JT. Central regulation of body temperature. *Perspectives in Exercise Science and Sports Medicine: Exercise, Heat and Thermoregulation.* V 6. Dubuque, IA: William C Brown & Benchmark; 1993:1-39.

46. Knight KL. *Cryotherapy: Theory, Technique, and Physiology.* Chattanooga, TN: Chattanooga Corp; 1985:73-82.