How Cryokinetics Affect Sensory Perception, Range of Motion and Postural Stability of Uninjured Ankles and Previously Injured Ankles.

by

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Abstract

Injury statistics report that 45% of all athletic injuries are ankle sprains, with 85% of those occurring at the lateral aspect of the ankle. Cryokinetics is a rehabilitation technique that uses cooling with the goal to decrease neural inhibition, thus allowing for greater pain-free range of motion. The present study evaluated how cryokinetics affected sensory perception, range of motion (ROM) and postural stability with previously injured (asymptomatic) versus uninjured ankles. Tactile sensation at the lateral ankle, dorsiflexion at the ankle, as well as postural stability (with eyes open and closed) before and after a cryokinetic protocol were evaluated. The results demonstrate how cryokinetics effects sensory perception, ROM and postural stability in relation to injury history. Two-point discrimination testing demonstrated a significant reduction in tactile acuity after cryokinetics. Functional range of motion testing demonstrated an interaction between a history of ankle injury compared to no injury history, where functional ROM was significantly greater after cryokinetics for previously injured ankles. Overall, vision had the largest impact on postural stability. However, there was an interaction across previous injury history, intervention and vision for median frequency of medial/lateral-Center of Pressure. The current results highlight that ankle injury history is a significant variable when assessing the affects of cryokinetics on functional ROM of ankles and that vision affects postural stability more than cryokinetics. Future research could investigate the effects of cryokinetics on acute care injury management of ankle sprains, and perhaps to ligamentous or soft tissue injuries at joints other than the ankle.

Key words: Cryotherapy, functional range of motion, balance, proprioception.

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Dedication

To my Mom. You supported me so much in all that I have ever done. I wish you would have been here to see me finish this chapter.

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Terminology

Throughout the review of literature, a number of terms are used that can have varied definitions within different sources and contexts. In particular, due to the breadth of disciplines reviewed (biomechanics, rehabilitation, medicine, motor control, motor learning) the terms and their definitions used in the respective literatures can vary. For consistency throughout the present document the definitions used for the present research are listed below:

Acute care: “Treatment of an acute injury during the first 4 days after the injury.” (Knight and Draper, 2008, page 371)

Ataxia: “Incoordination that is not due to weakness. There are three types of Ataxia: sensory, vestibular, and cerebellar.” (Lundy-Ekman, page, 128)

Ataxia, cerebellar limb: “Uncoordinated voluntary movements of the limbs.” (Lundy-Ekman, page, 508)

Ataxia, sensory: “Uncoordinated movement caused by a lesion along peripheral or central proprioceptive pathways.” (Lundy-Ekman, page, 509)

Ataxia, vestibular: “Gravity-dependent uncoordinated movement. Limb movements are normal when the person is lying down but are ataxic during walking.” (Lundy-Ekman, page, 509)

Balance: "A generic term describing the dynamics of body posture to prevent falling. It is related to the inertial forces acting on the body and the inertial characteristics of body segments." (Winter, 1995, page 194)

Center of mass (COM): "A point equivalent of the total body mass in the global reference system as is the weighed average of the COM of each body segment in 3D space." (Winter, 1995, page 194)

Center of Pressure (COP): "The point location of the vertical ground reaction force vector. It represents a weighted average of all the pressures over the surface of the area in contact with the ground. It is totally independent of the COM." (Winter, 1995, page 194)

Cryokinetics: "Alternating cold application with active graded exercise for rehabilitating acute joint sprains." (Knight and Draper, 2008, page 374)

Cryotherapy: "The therapeutic use of cold; the application of a device or substance with a temperature less than body temperature, thus causing heat to pass from the body to the cryotherapy device." (Knight and Draper, 2008, page 374)

Graded exercise: "A series of exercises of increasing complexity and difficulty used to progressively reorient a patient to full functional activity following injury." (Knight and Draper, 2008, page 375)

Kinesthesia: "The ability to detect movement, mediated by mechanoreceptors found in muscles and joints, and by cutaneous, visual and vestibular input. Neuromuscular control relies on the CNS to interpret and integrate proprioceptive and kinesthetic information and then to control individual muscles and joints to produce coordinated movement." (Prentice, 2014, page 424)

Neural inhibition: “The decreasing or stopping of neural activity, thus retarding or preventing normal musculoskeletal functioning.” (Knight and Draper, 2008, page 378)

Posture: “Describes the orientation of any body segment relative to the gravitational vector. It is an angular measure from the vertical.” (Winter, 1995, page 194):

Postural control: “Involves controlling the body’s position in space for the dual purposes of stability and orientation.” (Shumway-Cook and Woollacott, 2012, page 162)

Postural orientation: “The ability to maintain an appropriate relationship between the body segments, and between the body and the environment for a task.” (Shumway-Cook and Woollacott, 2012, page 162)

Postural stability: “Also referred to as balance, is the ability to control the center of mass in relationship to the base of support.” (Shumway-Cook, and Woollacott, 2012, page 162)

Proprioception: “A sense of perception, usually at a subconscious level, of the movements and position of the body, and especially its limbs, independent of vision: this sense is gained primarily from input from sensory nerve terminals in muscles and tendons (muscle spindles), and the fibrous capsule of joints combined with input from the vestibular apparatus.” (Stedman’s Medical Dictionary, 2001, page 806)

Sprain – Ligament: “Ligament injuries are divided into three grades. A grade I sprain represents some stretched fibers but clinical testing reveals normal ROM on stressing the ligament. A grade II sprain involves a considerable proportion of the fibers and, therefore, stretching of the joint and stressing the ligament show increased laxity but a definite end point. A grade III sprain is a complete tear of the ligament with excessive joint laxity and no firm end point. Although they are often painful conditions, grade III sprains can also be pain-free as sensory fibers are completely divided in the injury.” (Brunkner and Khan, 2006, page 11)

Subacute care: “Treatment of an acute injury during days 4-14 after the injury.” (Knight and Draper, 2008, page 382)

Transition care: “Treatment of an acute injury between 12 hours and 4 days after the injury; a subset of acute care.” (Knight and Draper, 2008, page 383)

Chapter 1 – Introduction

General Overview

Fong, Hong, Chan, Yung and Chan (2007) reported that ankle injuries are one of the most commonly injured areas on the body in sports, with ankle sprains being the most dominant type of ankle injury. In a position statement from the National Athletic Therapists' Association (Kaminski, Hertel, Amendola, Docherty, Hopkins, Nussbaum, Poppy, Richie, 2013) it was stated that ankle sprains are common in sport. Adams, Barton, Collings, DeBlieux, Gisondi, and Nadal (2008) estimated that 28,000 ankle injuries occurred daily in the United States. Ferran and Maffulli (2006) added that 45% of all athletic injuries were ankle sprains and that 85% of those occur at the lateral aspect of the ankle. Court sports, such as volleyball and basketball in particular, have a high incidence of ankle sprains (Fong et al., 2007). Hunt, Hurwit, Robell, Gatewood, Boster, and Matheson (2016) demonstrated a mean time missed from participation due to ankle injuries to be 12.3 days per 1000 athlete exposures. Together the high incidence and time missed from sport provide rationale for the importance to evaluate and treat ankle sprains as safely and efficiently as possible. Any improvement to the safe and efficient treatment of ankle sprains will aid in the successful return of an athlete to their previous/pre-injury level of function and activity.

Musculoskeletal therapists, including Athletic Therapists, have many options to choose from in which to assess and treat acute ankle sprains (Fong, Hong, Chan, Yung and Chan, 2007; Kaminski, Hertel, Amendola, Docherty, Hopkins, Nussbaum, Polly and Richie, 2013; Knight, 1979; Bleakley, O'Connor, Tully, Rocke, MacAuley and McDonough, 2007; Magee, 2008; Prentice, 2014). Acute injury is defined as an injury with sudden onset and short duration

(Prentice, 2014). The assessment process for acute injuries has become more standardized (Magee, 2008 and Prentice, 2014) over time. Treatments of acute injuries are also becoming more evidence-based among therapists (Barr and Harrast, 2005), despite the varied treatment options (Jones and Amendola, 2007).

Clinical assessments of acute injuries should follow a consistent order to ensure that the area is thoroughly evaluated. The standard clinical assessment should include: asking a number of relevant questions specific to the injury; an observation of the client; evaluation of Active Range of Motion (AROM) and Passive Range of Motion (PROM); Isometric Resisted Testing (IRT); Orthopedic Tests or “Special Tests”, followed by palpation (Magee, 2008). The information gathered from this evaluation should provide the therapist with enough information to determine the structures involved and the severity to which those structures are damaged.

Athletic Therapists, and other sport healthcare professionals, aim to provide the most evidence-based treatment strategies (Barr and Harrast, 2005) to ensure safe and prompt return to play by utilizing acronyms like PIER (P-pressure, I-ice, E-elevation, R-rest), RICE (R-rest, I-ice, C-compression, E-elevation), RICES (R-rest, I-ice, C-compression, E-elevation, S-stabilization) and PRICE (P-pressure, R-rest, I-ice, C-compression, E-elevation) to guide the treatment of acute injuries (Bleakley et al., 2007; Ferran et al., 2006; Kaminski et al., 2013; Knight and Draper, 2008; Prentice, 2014). Pressure, compression and elevation are used to address swelling, while ice, rest and stabilization are used to control pain (Knight and Draper, 2008; Prentice, 2014). Despite the obvious similarities among these acronyms, none of them include consistent timelines, standardized treatment parameters, or the incorporation of activity. Standardized acute treatment protocols are needed to better guide the therapist with a more thorough and evidenced-based therapeutic approach. Barr and Harrast (2005) stressed that the primary goal of rehabilitation after an ankle sprain should focus to restore normal mechanics to the ankle and improve joint stability in efforts to decrease the risk of re-injury. It was added that rehabilitation protocols should be a progression that begins with ROM, followed by restoring neuromuscular control, strengthening, proprioceptive training, and functional training before the return to regular activity (Barr and Harrast, 2005),

Cryokinetics is a dynamic and progressive form of management for acute ankle injuries that has been studied for many years (Knight and Draper, 2008; Hopkins and Stencil, 2002; Knight, 1995; Knight, 1979; Grant, 1965; Hayden, 1965). Cryokinetics includes a systematic combination of cold applications to numb the injured body part, followed by graded, progressive, active exercise (Knight, 1979; Moore, Nicolette & Behnke, 1967; Magee, 2008). Stedman's *Medical Dictionary for the Health Professions and Nursing* (2005) describes cryokinetics as the combination of cryotherapy with exercise. Knight and Draper (2008) define it as alternating cold application and active graded exercise for rehabilitating acute joint sprains.

The effect of cryokinetics on uninjured joints (Knight, 1979; Moore, Nicolette, and Behnke, 1967) and injured joints (Dehne and Torp, 1971) has been studied. During cryokinetics, joint movement was found to provide benefits that compensate for the decrease in circulation and metabolism caused by the ice application (Dehne, 1980; Knight and Londeree, 1980). The exercises performed during cryokinetics also increased blood flow (Knight and Londeree, 1980), and through analgesic induced ROM activities, delayed the progress of adhesions and altered neural inhibitions (Dehne and Torp, 1971). Knight and Londeree (1980), Swenson, Sward, and Karlsson (1996), and more recently, Knight and Draper (2008), have consistently agreed that to obtain the maximum amount of pain-free range of motion it is necessary the apply ice to reduce the tissue temperature enough to obtain total or near-total analgesia, prior to performing rehabilitation exercises.

While cryokinetics has been studied over the years, gaps in the research literature have been identified. Although there is evidence of how cold and cryokinetics impacts ROM on uninjured ankles (Knight and Londeree, 1980), no research has investigated how cryokinetics affects sensation, ROM and postural stability of asymptomatic ankles with a history of injury. Therefore, the goal of this thesis was to measure sensation, range of motion, and postural stability, before and after an intervention of cryokinetics on uninjured ankles and asymptomatic, previously injured ankles, to better understand how and why a dynamic cryokinetic protocol could lead to the reported shorter recovery times (Knight nd Draper, 2008) from acute ankle injury.

Studies have investigated ankle range of motion (ROM) and how it is affected by injury (Nisha, Megha, Paresh, 2014), therapeutic modalities (Bleakley, O'Connor, Tully, Rocke, MacAuley, McDonough, 2007), and exercise (Knight and Londeree, 1980). Range of motion is affected negatively by injury due to swelling, protective muscle spasm and increased pain levels (Knight and Draper, 2008; Prentice, 2014). Poor ankle ROM due to injury can be addressed with ice to control pain levels and decrease muscle spasm through enhancing neural inhibition (Knight and Londeree, 1980; Knight & Draper, 2008; Prentice, 2014). Knight and Draper (2008) proposed that ice application on acute injury would result in less pain and muscle spasm, which would permit an increase in ROM. An increase in ankle range of motion could in turn allow for longer force production in that joint range (Robert-Lachaine, Turcotte, Dixon, Pearsall, 2012). The research by Robert-Lachaine et al. (2012) showed that an increase from 5 to 10 degrees at the ankle produced 14%-20% more power. Cho, Jeon, and Lee (2016) correlated the importance of ankle dorsiflexion ROM and force production during simple movements of the ankle. Consistent with previous studies, these authors reported improved performance outcomes of strength related to improvements with ankle ROM.

Hopkins and Adolph (2003) assessed the effects of joint cryotherapy on uninjured ankle function, and concluded that cryotherapy is an effective treatment that will not inhibit normal motor function of the surrounding ankle musculature. The authors concluded this through quantified lower extremity joint kinetic and kinematic changes (joint ROM, peak torque, peak power, and root mean square [RMS] power from the ankle, knee, and hip) during gait, from cooling and subsequent rewarming of the joints. Hopkins and Adolph (2003) found ankle ROM to increase over time, but joint cooling had no effect on lower chain kinetics during resisted exercise. This study demonstrates that proper use of cryotherapy as treatment is safe to use in conjunction with movement.

Lundy-Ekman (2013) stated that during movement and static balance, somatosensation incorporates sensory information from the skin and musculoskeletal systems. This information is processed unconsciously. Somatosensory input is processed at different levels of the nervous system including the spinal level in local neural circuits and by the cerebellum to adjust movements and postures (Lundy-Ekman, 2013). Somatosensory input is gathered by touch receptors located in the skin that respond to mechanical deformation of the receptor by various intensities of pressure, while pain and cooling at the superficial level affect nociceptors and thermoreceptors respectively (Prentice, 2014; Lundy-Ekman, 2013; Deleo, 2006).

Lotze and Moseley (2007) stated that while two-point discrimination is dependent on peripheral innervation density and intact neural pathways, it is also believed to be dependent on response profiles of central somatosensory function. That is, when a palpable sensation is detected on the skin, like that of the two-point discrimination test, the signal is sent to the brain and is processed by the primary somatosensory cortex for comparison. Therefore, two-point discrimination has been recommended as a simple clinical tool to measure the magnitude of the primary somatosensory cortex (S1) representations (Cashin and McAuley, 2017).

Balance involves the complex integration of muscular forces, neurological sensory information received from the mechanoreceptors, and biomechanical information (Prentice, 2014). While postural stability is sometimes referred to as balance, postural stability specifically refers to the ability to control the center of mass in relationship to the base of support (Shumway-Cook and Woollacott, 2012). Center of mass (COM) and center of pressure (COP) are terms with distinct definitions that can be misinterpreted at times. The COP represents a weighted average of all the pressures over the surface of the area in contact with the ground, but is totally independent of the COM (Winter, 1995). Similarly, proprioception is the subconscious perception of the movements and position of the body, and especially its limbs. Proprioception is gained primarily from input from sensory nerve terminals in muscles, tendons and the fibrous capsule of joints combined with input from the vestibular apparatus (Stedman's Medical Dictionary, 2001).

Furmacek, Slomka and Juras (2014) reviewed literature regarding the influence of local cryotherapy on the proprioception system. Williams, Miller, Sebastianelli and Vairo (2013), as well as Dewhurst, Richies and De Vito (2007) used force plates as their instrument for measuring the effects of cryotherapy on proprioception. Furmacek et al. (2014) concluded that the effects of cryotherapy on proprioception were varied and frequently contradictory. Blaszczyk (2016) stated that force plate evaluation is the safest and most efficient method for assessing postural stability based on COP oscillations.

Current Study

Despite years of cryokinetic research, gaps in the research literature have been identified. The present study evaluated how cryokinetics affects sensory perception, ROM and postural stability with previously injured and uninjured ankles. Participants were asymptomatic, with either a past ankle injury, or no injury history. All participants performed the tactile perception, ROM and postural stability tasks with and without cryokinetics.

In an Athletic Therapy clinical setting, there are a number of methods to evaluate an injury and its progress. Therefore, for this study, each participant provided a list of ankle injury history, including which ankle was affected, how many sprains had occurred and when the injuries were sustained. Objective (sensory perception, ROM, and postural sway) data collected was collected. Sensation was evaluated using 2-point discrimination test and monofilament stimulus. Performance of ankle dorsiflexion was quantified during active range of motion, passive range of motion and a functional lunge through the use of a manual goniometer. Postural stability was evaluated using a force platform, gathering data on Center of Pressure (C.O.P.) during double and single leg stance, before and after intervention as well as with eyes open and eyes closed.

Three independent variables included “previous injury history” (uninjured / previously injured), “intervention” (before cryokinetics / after cryokinetic application) and “vision” (eyes open / eyes closed). Dependent variables included sensation, range of motion (active range of motion, passive range of motion and functional range of motion), and postural stability. Statistical analysis involved a paired *t*-test comparing ROM before and after the intervention (cryokinetics). In addition, a two-way mixed ANOVA was completed to address the interactions among Previous Injury History (PIH) and Intervention (INT) (2 PIH x 2 INT). Postural sway was analyzed by completing a mixed ANOVA evaluating 2 PIH, 2 INT (before and after intervention) and 2 Vision (VIS) (eyes open and eyes closed).

The results of the present study provide introductory information involving how and why cryokinetics affects sensory perception, range of motion and postural stability. Sensory perception was evaluated with the use of a Two-Point Discrimination Wheel and monofilament and ankle dorsiflexion was measured with a manual goniometer. These measurements were collected before and after cryokinetics. Postural stability was measured with the use of a force platform, with the participants' eyes open, then closed. Postural stability was also measured before and after cryokinetics. The interactions between these variables were studied to determine any significance.

Review of Literature

Prevalence of Ankle Injury in Sport

Ankle sprains are common at all ages and sporting activities (Kaminski and colleagues, 2013). Epidemiological studies have shown ankle sprains to be one of the most common injuries (Doherty, Caulfield, Hertel, Ryan, and Bleakley, 2013), and that the incidence during sport is increasing (Hunt, Hurwit, Robell, Gatewood, Botser, and Matheson, 2016). Twenty-eight thousand ankle injuries are reported to occur daily in the United States (Kaminski and colleagues, 2013) with 45% of all athletic injuries being ankle sprains (Ferran and Maffulli, 2006).

Incidence rate (IR), or incidence of injury is defined as the number of injuries in a particular category divided by the number of athlete exposures (AE) in that category, where an AE is defined as 1 student-athlete participating in 1 practice or competition in which they are exposed to the possibility of injury (Dick, Agel, Marshall, 2007). Fong, Hong, Chan, Yung & Chan (2007) demonstrated that there was a statistical significance (*p* = 0.01) regarding the mean overall incidence rate for lower leg, foot and ankle musculoskeletal injury at 3.80 per 1000 AE's. It was concluded that ankle injury was one of the most commonly injured areas on the body in sports and ankle sprain was the most dominating type of ankle injury in the majority of the sports (Fong et al., 2007).

Fong et al. (2007) performed an epidemiological study on sports from 1977 to 2005 that included ankle injuries. Demographic data of the studies was summarized to include the geographical location, period of the study, population, prospective or retrospective nature of the study and number of participants. After the screening process, 227 articles were included in the analysis. These articles included 70 sports from 38 countries and 201,600 participants who had sustained 32,509 ankle injuries. Ankle sprain was the major ankle injury in 33 of 43 sports. The incidence of ankle injury was high in soccer, volleyball and basketball. This systematic review provided a thorough summary of the epidemiology of ankle injury in sport. Specifically, the incidence of ankle sprains in terms of incidence per 1000 person-hour, revealed that soccer was at 2.52, volleyball at 1.99, and basketball at 1.00, but during games, the incidence was highest in soccer at 11.68.

Court sports have also been shown to have a high incidence of ankle injuries. A meta-analysis of epidemiological studies, performed by Doherty et al. (2013), revealed three main findings. Indoor court sports had the highest risk of ankle sprains with 7 per 1,000 cumulative exposures, while field sports scored 1 per 1000; lateral ankle sprains were the most commonly observed type of ankle sprain; and that the meta-analysis demonstrated a higher incidence of ankle sprains in females compared with males (13.6 vs. 6.94 per 1,000 exposures).

Hunt et al. (2016), collected data from injury records of all varsity sports at one NCAA Division 1 athletics program over a 2-year period. This study involved 1076 athletes and 37 sports. The injury records included 3861 total musculoskeletal injuries of which 1035 (27%) of them were foot/ankle injuries. Court sports (including basketball and volleyball) made up 33% of ankle injuries while soccer accounted for 14%. Reeser, Verhagen, Briner, Askeland and Bahr (2006), presented similar prevalence of ankle sprains in volleyball through their evaluation of data collected between 1984 and 2005, by the National Collegiate Athletic Association's (NCAA) Injury Surveillance System (ISS). The ISS consistently revealed acute ankle sprains to be the most common injury suffered by women's collegiate (indoor) volleyball athletes. Bahr and Bahr (1997) documented an incidence of 3.5 injuries per 1000 hours during competition and 1.5 injuries per 1000 hours during training among 273 male and female athletes competing over one season in the Norwegian Volleyball Federation amateur league, while Verhagen, Van der Beek, and Bouter (2004) found an overall injury rate of 2.6 injuries per 1000 hours among a cohort of 486 male and female athletes competing in Dutch volleyball leagues. These studies highlighted that indoor court sports had the highest risk of ankle sprains; lateral ankle sprains were the most common type of ankle sprain; and that females had a higher incidence of ankle sprains compared with males.

Wang, Chen, Shiang, Jan and Lin (2006) gathered pre-season baseline data on 42 male high school basketball athletes in Taiwan. Eighteen ankle injuries were recorded during the follow-up season. High variation of postural sway in both antero-posterior and medio-lateral directions corresponded to occurrences of ankle injuries. Wang et al. (2006) concluded that high variations of postural sway in a single-leg standing test could explain partly the increased prevalence of ankle injury in basketball players. Similarly, McGuine, Green, Best and Leverson (2000) demonstrated that basketball players with increased sway scores suffered ankle sprains 7-times that compared with those with normal sway.

Tropp, Ekstrand and Gillquist (1984) measured postural sway during the preseason in 127 soccer players in Sweden, who were then followed for a complete season. An elevated postural-sway value also identified an athlete at increased risk of suffering an ankle sprain. This study demonstrated that ankle sprains affected more subjects with abnormal posture (12 of 29 = 42%) than with normal posture (11 of 98 = 11%). In summary, ankle sprains are one of the most common musculoskeletal injuries for both males and females in various sports and at different competitive levels around the world (Fong et al., 2007). Given the high prevalence of ankle sprains in court sports and soccer, the current study will focus exclusively on ankles and ankle injuries of male and female volleyball, basketball and female soccer athletes.

Severity of Injury

Severity of acute ankle sprains can vary and be classified in a number of ways. Grading can be based on anatomical damage, clinical presentation, mechanism of injury or a combination of these aspects (Nyska and Mann, 2002; Magee, 2008; Prentice 2014; Northrup et al., 2005; Stiell et al., 1994). Frequently used terms to express severity of injury are mild, moderate and severe (Nyska and Mann, 2002; Magee, 2008; Anderson, Parr and Hall, 2009; Prentice, 2014). These are also known as grade I, grade II and grade III, or first degree, second degree and third degree respectively (Anderson et al., 2009; Barr & Harrast, 2005). Anderson et al. (2009) classifies sprains as follows: A first-degree sprain is described as having a few fibers of the ligament torn associated with minimal distraction of the joint and mild weakness, loss of function and swelling. The second-degree sprain displays close to half of the ligament being torn which allows for more distraction within the joint compared to the first degree. Weakness is mild to moderate, while swelling is moderate which contributes to the loss of function to range from moderate to severe. In a third-degree sprain, all fibers are torn (ruptured) leading to the most mobility during assessment. Weakness is mild to moderate, swelling is moderate to severe and loss of function is severe. For continuity of clinical assessment throughout this study, the ligament sprain classification summarized from Anderson et al. (2009) will be used to classify the severity of injury to the ankle (Table 1).

Table 1: Classification of Sprains

Summarized from Anderson, M., Parr, G., Hall, S. (2009).

	First degree	**Second degree**	**Third degree**
Damage to ligament	Few fibers of ligament are torn	Nearly half of the fibers are torn	All ligament fibers are torn (rupture)
Distraction with stress test	<5 mm distraction	5-10 mm distraction	>10 mm distraction
Weakness	Mild	Mild to moderate	Mild to moderate
Muscle spasm	None	None to minor	None to minor
Loss of function	Mild	Moderate to severe	Severe (instability)
Swelling	Mild	Moderate	Moderate to severe
Pain on contraction	None	None	None
Pain with stretching	Yes	Yes	No
Range of motion	Decreased	Decreased	May increase or decrease depending on swelling; dislocation /subluxation possible

Acute Injury Assessment

In a clinical rehabilitation setting the assessment and recording of injury data is a standardized practice. A standardized acute injury assessment is included in this document to reinforce the importance of being consistent while gathering injury related data for research purposes and for clinical use. However, it should be noted that no acute injuries were assessed during this study because there were no acute ankle injuries that occurred during the data collection period.

The assessment process of any injury is the foundation of investigation to determine which structures are involved and to what extent these structures are damaged. For this study, the standardized injury assessment is also used to determine inclusion criteria. The “Acute injury assessment" section outlines the importance and clinical expectation of the standardized injury assessment. Although, the acute injury assessment is not included within the dependent variables of this study, the clinical evaluation of the injury is necessary to ensure that each participant that sustains an ankle injury is evaluated thoroughly and consistently to establish inclusion criteria and clear documentation of the injury. A detailed and itemized description of the assessment can be seen in table 2. An assessment template was also created to be a one-page document to record all relevant injury information gathered following an injury. The assessment template can be viewed in Appendix G.

Table 2: Standardized Ankle Assessment

Summarized from Brunkner and Khan (2009); Magee (2008)

History questions (i.e., mechanism of injury, pain levels, current function, previous injury).
Observation
Figure-8 Ankle Measurement for Swelling
Standing (Bilateral anterior, right lateral, left medial, bilateral posterior, left lateral, right medial)
Supine (bilateral anterior, medial and lateral)
Functional Testing
Standing calf raise (bilateral); Mini Squat; Kneeling lunge test; Gait (heel strike, mid foot stance, toe off, swing phase)
Active Range of Motion
Plantarflexion; Dorsiflexion; Inversion; Eversion
Passive Range of Motion
Plantarflexion; Dorsiflexion; Inversion; Eversion
Isometric Resisted Tests
Plantarflexion; Dorsiflexion; Inversion; Eversion
Orthopedic Special Testing
Anterior Drawer (lateral ankle – ATF ligament)
Talar Tilt (lateral ankle – CF ligament and AFT ligament)
Kleiger Test (high ankle sprain and/or medial deltoid ligament)
Palpation
Distal fibula (from the head to the malleolus); Lateral malleolus; Lateral ligaments (PTF, CF, ATF); Talus; Peroneal tendons; Base of the 5th metatarsal; Anterior joint line; Dome of talus; Medial ligament (deltoid); Sustentaculum tali; Sinus tarsi

Assessments of acute injuries have become more standardized over time (Magee, 2008 and Prentice, 2014), and treatments of acute injuries are becoming more evidenced-based among therapists (Barr and Harrast, 2005), despite being more varied (Jones and Amendola, 2007). Evaluation of acute injuries should follow a consistent order and flow to ensure that the area is evaluated thoroughly. Magee (2008) and Prentice (2014) suggest that a standard assessment include: asking a number of relevant questions specific to the injury; an observation of the client; evaluation of Active Range of Motion (AROM); Passive Range of Motion (PROM); Isometric Resisted Testing (IRT); Orthopedic Tests or "Special Tests", followed by palpation. In addition to this general assessment, researchers suggest to include the Ottawa ankle rules to assist with determining if the athlete with ankle pain should have a radiograph to rule out a fracture (Northrup, Ragan, Bell, 2005; Stiell, McKnight, Greenberg, 1994). The Ottawa Rules are a set of clinical decision rules developed by Dr. Ian Stiell and his research team at The Ottawa Hospital Research Institute and the University of Ottawa. The rules have shown to decrease unnecessary diagnostic imaging of acute ankle injury (Stiell, Greenberg, McKnight, Nair, McDowell, Worthington, 1992). Stiell et al. (1992) demonstrated that an ankle X-Ray series is only required if there is any pain in the malleolar zone and bone tenderness at the posterior edge or tip of the lateral malleolus, or bone tenderness at the posterior edge or tip of the medial malleolus, or an inability to bear weight immediately or during four steps. This evaluation will be utilized as it would be in a typical clinical setting in which the participant would be referred to a physician should the Ottawa ankle rules be positive. A participant with a positive result from the Ottawa ankle rules would not be eligible to participate further in the present study.

The summation of the subjective and objective injury information gathered from the history, observation, range of motion testing, strength testing, orthopaedic testing and palpation should provide the therapist with sufficient information to determine the structures involved and the severity to which those structures are damaged. These assessment findings can assist with guiding the therapist through the next steps of their rehabilitation. For the purpose of this study, the assessment and assessment findings will help to determine the participants' current injury status and their eligibility to participate in the study.

Acute Injury Management

Acute injury management has a long history and has evolved over the years to what is performed clinically today (Table 3). Standardized clinical management is a necessity for accurate treatment of injury. The standardized clinical assessment included in the study is not a variable to be evaluated, but the standardization of the intervention (cryokinetics) as an independent variable is valuable in assuring consistent delivery for all participants.

Once the assessment findings are complete, appropriate acute injury management can be provided. Athletic Therapists and other sport healthcare professionals aim to provide the most evidence-based treatment strategies to ensure an athletes' safe and prompt return to play. Acronyms like PIER (Pressure, Ice, Elevation, Rest), RICE (Rest, Ice, Compression, Elevation), RICES (Rest, Ice, Compression, Elevation, Stabilization), and PRICE (Protection, Rest, Ice, Compression, Elevation) frequently guide the treatment of acute injuries (Bleakley et al., 2007; Ferran et al., 2006; Kaminski et al., 2013; Knight and Draper, 2008; Prentice, 2014).

A variety of treatments for ankle sprains have been used, including surgical repair, casting or splint immobilization and functional treatment, consisting of an early mobilization program, combined with the use of compression or brace (Kannus & Renstrom, 1991). Kannus and Renstrom (1991) were among the first to conclude that functional treatment, inclusive of movement and acute symptomatic management, should be the preferred method in cases of complete lateral ankle ligament rupture. The findings of Kannus and Renstrom (1991) have been corroborated by several other researchers (Kerkhoffs, Rowe, Assendelft, Kelly, Struijs, van Dijk, 2001; Jones and Amendola, 2007).

Knight and Draper (2008) focus on RICES for immediate management of musculoskeletal injuries to protect from further damage and to minimize the development of swelling, pain, muscle spasm, neural inhibition and secondary injury. Knight and Draper (2008) define rest as moving the limb as little as possible. Rest should be active as opposed to absolute rest (Garrett, 1990), so as to not aggravate the damaged tissue further (Bergfeld and Halpern, 1991). Too little activity can be as detrimental as too much activity, according to Knight and Draper (2008), which could result in delayed healing, adhesions, muscular atrophy, loss of conditioning, skills becoming rusty and loss of confidence. Knight and Draper (2008) recommend using crutches for acute management of pain, until walking can be accomplished with a normal gait. The use of crutches would allow for a “non-weight bearing” form of walking regarding the injured ankle. If the ankle is not permitted to be used normally (during gait), less irritation and pain should be present, which can also aid in decreasing neuromuscular inhibition.

Ice or cryotherapy also plays a key role in combination with crutches in controlling pain to permit active rest. Knight and Draper (2008) describe active rest, also known as relative rest, as protecting the injury while also using the rest of the body to prevent deconditioning. Cryotherapy application reduces cellular energy needs, which decreases the tissue’s need for oxygen (Seiyama, Shiga and Maeda, 1990). Seiyama et al. (1990) state that there is a direct relationship between tissue temperature and metabolism in that the greater the cooling, the greater the decrease in metabolism. Knight and Draper (2008) suggest application of ice should be within minutes of injury for best results in limiting secondary injury and controlling neural inhibition. Knight and Draper (2008) state that crushed ice packs are the most effective type of cold modality because they extract greater amounts of heat from the body when applied directly to the skin (LaVelle and Snyder, 1985; Mac Auley, 2001). At the same time, crushed ice packs are not so cold that they cause frostbite. Thygerson and Gulli (2005) recommend application of crushed ice, in bags, directly on the skin (Knight, 1995). In addition, intermittent application of ice has been shown to be a better therapeutic application than an application of a long duration (Knight and Draper, 2008). Frostbite (Bonney, Hughes and Janus, 1952) and nerve palsy (Dehne and Torp, 1971) can occur with continuous ice application, whereas, with intermittent ice application the tissue temperature remains low after each removal of the ice (Knight and Draper, 2008).

Compression is most beneficial once edema begins and will be effective as long as edema is present. Similar to cryotherapy, compression should be applied within minutes following injury (Knight and Draper, 2008). Constant compression is essential during immediate care, however intermittent compression is most effective when the goal is to remove edema through the lymphatic system (Knight and Draper, 2008). Compression also enhances the cooling effect of the ice application by reducing the amount of heat delivered to the tissue (Merrick, Knight, Ingersoll, Potteiger, 1993).

Elevation is also used to decrease capillary and tissue hydrostatic pressure due to the relative position and weight of the fluid at an injury site. Hydrostatic pressure is greater when a body part is in a dependent position (lower) than when it is elevated because there is more fluid above (Knight and Draper, 2008; Hargens, 1982). Finally, Knight and Draper (2008) describe the importance of stabilization of the injured limb is to reduce pain and neural inhibition through minimizing the need for muscle spasm and guarding as a natural body protective mechanism.

Table 3: Acute Injury Management Historical Timeline

(Mobility, Cryotheapy and Cryokinetics)

1867	**PAGET, J.** Questioned "rest" for all painful joints following injury. Started looking at mobility early after injury.
1919	**EVERIDGE, J.** Following WWI: Ice treatment method.
1930	**Heyman, C.** Joint manipulation.
1954	**Perkins,G.** Joint movement.
1964	**GRANT, A.** Cryokinetics: ice massage. **HAYDEN, C.** Cryokinetics: early tx program.
1967	**MOORE, R., NICOLLETTE, R. & BEHNKE,R.** Therapeutic use of cryotherapy for athletic injuries.
1971	**DEHNE, E & TORP, R** Treatment of joint injuries by immediate mobilization.
1979	**KNIGHT, K.** Ankle rehab with cryotherapy and exercise.
1982	**HOCUTT, J., JAFFE, R., RYLANDER, C. & BEEBE,J** Cryotherapy and ankle sprains.
1991	**KANNUS, P. & RENSTROM,P.** Intervention: operation, cast or early controlled mobilization.
1996	**SWENSON, C., SWARD, L. & KARLSSON, J.** Cryotherapy in sports medicine.
2003	**HOPKINS, J. & ADOLPH, J.** Affects of joint cryotherapy and lower chain function.
2007	**JONES,M. & AMENDOLA, A.** Immobilization vs. functional treatment of acute injury.
2013	**WILLIAMS, E., MILLER, S., SEBASTIANELLI, W. & VAIRO, G** Functional outcomes and cryotherapy of the ankle.

In summary, following acute injury assessment, injury management should include the implementation of rest, ice, compression, elevation and stabilization (RICES). RICES should be implemented within minutes of injury to control swelling, pain, muscle spasm, neural inhibition and secondary injury at the injury site (Knight and Draper, 2008; Hocutt, Jaffe, Rylander and Beebe, 1982). Application of RICES immediately following injury can aid in preparing the injury for appropriate clinical treatment, thus producing positive clinical outcomes. Acute injury management was not utilized during this study because there were no acute ankle injuries that occurred during the data collection period.

Cryokinetics

Knight and colleagues (1979, 1995, 2008) have investigated various acute treatment methods but have focused on one particular method: *cryokinetics*. Cryokinetics is defined as alternating cold application with active graded exercise for rehabilitating acute joint sprains (Knight and Draper, 2008) with the goal of numbing the injured body part to a level of analgesia and then working toward achieving pre-injury range of motion through progressive active exercise (Prentice, 2014). Cryokinetics was founded by Grant (1965) and Hayden (1965), but neither explained why they believed it worked. Moore, Nicolette and Behnke (1967) stated that one purpose of their research was to encourage additional research in the area of cryokinetics. Knight (1979) studied cryokinetics' effects within rehabilitation of injuries. Knight, Bryan, and Halvorsen (1981) concluded that: a) the purpose of cold applications post-immediate care was to facilitate pain-free exercise with less muscle spasm, allowing exercise to begin earlier and progress faster during rehabilitation; b) properly executed therapeutic exercise and cold application promote rehabilitation. Kerkohoff and associates (2001, 2002) emphasized that functional treatment is most effective in acute ankle sprain injuries. Therefore, performing intermittent exercise between icing of the cryokinetic protocol would meet the recommendation of Kerkohoff and colleagues.

Decreased circulation, metabolism and inflammation, and increased tissue stiffness are detrimental to acute injury rehabilitation because of the need for increased circulation and metabolism (Abakumova, 1978). However, cryokinetics provides benefits that compensate for the decrease in circulation and metabolism caused by the ice application (Dehne, 1980; Knight and Londeree, 1980). The exercises performed during cryokinetics should increase blood flow greater than that of heat application (Knight and Londeree, 1980), impedes the development of adhesions and reverses neural inhibitions (Dehne and Torp, 1971), and activates the lymphatic system to remove waste from the injured area (Bohlen, 2003; Porth, 2004).

RICES has been shown to be a thorough approach for immediate management of acute musculoskeletal injuries to address the development of swelling, pain, muscle spasm, neural inhibition and secondary injury, in preparation for clinical treatment of cryokinetics. Intermittent ice application and functional movement have been successful methods in the early treatment of acute ankle injuries. Pincivero, Gieck and Saliba (1993) demonstrated that the use of cryokinetics allowed for a return to pre-injury status within 6 days following a lateral ankle sprain. More recently, Kaur, Kaushal and Kaur (2019) concluded that cryokinetics was effective in improving proprioception of a laterally sprained ankle. However, the relationship between changes in perception and performance of an ankle sprain following a cryokinetic intervention is still unknown. Understanding this relationship may provide insight into how a cryokinetic intervention may improve the recovery process by assessing if changes in perception correspond with changes in performance.

Motor Control (Postural Control)

Stedman's Medical Dictionary (2001) defines proprioception as, "a sense of perception, usually at a subconscious level, of the movements and position of the body, and especially it's limbs, independent of vision: this sense is gained primarily from input from sensory nerve terminals in muscles and tendons (muscle spindles), and the fibrous capsule of joints combined with input from the vestibular apparatus." (page 806)

Lundy-Ekman (2013) stated that normal proprioception requires muscle spindles, joint receptors as well as cutaneous mechanoreceptors, and that the redundancy of this reflects the importance of proprioception to the control of movement. The interpretation of sensation into meaningful forms occurs in the cerebrum, however, to "perceive" involves acting on the environment and interpreting the sensation (Lundy-Ekman, 2013).

Somatosensation is sensory information from the skin and musculoskeletal systems. Much of the somatosensory information is not consciously perceived. Instead it is processed at the spinal level in local neural circuits or by the cerebellum to adjust movements and postures (Lundy-Ekman, 2013). Somatosensory receptors are classified as mechanoreceptors, which respond to mechanical deformation of the receptor by touch, pressure, strength, or vibration; chemoreceptors respond to substances released by cells; and thermoreceptors respond to heating or cooling at the superficial level (Lundy-Ekman, 2013). Nociceptors are pain receptors sensitive to stimuli perceived from mechanoreceptors, chemoreceptors and thermoreceptors that damage or threaten to damage tissue (Prentice, 2014; Lundy-Ekman, 2013; Deleo, 2006).

Prentice (2014) described that afferent nerves transmit impulses from the nociceptors toward the spinal cord, while efferent nerve fibers transmit impulses from the spinal cord toward the periphery. First order afferents transmit impulses from a nociceptor to the dorsal horn of the spinal cord. There are four types of first-order neurons: Aα, Aβ, Aδ, and C. Aα and Aβ have a larger diameter while Aδ and C are characterized with a smaller diameter. Aδ and C transmit sensations of pain and temperature. Aδ neurons originate from nociceptors in the skin and C neurons originate from the skin as well as ligaments and muscle (Prentice, 2014) as summarized in Table 4. Lundy-Ekman (2013) added that cutaneous receptors are not proprioceptors but contribute to stretching or increases in pressure on the skin and that Ruffini's corpuscles (type II) discharge in response to static joint angles. Joint receptors respond to mechanical deformation of the capsule and ligaments (type Ib) as well as inflammation (free nerve endings) as shown in Table 5.

Table 4: Nerve Classification - Letter System

Summary table from information gathered from:
Prentice, 2014; Lundy-Ekman, 2013; Denegar and Prentice, 2010; Knight and Draper, 2008.

Type of fiber	Diameter (μ M)	Conduction velocity (M/sec)	Structure	General function
A-Alpha	13-22	70-120	Alpha-motor neurons, muscle spindle primary endings, GTO.	Touch.
A-Beta	8-13	40-70	Muscle spindle secondary endings, skin.	Touch, kinesthesia.
A-Gama	4-8	15-40	Gama-motor neurons, skin.	Touch, pressure.
C	0.1-1	0.2-2	Skin, ligaments, muscle.	Pain, touch, pressure, temperature.

Table 5: Nerve Classification - Roman Numeral System

Summary table from information gathered from:
Prentice, 2014; Lundy-Ekman, 2013; Denegar and Prentice, 2010; Knight and Draper, 2008.

Type of fiber	Diameter (μ M)	Conduction velocity (M/sec)	Structure	General function
Ia	12-20	70-120	Muscle spindle primary endings.	Muscle stretch.
Ib	11-19	66-114	GTO, capsule, ligament,	Mechanical deformation.
II	5-12	20-50	Muscle spindle secondary endings.	Static joint position.

Second-order afferent fibers carry sensory messages from the dorsal horn to the brain and are categorized as nociceptive specific (Prentice, 2014). Second-order afferents receive input from Aβ, Aδ and C fibers, but nociceptive-specific second-order afferents respond exclusively to noxious stimulation and receive input only from Aδ and C fibers (Prentice, 2014; Lundy-Ekman, 2013). Third-order neurons carry information via ascending spinal tracts to various brain centers where the input is integrated, interpreted and acted upon (Denegar and Prentice, 2010). During this study, when the sensation of touch is applied, it is delivered through Aα, Aβ, Aδ and C fibers at various levels of conduction velocity. However, when the initial ice application of cryokinetics is applied, it takes 15 to 20 minutes for the sensation to progress to a state of numbness. This may be due to the conduction velocity and diameter of the C fibers that affect temperature sensitivity. C fibers have a very slow conduction velocity and small diameter compared to the other fibers. Therefore, the continued intermittent application of ice during cryokinetics further enhances the numbness at the ankle.

Ankle ROM or changes in ankle joint position stimulate Ia (muscle stretch), Ib (capsule) and II fibers (joint position). Ia, Ib and II fibers all have a faster conduction velocity and larger diameter than that of the C fibers (temperature). Therefore, temperature changes take a longer time to affect ROM changes. Increased time of ice exposure is needed to observe decreased function of an uninjured ankle due to significant difference between conduction velocities and diameters of nerve fibers involved.

Previous studies have investigated ankle range of motion and therapeutic modalities (Bleakley, O’Connor, Tully, Rocke, MacAuley, McDonough, 2007), and exercise (Knight and Londeree, 1980). Cryotherapy as treatment for ankle injuries specifically has also been studied (Hopkins and Adolph, 2003; Knight and Draper, 2008). Research considering how a cryokinetic protocol affects postural stability and perceptual motor function of an uninjured ankle versus a previously injured ankle has yet to be studied. This area of research could identify the importance of cryotherapy as injury management and provide evidence of why an injured person should or should not return to previous activity. The aim of this study is to begin to understand how changes in sensory perception, as a result of cryokinetics, relate to voluntary motor performance (ROM) and postural stability.

Measurement Tools

A number of tools will be used to gather data in evaluation of ROM, sensation and postural stability throughout this study. The primary tools include: manual goniometer; aesthesiometer (two-point discrimination tool); monofilament; and force platform. In addition to the previous objective test tools, a subjective questionnaire (L. E. F. S.), which is a standardized clinical outcome measurement tool, will be used to gather participant perception of function.

Reliability, Validity and Standardization

Reliability indicates how well a certain procedure or instrument is able to produce the same result under the same conditions (Kerlinger, 1973; Clarkson, 2005), while validity establishes how well a method or device measures what it is intended to measure (Currier, 1984; Clarkson, 2005). Validity requires reliability, but reliability does not ensure validity (Lea and Gerhardt, 1995). Many researches (Lea and Gerhardt, 1995; Clarkson, 2005; Bell-Krotoski, Fess, Figarola, and Hiltz, 1995) report a common theme of standardizing tests to increase the reliability and validity when gathering data.

Outcome Measures

Outcome measures are standardized assessments that are linked to performance. The error of measurement associated with a specific outcome measure is tied to the measurement of clinically meaningful change. In order to document change it is necessary for the difference in outcome scores to surpass the error of measurement (Dvir, 2015).

The smallest detectable difference (SDD) on a measurement scale is the amount of difference for which anything smaller cannot be reliably distinguished from random error in the measurement (Lassere, Van der Heijde, Johnson, Boers and Edmonds, 2001). Whereas the minimal detectable change (MDC) or standard error of measurement (SEM) is a function of the standard deviation of the study sample and the reliability of the measurement instrument (Wyrwich, 2004). Additionally the minimal clinically important difference (MCID) is the smallest difference in outcomes that participants/clients perceive as beneficial (Jaeschke, Singer and Guyatt, 1989). To my knowledge there is no data specific to clinically significant change in ankle range of motion.

Goniometer

Range of motion measurements should be objective as well as reliable and valid (Lea and Gerhardt, 1995). Researchers have concluded that the universal, two-arm goniometer is the preferred instrument for measuring range of motion of extremities (Gajdosik and Bohannon, 1987; Lea and Gerhardt, 1995). Lea and Gerhardt (1995) stated that the two-arm goniometer is also the most economical and most portable device for range of motion measurement. This particular goniometer is transparent with two arms connected in the middle with a protractor. When measuring range of motion, one arm remains stationary while the other arm moves with the other segment of the joint being measured.

That said, research has reported that the use of a goniometer has poor inter-rater and intra-rater reliability (Elveru, Rothstein, Lamb, 1988; Martin and McPoil, 2005; Wrobel and Armstrong, 2008; Rome, 1996). However, adhering to a standardized method of gathering range of motion increases validity and reliability (Lea and Gerhardt, 1995; Clarkson, 2005). Gerhardt (1992) suggested that the following list of procedural principles be followed to enhance reliability and validity: accurate identification of anatomical landmarks; proper positioning and stabilization of proximal and distal components of the joint being measured; correct application and stabilization of the goniometer; consistency of techniques used to measure the range of motion; appropriate recording of the results; and recognition and documentation of all factors that may affect the measurement. Additional studies have suggested that the use of standardized measurement techniques that assisted in accurate identification of landmarks, consistent identification of the starting position (neutral zero method), and secure application of the goniometer showed improved intra-tester reliability. Photographs are accepted standards used for comparison to determine the accuracy of the universal goniometer, and when these photographs are used at the same time as the measurement, concurrent validity can be assessed (Clarkson, 2005).

Lea and Gerhardt (1995) stated that if accuracy requires repeatability, multiple measurements should be performed unless an acute condition is present. Passive range of motion can be of greater value than active range of motion in athletes who are experiencing pain and may serve as a more valid indicator of change within connective tissues of the joint (Flowers and Michlovitz, 1988). Lea and Gerhardt (1995) summarized that if a specific range of motion of a joint is to be measured more than once it should be obtained by the same examiner and should be measured using the same device for subsequent or repetitive measurements. To obtain the most reliable measurements of joint range of motion, the method should include standardized measurement techniques, a single device for measurement, and a single system of documentation (Lea and Gerhardt, 1995). It can be concluded that in order to ensure validity and reliability of range of motion testing, clinicians using goniometers should adopt standardized methods of testing including the use of one or the same examiner; use of the same tool; and use of the tool under the same environment (Gajdosik and Bohannon, 1987; Lea and Gerhardt, 1995; Clarkson, 2005). Adoption of these principles as a standard of practice would enhance the quality of test-retest reliability.

Two-Point Wheel (Aesthesiometer)

Cashin and McAuley (2017) describe the two-point discrimination (TPD) test as a quantitative assessment of tactile acuity, defined as the distance between compass points necessary to feel two contacts. The TPD test continues to be extensively used clinically with the use of an aesthesiometer (Lundborg and Rosen, 2004; Jerosch-Herold, 2005). It is a tool that measures an individual's cutaneous two-point perceptual threshold. The aesthesiometer is arranged with its two points close together, and are simultaneously touched to the skin. Without the aid of vision, each participant reports whether they felt one or two points of contact. The points are systematically separated from each other and reapplied to the skin until the participant has reported the perception of two points. The distance separating the two points represent the two-point threshold. During the current study, the test will be performed before and after the cryokinetic protocol.

Lotze and Moseley (2007) stated that while TPD is dependent on peripheral innervation density and intact neural pathways, it is also believed to be dependent on response profiles of central somatosensory function. The TPD test has therefore been recommended as a simple clinical tool to measure the magnitude of the S1 representations (Cashin and McAuley, 2017).

Monofilament

Semmes-Weinstein monofilaments (SWM) provide a repeatable instrument stimulus with a small standard deviation in contrast to other handheld tools (Bell-Krotoski, Fess, Figarola, and Hiltz, 1995). Bell-Krotoski et al. (1995) stated that SWM's are the best choice for objective sensory testing for light touch-deep pressure threshold. Collins, Visscher, De Vet, Zuurmond, and Perez, (2010) determined that the SWM are capable to detect true changes in sensory thresholds and concluded that SWM measurements are reliable when performed by one researcher. In addition, Bell-Krotoski (1995) stated that there was no evidence to support that summation in light touch-deep pressure testing would be an issue. That is, detection threshold would not be changed if the filaments were applied more than once.

Force Platform – Center of Pressure

Center of mass and center of pressure are terms with distinct definitions that can be misinterpreted at times. Winter (1995) defines center of mass (COM) as, "a point equivalent of the total body mass in the global reference system as is the weighed average of the COM of each body segment in 3D space." (page 194), and the center of pressure (COP) as, "the point location of the vertical ground reaction force vector. It represents a weighted average of all the pressures over the surface of the area in contact with the ground. It is totally independent of the COM." (page 194). Blaszczyk (2016) stated that force plate evaluation is the safest and most efficient method for assessing postural control based on COP oscillations. Research of COP have included studying Parkinson's disease (Blaszczyk and Orqwiec, 2001), aging (Singer, Prentice, Mcllroy, 2013) and individuals post-stroke (Schnikel-Ivy, Singer, Inness, 2016), as well as postural stability (Blaszczyk, 2008; Blaszczyk, Beck and Sadowska, 2014), quiet stance and postural control in young adults (Winter, Prince, Powell, Zabjek, 1996; Maurer and Peterka, 2005).

The COP sampling frequency, trial length, and number of trials are all considerations that may impact test results (Blaszczyk and Orawiec, 2001; Corriveau, Hebert and Raiche (2000); and Pinsault and Buillerme, 2009). Scoppa, Capra, Gallamini, and Shiffer (2013) described the Center of Pressure Sway Signal as consisting of the X, Y time plot of the COP during a test in that the X axis is the horizontal medio-lateral plane and the Y axis is the horizontal trace of the antero-posterior plane. The technical performance of the force platform should have an accuracy better than 0.1 mm; precision better than 0.05 mm; resolution higher than 0.05 mm; and linearity better than 90% over the whole range of measurement parameters (Scoppa et al., 2013). Scoppa et al. (2013) concluded that a steady and reliable recording time for a quiet standing test should be no less than 25 seconds with a sampling rate of at least 50 Hz. Following these parameters would encourage accuracy and sensitivity during a quiet standing test (Scoppa et al., 2013). Blaszczyk (2016) stressed the importance of the directional measures of the sway vector, sway directional index and sway ratio to detect postural stability impairments, stating that these measurements can provide a better assessment of postural control. The results of Blaszczyk's (2016) investigations provided a reliable standard for the assessment of postural stability to be used as a predictor of balance impairments.

Furmacek, Slomka and Juras (2014) reviewed literature regarding the influence of local cryotherapy on the proprioception system. Williams, Miller, Sebastianelli and Vairo (2013), as well as Dewhurst, Richies and De Vito (2007) used force plates as their instrument for measuring the effects of cryotherapy on proprioception. It was summarized that the effects of cryotherapy on proprioception were varied and frequently contradictory (Furmacek et al., 2014). Twelve studies reported no adverse effects of proprioception resulting from cryotherapy application and five studies demonstrated a negative effect (Furmacek et al., 2014). Williams et al. (2013) did not observe any difference after application of cryotherapy (crushed ice). Dewhurst et al. (2007) evaluated two quiet standing positions with a large and narrow support base with eyes open and eyes closed and also found no significant change following cryotherapy. Ingersoll, Knight and Merrick (1992) assessed single-leg balance, using only a stopwatch for timing, following cryotherapy and found that none of their dependent variables were significantly changed. Despite force plate measurements of postural stability having consistent results, considerable variability is present when evaluating the impact of cryotherapy protocols on postural stability. The differences across studies in the cryotherapy protocol used make it difficult to compare studies or suggest why the results are so mixed.

Summary

Ankle injuries occur frequently in soccer and in court sports like volleyball and basketball, and the incidence during sport is increasing at all ages and sporting activities. To summarize the identified gaps in the literature review: No research has reported how a dynamic protocol, like cryokinetics, affects an ankle with a history of injury; There is a lack of published research regarding why, or if, cryokinetics is more effective than standard acute care; Acute injury management does not include consistent timelines, standardized treatment parameters, or the incorporation of activity; The neural pathway involving neural inhibition has not been empirically tested; and Standardized acute treatment protocols are needed to better guide the therapist with a more thorough and evidenced-based therapeutic approach.

Therefore, the present research will measure range of motion, sensation and postural stability, before and after a cryokinetic intervention on uninjured ankles, compared to previously injured ankles, to better understand how and why a dynamic cryokinetic protocol could lead to the reported shorter recovery times from acute ankle injury. The results of the present study will provide introductory information involving how changes in sensory perception relate to cryokinetics, motor performance and injury, which can aid in understanding the role that sensory perception plays during rehabilitation.

Objectives

The primary aim of the current study was to investigate how cryokinetics relate to changes in sensory perception (pain and tactile acuity) in association with motor performance of uninjured and previously injured ankles. Introductory information involving the relationship of cryokinetics with sensation, AROM, PROM, functional range of motion and postural stability, of uninjured ankles and ankles with previous history of injury, can aid in understanding both the mixed findings reported in the literature reviewed above, as well as the role that cryokinetics plays during rehabilitation of acute injury.

The objective to better understand the role that cryokinetics plays during rehabilitation of acute injury included was broken down to include: 1. How cryokinetics affects sensory perception of the uninjured and previously injured ankle; 2. How cryokinetics affects range of motion of the uninjured and previously injured ankle; 3. How cryokinetics affects motor performance of the uninjured and previously injured ankle

Hypotheses

Originally, the focus of this thesis was on acute injury response to cryokinetics. Without any acute injury cases during the defined data collection period the focus was shifted to evaluate uninjured and previously injured ankles' response to cryokinetics. Table 6 outlines the four hypotheses that guided the current research. First, range of motion of an uninjured ankle will decrease following a cryokinetic protocol. This range will be observed through active, passive and functional range of motion testing of the ankle joint in the sagittal plane. Secondly, range of motion of an ankle with a previous injury history will also decrease following cryokinetic protocol. This too will be observed through active, passive and functional range of motion testing of the ankle joint in the sagittal plane. Thirdly, sensation to light touch will decrease following cryokinetic protocol for the uninjured and injured ankles. Sensation will be evaluated through the use of a 2-point wheel and monofilament. Lastly, Centre of Pressure values will be more variable following the cryokinetic protocol for both uninjured and injured ankles, as demonstrated through postural stability tasks performed on a force platform.

Table 6: Hypotheses
1. ROM of an uninjured ankle will decrease following cryokinetic protocol.
2. ROM of a previously injured ankle will decrease following cryokinetic protocol.
3. Sensation to light touch will decrease following cryokinetic protocol for uninjured and previously injured ankles.
4. COP values will be more variable following cryokinetic protocol for uninjured and previously injured ankles.

Thus, the present study will investigate how a cryokinetic protocol affects an uninjured ankle and a previously injured ankle that is asymptomatic, with regards to sensation, ROM, and postural stability (C.O.P). Through evaluation of an uninjured ankle and an ankle that is asymptomatic from a recent sprain, I predict: 1. ROM of an uninjured ankle will decrease following cryokinetic protocol as evident through ROM testing; 2. ROM of a previously injured ankle will decrease following cryokinetic protocol as evident through ROM testing; 3. Sensation to light touch will decrease following cryokinetic protocol for uninjured and previously injured ankles as evident through scores from two-point wheel and monofilament testing; and finally, COP values will be more variable following cryokinetic protocol for uninjured and previously injured ankles as evident by data gathered by force plates.

Chapter 2 - Methods

Eligibility Criteria

Participants in this study were healthy, university level volleyball, basketball and soccer athletes, who were uninjured, or currently asymptomatic from a previous knee or ankle injury and did not have a history of ankle or knee surgery within the past year. All participants were enrolled academically at the University of Manitoba, active participants in Canadian university sport ("U-Sport"), and competed for the University of Manitoba. Written informed consent forms were completed prior to any testing.

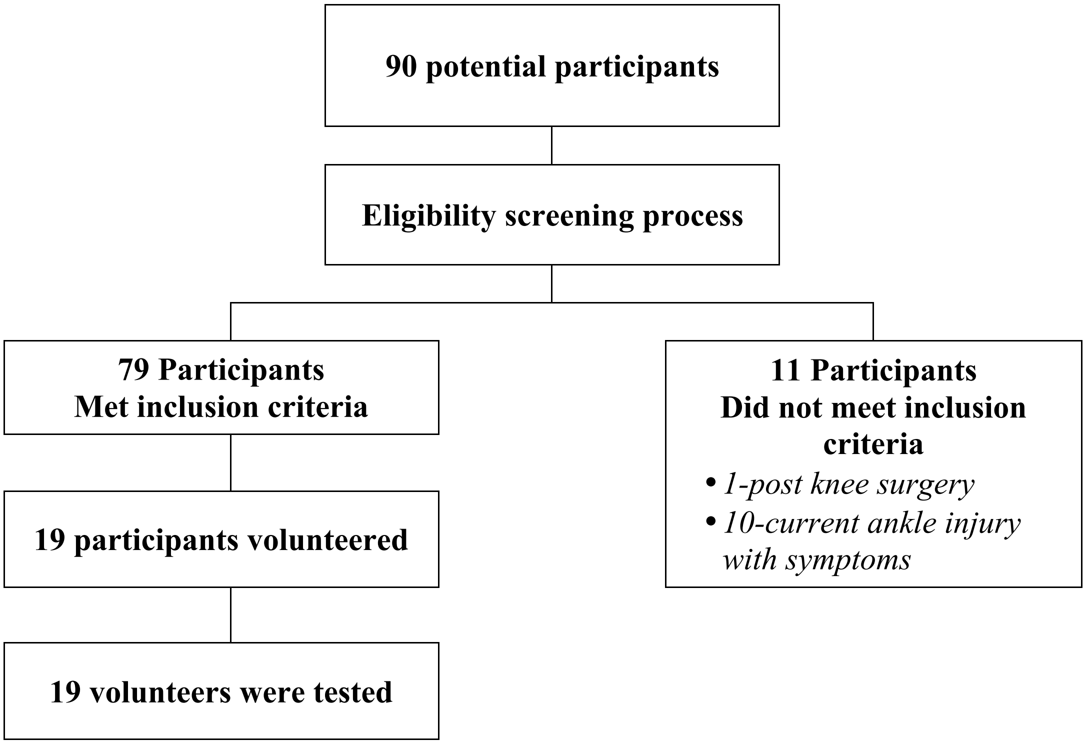
All eligibility criteria were approved by the University of Manitoba Research Ethics Board – Education and Nursing (ENREB).

Participant Recruitment

Participant recruitment was from a fixed sample from varsity teams. Corespondence (Appendix A) was sent to five coaches (men's and women's volleyball and basketball and women's soccer) at the University of Manitoba via e-mail. This e-mail included the outline of the study and the request for a graduate student to present this opportunity to their athletes at a time convenient for each team. Following approval from the coaches, participants were provided details about the requirements of the study through a face-to-face presentation of this opportunity by a student researcher. Scripts for various presentation options can be found in Appendix B.

As approved by University of Manitoba Research Ethics Board – Education and Nursing (ENREB), the current study was presented to 90 potential participants. Eleven of the initial group did not meet inclusion criteria due to injury history. Of the 79 remaining potential participants, 19 athletes volunteered to participate in the baseline group and were tested. The participant recruitment flow chart is demonstrated below:

Participant Recruitment Flow Chart



Participants

Demographic information was gathered and is presented in table 7, including height, weight, age, sex, dominant foot for kicking a ball or a single leg jump, lower leg injury history, team affiliation, and years of experience at the U-sport level. Of the 19 participants (9 from the men's team, 10 from the women's team), eight participants were from basketball (6 from the men's team, 2 from the women's team), five from the women's soccer team and six from volleyball (3 from each team). The U-Sport experience ranged from being a rookie to a graduating fifth-year player. The age range of the athletes was 18-23 years with a mean of 20.3 years.

Table 7: Participant Demongraphics Summary

		History of Previously Injured Ankles	No History of Previously Injured Ankles	Summary
Participants		10	9	19
Basketball		4	4	8
Soccer		2	3	5
Volleyball		4	2	6
Mean ht (cm)		185.8	175.6	180.9
Mean wt (kg)		83.6	71.8	78.0
Age range (years)		18-23	18-23	18-23
Mean age range (years)		20.2	20.3	20.3
Mean experience at U-sport level (years)		2.2	2.1	0-5
Dominant leg – kick	**R**	8	6	14
	L	2	3	5
Dominant foot – jump	**R**	5	6	11
	L	5	3	8

Ethical considerations

I (the student researcher for this study) am one of the current Certified Athletic Therapists (CAT(C)) in the Bison Athletic Therapy Centre, but not currently the head CAT(C) for Bison volleyball or basketball. I am, however, the head Certified Athletic Therapist for the women's soccer team. The sports of basketball, soccer and volleyball are the source of the baseline group as well as the participant pool in which to draw injured athletes from. Recruitment presentations to the soccer team were performed by a different student researcher to mitigate the opportunity of "position of authority" during the recruitment process. All procedures were approved by the University of Manitoba Research Ethics Board – Education and Nursing (ENREB).

Research Setting

All research (before and after injury) was conducted at the University of Manitoba, in the biomechanics lab, within the Faculty of Kinesiology and Recreation Management. This lab housed all the required tools for this current study. The graduate student and author of this thesis has been a Certified Athletic Therapist (CAT(C)) since December 2000, and was the primary researcher to collect all initial, uninjured data, as well as perform any assessments and treatments after injury. All data collected was also recorded by the same assessing/treating CAT(C). Additional personnel were present during the collection of data to assist with gathering demographic information and capturing aspects of the testing with digital photography.

Upon entry to the lab, each participant was provided the consent forms (Appendix C) and demographic information sheet (Appendix E) for review and completion. A verbal overview of the testing procedure was also completed followed by an opportunity to ask questions about the process.

The lab was arranged to accommodate a plinth (used for AROM and PROM testing, sensation testing and icing) (Figure 1a), an area against the wall for performing squats, side squats, lunge ROM testing (Figure 1b and 1c), walking and postural stability testing. The floor (Figure 1d) and force platforms (Figure 1e) were marked to standardize the foot placement.

Figure 1: Data Collection Set-up and Apparatus

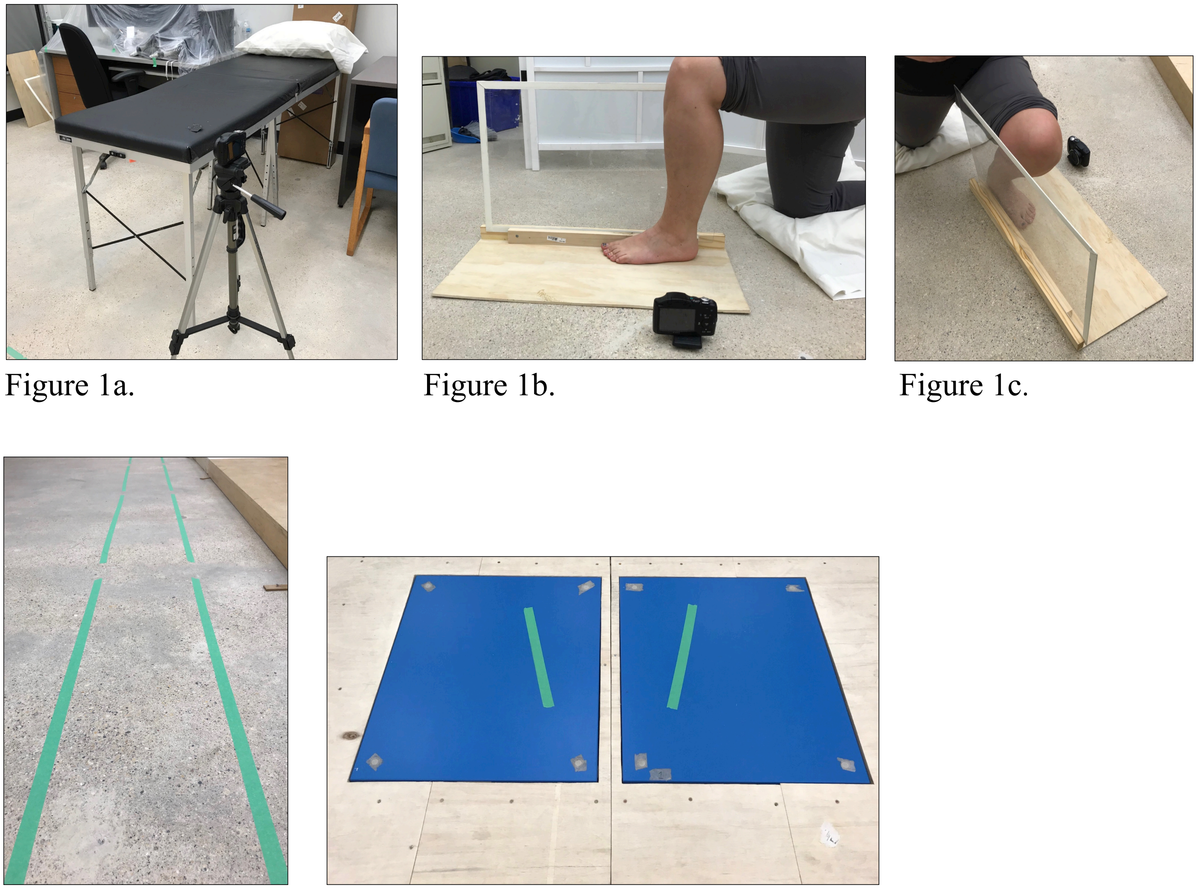


Figure 1a. Figure 1b. Figure 1c.

Figure 1d. Figure 1e.

Figure 1: Data collection set-up and apparatus used. a. Plinth and camera set-up; b. Kneeling lunge with anti-pronation apparatus and camera; c. Kneeling lunge with anti-pronation apparatus and camera; d. Marked floor for walking; e. Marked force platform for foot position.

Research Outline

Original Study Plan

Baseline data was collected from each participant. O_1 represents the observation/performance evaluation of each participant regardless of previous ankle injury history. The collection of O_1

was followed by the cryokinetic protocol (T), and a second collection of data represented as O_2 was completed immediately following T.

Table 8 outlines the timeline for the established assessment and treatment protocols for the original study plan.

Table 8: Original Research Outline

Baseline	UI	O_1	T	O_2
Case Study				
Treatment Day 1	I	O_3	T	O_4
Treatment Day 4	I	O_5	T	O_6
Week 3 (after injury)		O_7		
Week 6 (after injury)		O_8		

UI = uninjured ankle/asymptomatic ankle
I = injured ankle
T = treatment (cryokinetic protocol)
O = observation/performance (eval of sensation, ROM & postural sway)

If an injury had occurred by one of the participants following the baseline, the study would have proceeded as follows: After sustaining an ankle injury ("day 1" – within 24 hours of injury), each participant would undergo a physical/clinical assessment, and an observation/evaluation (O_3). T would then be completed, followed by O_4. Treatment would be provided for days 2, 3 and 4, however, for the purpose of this case study, only days 1 and 4 would be evaluated. O_1 and O_2 would serve as baselines in which to compare additional data to. T remains constant throughout the study. O_3 and O_4 would serve as base line after injury. O_5 to O_6 would be used to record the effects of T. Subsequent observation/evaluations would be completed at week 3 (O_7) and again at week 6 (O_8) following the initial injury to investigate the long-term effects of the treatment provided.

In addition to cryokinetics on the treatment days, the ankle would be supported with a standard ankle tape job to provide stability and limit painful movements of the ankle joint. If the tape is needed to be removed by the participant, a tensor wrap will be provided (with instructions for application). Instructions would be provided to each participant guiding them to: perform the cryokinetic protocol independently at home, once per day (in addition to the clinical session) for the first four days following injury; elevate the injury when sitting or lying down (elevate the foot higher than the hip). Crutch usage would be determined on an individual basis, dependent on each participant's function.

Current Study

No acute ankle sprains occurred during the time in which data was collected. Following analysis of the baseline data, a pattern was identified regarding the ankles that were previously injured, compared to the uninjured ankles. At that time, the focus of the study changed to further investigate the baseline data and evaluate the uninjured and previously injured ankles and their relationship with cryokinetics.

Clinical Tools and Research Instruments

Table 9: Summary of Clinical Tools and Research Instruments of the Original Study

(To identify tools/instruments used for the current study vs. typical clinical/therapy use.)

Tool/Instrument	Description	Data Collection Tool for DV	Typical Clinical Assessment	Current Research
Demographic information sheet	Collecting inclusion criteria information	✗	✗	✔
L.E.F.S.	Selected for standardized participation feedback	✗	✔	✗
Standardized assessment form	Created for this research	✗	✔	✗
Numeric pain scale	Selected for standardized participation feedback	✗	✔	✗
Two-point wheel	To evaluate sensation	✔	✔	✔
Monofilament	To evaluate sensation	✔	✔	✔
Manual goniometer	To evaluate range of motion	✔	✔	✔

Force platform	To measure COP	✔	✗	✔
Standardized treatment form	Created for this research	✗	✔	✗

A number of clinical tools were used in this study that are used during typical clinical evaluation of an injury as well as some more advanced instruments, not typically used in a clinical setting. Table 9 outlines which of the research instruments are typically used in a clinical setting and which were selected for this current study.

Demographic Information Sheet (Appendix E)

The demographic information document was used to gather pertinent personal information and information regarding their ankle injury history. This information included: participant number, age, height, weight, leg dominance, current team competing on, years of experience at the U-Sport level, history of neurological or orthopedic ankle injury and history of surgery in the past 12 months.

Lower Extremity Functional Scale (L.E.F.S.) (Appendix J)

The Lower Extremity Functional Scale (L.E.F.S.) is a subjective clinical questionnaire that has very good reliability reflecting the participants' interpretation of their ability (Binkley, Stratford, Lott and Riddle, 1999). This tool is specifically designed for the lower leg and is freely available to anyone who decides to use it. The L. E. F. S. is thought to inform the clinician of the subject's perception of their abilities at that time. This form will be completed at the beginning of every clinical session after an injury has occurred.

Standardized Ankle Assessment (Appendix H)

The standard clinical ankle assessment summarized from Brunkner and Khan (2009) and Magee (2008) was created and included in this study to ensure injury evaluation was consistent among participants. It was not included as an independent or dependent variable. The assessment included: an observation; function testing; active range of motion testing; passive range of motion testing; isometric testing; orthopedic testing; and palpation. All relevant injury information gathered would be recorded on the assessment sheet (Appendix G).

Numeric Pain Scale (Appendix K)

The numeric pain scale (0-10, with 0 representing no pain and 10 representing extreme pain) is a typical clinical tool used to gather the clients' interpretation of severity of pain following injury. Participant response was recorded while taking a history of the injury and at the beginning of each subsequent session of therapy.

2-Point Wheel, Monofilament (Sensory Perception)

Two-point wheel (Figure 2a) and monofilament (Figure 2b) are used during a typical assessment for evaluating skin sensation or altered skin sensation in a clinical setting. The tools will be used on the lateral aspect of the foot and ankle to gather participant feedback about sensation in the tested area.

Figure 2: Sensory Tools

Figure 2a. Figure 2b.

Figure 2: Application of sensory tools on the lateral aspect of the ankle. a. Two-point wheel; b. Monofilament.

Manual Goniometer (Range of Motion)

This type of goniometer (Figure 3a) has shown to be accurate in measuring range of motion at joints of the body. The non-invasiveness, relative ease and accuracy of this tool is the rationale for its' use in a typical clinical environment. The tool was placed on the surface of the skin in line with identified landmarks on the lateral ankle (Figure 3b), then the participant was asked to move their ankle in a desired direction. The range motion observed was then recorded. This will be followed by the examiner moving the ankle in a passive manor while measuring the range of motion, and again, recording the result.

Figure 3: Manual Goniometer

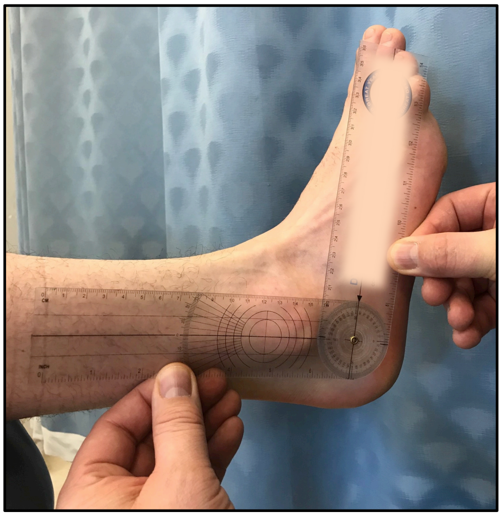


Figure 3a

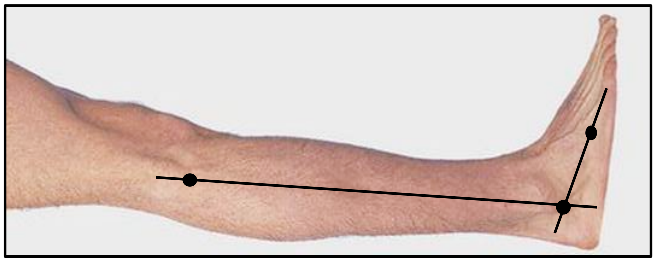


Figure 3b

Figure 3: Manual goniometer at lateral ankle. a. Manual goniometer at lateral ankle; b. Landmarks for goniometer.

Force Platform (Center of Pressure)

The force plate used for this study is the Kistler Type 9286B force plate. It is calibrated to detect small forces and place them into x, y and z dimensions using piezoelectric sensors. The signal from the force plate is sent to a Data Acquisition Device (DAQ), which relays a digital signal to the computer. BioWear is the software that records force data such as Center of Pressure and processes it for analysis. The data is saved as a text file as column formatted text for easier import for analysis. The length of each of the 3 trials for each condition is 30 seconds with a sampling frequency of 250 Hz. This rate was selected because of the low frequency content during standing static balance.

Evaluation of postural stability included trials of quiet standing with double and single leg support. The COP, measured with the force plate, was recorded during two-foot, quiet stance (bilateral); single leg (left foot) stance; and single leg (right foot) stance. Each of these conditions was repeated with the participants' eyes open and eyes closed, before and after an intervention. Thus, the independent variables were Previous Injury History (No Injury History; Injury History), Intervention (Before Cryokinetics; After Cryokinetics) and Vision (Eyes Open; Eyes Closed).

The specific dependent measures for Center of Pressure included:

COP Dependent Measures *Larger values demonstrated through these dependent measures can indicate less postural stability.*
Anterior/Posterior, Root Mean Square, Center of Pressure, Velocity (m/s)
Medial/Lateral, Root Mean Square, Center of Pressure, Velocity (m/s)
Anterior/Posterior, Root Mean Square, Center of Pressure (m)
Medial/Lateral, Root Mean Square, Center of Pressure (m)
Anterior/Posterior, Center of Pressure, Median Frequency (Hz)
Medial/Lateral, Center of Pressure, Median Frequency (Hz)

As previously performed by Hasan, et al (1996), the postural stability dependent variables were digitally calculated according to the following relationships:

$x_p= (-M_y + (F_x \times z_p))/F_z$

$y_p= (M_y + (F_y \times z_p))/F_z$

where x_p and y_p are the sagittal and lateral coordinates of COP, F_x, M_x, and F_y, M_y are the corresponding shear forces and moments of force, F_z is the vertical force, and z_p is the fixed height of the force platform surface relative to a reference frame whose origin is at the electronic center of the force platform (Hasan, Robin, Szurkus, Ashmead, Peterson and Shiavi, 1996).

The root mean square was calculated as a square root of the mean of the squared discrete anterior/posterior points in the COP timeseries. The velocity was calculated as the first time derivative of the COP displacement timeseries. The median frequency was calculated by subjecting the COP timeseries to the Fast Fourier Transform to obtain the frequency distribution. The median of the distribution was calculated by finding the central frequency that divides the frequency axis in half.

Protocol Design

A number of protocols were specifically created for use in the current study to ensure consistency of clinical execution and recording of the data. The protocols included were: Sessional timeline (Figure 4), clinical assessment process (Appendix H), sensory perception process, cryokinetic process, a process for measuring range of motion at the ankle, and a force platform measurement process. Templates for recording data were designed with this specific study in mind. These templates ensured that a systematic and organized gathering and recording of data was completed according to the protocols (Appendix F & G).

Figure 4: Session Timeline

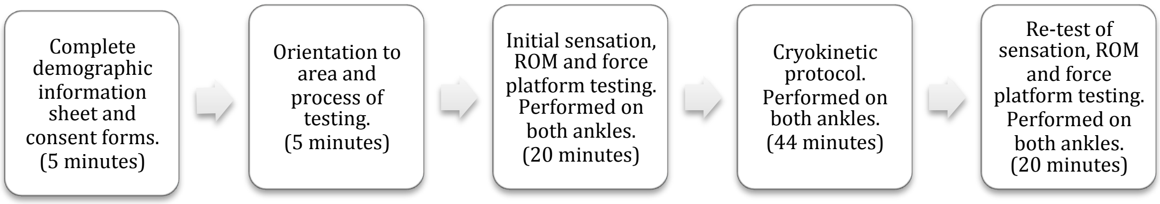


Figure 4: Timeline of experimental session.

Range of Motion Protocol

To standardize the evaluation of ROM, specific details were completed for each subject in attempts to maintain a high reliability and validity component throughout the study. The process was as follows:

With the subject lying supine on the plinth, they were asked to initially relax the foot and ankle while landmarks were identified on the skin bilaterally. The landmarks included: the head of the fibula; lateral malleolus; the base of the 5th metatarsal along with the shaft of the 5th metatarsal. A dot was first applied on the skin at the mid-point between the head of the fibula and the lateral malleolus; second at the hinge or center of the goniometer (just inferiorly to the lateral malleolus; and thirdly along the fifth metatarsal. These three markings served as the points of reference for the placement of the goniometer during active and passive ROM testing.

Active and passive ROM was evaluated with the subject supine on a plinth, while dynamic ROM was evaluated during a kneeling-forward lunge with the aid of a device (Figure 1b & 1c) to ensure that pronation was minimized during the movement of dorsiflexion at the ankle.

During functional range of motion testing, the test foot was placed on the board, which was attached to a thin sheet of Plexiglas. The Plexiglas was located on the medial side of the knee. The subject was instructed to keep the medial aspect of their knee at, but not touching or moving the Plexiglas. Subsequently, this device would keep the ankle neutral during the dorsiflexion movement. Each ROM measurement was performed three times and averaged (Clarkson, 2005), with the end ROM captured on a digital camera to ensure accurate results. The ROM data was also recorded manually then input in to R-Studio for analysis.

Two-Point Wheel Protocol

The aesthesiometer (two-point wheel) is a tool that measures an individual’s cutaneous two-point perceptual threshold. The aesthesiometer is arranged with its two points close together, and are simultaneously touched to the skin. Without vision, each participant would report whether they felt one or two points of contact. The points are systematically separated from each other and reapplied to the skin until the participant has reported the perception of two points. The distance separating the two points would represent the two-point threshold.

Monofilament Protocol

Without vision, each participant is asked to report whether they felt a sensation of light touch on contact with the tool. If no contact is felt, no response is expected.

- Touch skin with tool, beginning with the lateral proximal ankle of the participant and progress inferiorly.
- Record weather or not a sensation is felt by the participant by noting the size of the monofilament for that application.
- Repeat the process moving in an inferior direction from the point of origin.
- Record participant perception of sensation according to the size of the monofilament.

Force Platform Protocol

Table 10: Force Platform Protocol

Calibrate computer and platforms:	**Parameters set to: (Kistler, 30 seconds, sampling frequency = 250Hz)**
Instructions provided to each participant:	
“Step on force platforms with the center of the heel and the “ball of the foot” (1st MTP) on the tape provided”.	
“Place hands on hips and look forward at object on the wall in front of you”	
“Stand still for 30 seconds”. During eyes closed condition, participants were instructed to look at the image in front of them,	

on the wall and visualize it with their eyes closed.
“Step off the force platforms”.
Perform previous steps for each of these conditions. Eyes open bilateral stance Eyes open right foot stance Eyes open left foot stance Eyes closed bilateral stance Eyes closed right foot stance Eyes closed left foot stance

The force platform was used for evaluation of standing balance during double and single foot stance. Each participant stood on the platform without shoes. They were asked to initially stand on the platform with both feet (placed on independent platforms), then with each foot independently on a single platform and instructed as per table 10. Two foot and single foot stances were completed with eyes open and with eyes closed. Center of Pressure readings were recorded and evaluated for each of the conditions. Postural sway data was collected using the Kistler force platforms, using a sampling frequency of 250 Hz (Scoppa, et. al., 2013). There were six conditions (eyes open: bilateral, left and right foot stance; and eyes closed: bilateral, left and right foot stance) performed and recorded for 30 seconds each (Scoppa, et. al., 2013). The data obtained from the force platforms was summarized using MatLab, then input into R-Studio for analysis.

Cryokinetics

The cryokinetic protocol for this research summarized in the table below has been adapted from previous research based on Knight and Draper (2008) and through my clinical experience over the past 5 years. The technique begins with numbing of the injured area. Prentice (2008) suggested that clients may report a feeling of numbness within 12-20 minutes, however, if numbness is not perceived at the 20-minute marker, the initial exercise component should proceed. The numbness can last for 3-5 minutes (exercise execution) followed by an additional

3-5 minutes of ice (Knight, 1995). The exercises should be pain free and progressive, and allow for the athlete to concentrate on flexibility and strength (Rubley, Denegar, Buckley, 2003).

Summary of Cryokinetics (Knight, 1995; Knight and Draper, 2008):

1. Apply crushed ice until numb (12-20 minutes).
2. Exercise within limits of pain (3-5 minutes).
3. Re-numb ankle with ice (3-5 minutes).
4. Exercise within limits of pain (3-5 minutes).
5. Repeats steps 3 and 4.
6. Principles of exercising:
    a. All exercise should be active – performed completely by the athlete.
    b. All exercise must be pain-free.
    c. All exercise must be performed smoothly, without limping, twitching, or other abnormal motion.
    d. The exercise must be aggressively progressive but pain-free.

Protocol - Current Study

The cryokinetic protocol for the present study was as follows (summarized in table 11): Bagged crushed ice was secured to the medial and lateral aspects of the ankle for 15 minutes. At the 15minute time-point the lateral superficial skin was tested for sensation changes. If any changes in sensation were noted then the cryokinetic protocol was implemented. If sensation did not change from the original score, the bags of crushed ice would be reapplied for an additional five minutes. At that time, sensation at the lateral ankle was reevaluated. Immediately following the 15-20 minute application and subsequent removal of the ice, the participant would begin with a “mini squat” (feet hip-width apart with the upper back, glutes and heels against the wall – lowering to restriction). Three minutes of that activity would be completed, followed immediately by 5 minutes of bagged crushed ice secured to the ankle. The sequence of ice and movement would be repeated with changes in each movement pattern. Subsequent movements would include forward walking in a heel-toe fashion with the insteps of both feet 30 cm apart (like being on rails); and side lunge (with feet shoulder width apart) keeping the upper back, glutes and heels against the wall during the movement. The cryokinetic protocol would end with application of bagged crushed ice secured to the ankle for five minutes, followed by re-evaluated of ROM, sensation and postural sway.

Table 11: Cryokinetic Protocol

Crushed ice application	**15-20 minutes**
Movement “ mini squat ”	3 minutes
Crushed ice application	5 minutes
Movement “walk”	3 minutes
Crushed ice application	5 minutes
Movement “side lunge”	3 minutes
Crushed ice application	5 minutes

Statistical Analysis

This study considered how changes in sensory perception associated with cryokinetics relate to motor performance of uninjured ankles and previously injured ankles. There were three independent variables (IV) and three dependent variables (DV). The first of the IV was “Previous Injury History”, which included participant history of ankle injury. Participants reported either no ankle injury history or a history of ankle injury. The second IV was “Intervention”. This IV included the status before and after an intervention of cryokinetics. The third IV was “Vision”. This IV involved the participants’ eyes being open or closed. The dependent variables included sensation, end range of motion of dorsiflexion (averaged over three trials) and postural stability.

In order to test the interaction of the independent variables, for sensation and range of motion, a 2-Previous Injury History (injury history, no injury history) x 2-Intervention (before cryotherapy, after cryotherapy) mixed ANOVA was conducted. Previous Injury History was the between subject and the time period was within subject. Postural stability was evaluated using a 2-Previous Injury History (injury history, no injury history) x 2-Intervention (before cryotherapy, after cryotherapy) x 2-Vision (eyes open, eyes closed) mixed ANOVA. The data analysis of double leg quiet standing evaluated 19 participants whereas each ankle was analyzed separately for single leg quiet standing (N=38). Previous Injury History was the between subject while Intervention and Vision was within subject. Post hoc analyses were conducted using Tukey's HSD.

Chapter 3 – Results

Sample Characteristics

Ten of the participants had reported a history of ankle injury but were asymptomatic at the time of the testing. Table 12 outlines the details of the ten participants who reported a history of a sprained ankle. One of the participants reported one ankle fracture but no history of ankle sprains. Of the nine remaining participants, one reported multiple ankle sprains (3), over a six-year span, prior to this study. The remaining eight participants reported that they sustained only one ankle sprain prior to this study. The time frame in which these ankle sprains reportedly occurred was between one and ten years leading up to this study.

Table 12: Participant Ankle Injury History - Detail

	Male Athletes	Female Athletes	Summary
Previous injuries (self-report)	7	2	9
Basketball athletes reported previous ankle sprain	4	0	4
Soccer athletes reported previous ankle sprain	x	2	2

Volleyball athletes reported previous ankle sprain	3	0	3
Athletes reporting history of one ankle sprain	6	3	9
Athletes reporting history of multiple ankle sprains	1	0	1
Athletes reporting history of previous fracture (lower leg)	1 (MVB)	1 (WVB)	2
Ankle sprain of dominant leg-kick	3	2	5
Ankle sprain of dominant leg-jump	4	2	6
Year-range of ankle sprains prior to this study	1-10	2-6	1-10
Mean years of ankle sprains prior to this study	4.1	4	x

Sensation – Two-Point Discrimination

Analysis of the two-point discrimination data revealed a significant main effect for Intervention, *F* (1,36) = 52.5, *p* < .001. The main effect of Intervention demonstrated that the mean two-point discrimination was 10.4 mm (SD=3.65) Before Intervention, which was lower than the mean for the After Intervention, which was 15.8 mm (SD=5.41). There was no significant difference between the groups for the two-point discrimination regardless of Previous Injury History, *F* (1,36) = 2.11, *p* = .15, nor the interaction between Previous Injury History and Intervention for two-point discrimination, *F* (1,36) = 0.013, *p* = .90. The complete summary of statistical data for two-point discrimination can be viewed in Appendix M.

Sensation – Monofilament

Monofilaments are not continuous variables. The set used for this study included 0.07, 0.4, 2.0, 4.0 and 300 gram monofilaments. A comparison of before and after cryokinetics demonstrated that all, but one ankle (P14, left ankle) displayed a decrease in sensation, after cryokinetics. The complete summary of the monofilament test results can be found in Table 13.

Table 13: Summary of Monofilament Testing

Summary of Monofilament Testing

	Monofilament Right Ankle			Monofilament Left Ankle		
Participant	**Before Cryokinetics**	**After Initial Ice**	**After Cryokinetics**	**Before Cryokinetics**	**After Initial Ice**	**After Cryokinetics**
P1	2.0	4.0	4.0	2.0	4.0	4.0
P2	0.4	4.0	4.0	0.4	2.0	4.0
P3	2.0	4.0	300.0	2.0	4.0	300.0
P4	2.0	4.0	4.0	2.0	4.0	4.0
P5	2.0	4.0	4.0	2.0	2.0	4.0
P6	2.0	4.0	4.0	2.0	4.0	4.0
P7	2.0	4.0	4.0	2.0	4.0	4.0
P8	2.0	4.0	300.0	2.0	4.0	4.0
P9	0.4	2.0	4.0	0.4	2.0	2.0
P10	2.0	4.0	4.0	2.0	4.0	4.0
P11	2.0	4.0	4.0	0.4	2.0	4.0
P12	2.0	4.0	300.0	2.0	4.0	4.0
P13	0.4	2.0	2.0	0.4	2.0	2.0
P14	0.07	0.4	2.0	2.0	0.4	2.0
P15	2.0	2.0	2.0	4.0	2.0	4.0
P16	2.0	4.0	4.0	2.0	2.0	4.0
P17	2.0	4.0	4.0	2.0	4.0	4.0
P18	0.4	0.4	2.0	0.4	0.4	2.0
P19	4.0	4.0	4.0	0.4	4.0	4.0

All measurements are in grams of pressure.

Active Range of Motion

The complete summary of statistical data for all types of range of motion can be viewed in Appendix N. Analysis of the active range of motion data did not demonstrate any significant main effects or interactions. Previous Injury History, $F(1,36) = 2.84$, $p = .10$; Intervention, $F(1,36) = 1.83$, $p = .18$; interaction of Ankle Injury History and Intervention, $F(1,36) = 1.40$, $p = .24$.

Passive Range of Motion

Analysis of the passive range of motion data did not demonstrate any significant main effects or interactions. Previous Injury History, $F(1,36) = 0.69$, $p = .40$; or Intervention, $F(1,36) = 0.47$, $p = .49$; interaction of Ankle Injury History and Intervention, $F(1,36) = 0.53$, $p = .47$.

Functional Range of Motion

Analysis of the functional range of motion data did not demonstrate a main effect for Previous Injury History $F\ (1,36) = 1.33$, $p = .25$; or Intervention, $F(1,36) = 0.17$, $p = .67$. There was a significant interaction effect between Previous Injury History and Intervention for functional range of motion, $F\ (1,36) = 4.71$, $p = .03$. A post hoc test using Tukey's HSD showed that the No Previous Injury:After and Previous Injury:After groups differed significantly at $p < .05$.

Figure 5: Functional Range of Motion

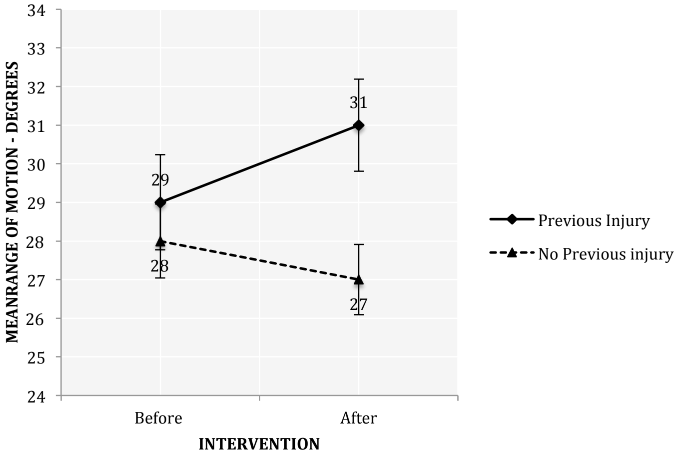


Figure 5: Functional range of motion interaction between Previous Injury History (previous injury and no previous injury) and Intervention (before and after cryokinetic protocol).

Figure 5 illustrates the inverted relationship with Previous Injury History and Intervention on functional range of motion. Post hoc analysis found that functional range of motion before the cryokinetic intervention did not demonstrate a significant difference between Previous Injury History (no history of ankle injury and history of ankle injury). However, after the cryokinetic intervention there was a statistically significant difference of functional range of motion where ankles with a history of injury had a larger functional dorsiflexion range compared to ankles without injury history. In other words, after a cryokinetic intervention, previously injured ankles demonstrated an increase in dorsiflexion functional range of motion compared to that of ankles without previous injury.

Postural Stability

Table 14: Summary Table of Postural Stability - Two Legged Stance

COP Dependent Measures		Main Effects						*p-values* Main Effect			*p-values* Interactions			
		Intervention		Previous Injury History		Vision		INT	PIH	VIS	INT:PIH	INT:VIS	PIH:VIS	INT:PIH:VIS
		Before	After	No Previous Injury	Previous Injury	Eyes Open	Eyes Closed							
Postural Stability Two Leg Stance **(Velocity: Meters/second) (COP: Meters) (Median Frequency: Hz)**	BAPrmsCOP_vel N=15	0.01^{b} ± 0.004	0.012^{b} ± 0.003	0.009$^{b\,c}$ ± 0.004	0.014$^{b\,c}$ ± 0.004	0.01$^{b\,c}$ ± 0.004	0.013$^{b\,c}$ ± 0.004	< .001^{b}	< .001^{b}	< .001^{b}	.057	.29	.015^{c}	.47
	BMLrmsCOP_vel N=15	0.0056^{b} ± 0.002	0.0041^{b} ±0.001	0.0043 ± 0.001	0.0047 ± 0.001	0.0043 ± 0.001	0.0047 ±0.001	< .001^{b}	.16	.32	.82	.25	.13	.78
	BAPrmsCOP N=17	0.01 ±0.004	0.012 ± 0.003	0.0114 ± 0.004	0.0112 ± 0.004	0.009 ± 0.003	0.013 ± 0.004	.11	.19	.83	.18	.87	.51	.23
	BMLrmsCOP N=15	0.0013^{b}±0.0006	0.0018^{b} ±0.0008	0.0146^{b} ±0.0007	0.0017^{b} ±0.0008	0.001 ± 0.0005	0.001 ± 0.0006	.003^{b}	.043^{b}	.87	.84	.63	.09	.82
	Bfmed_APCOP N=17	0.32 ± 0.09	0.34 ± 0.15	0.34 ± 0.13	0.32 ± 0.12	0.29^{b} ± 0.11	0.39^{b} ±0.15	.96	.07	< .001^{b}	.34	.57	.06	.106
	Bfmed_MLCOP N=16	0.64 ± 0.17	0.58 ± 0.15	0.66 ± 0.16	0.57 ± 0.16	0.6 ± 0.16	0.63 ± 0.17	.38	.99	.61	.4	.87	.5	.95
	MLrmsCOP N=33	0.009 ± 0.003	0.01 ± 0.005	0.01 ± 0.005	0.01 ± 0.003	0.007^{b} ±0.001	0.01^{b} ± 0.005	.43	.79	< .001^{b}	.22	.93	.58	.18
	fmed_MLCOP N=33	0.97$^{b\,c}$ ±0.24	0.86^{b} ±0.2	0.9^{c} ± 0.23	0.095^{c} ± 0.228	0.83$^{b\,c}$ ± 0.22	1.0$^{b\,c}$ ± 0.21	.01^{b}	.29	.001^{b}	.87	.28	.68	.01^{c}

Summary Table of Postural Stability [a]
INT=Intervention; PIH=Previous Injury History; VIS=Vision; B=bilateral; AP=anterior /posterior; ML=medial/lateral; rms=root mean square; vel=velocity; COP=center of pressure; fmed=median frequency; [a] Values are presented as mean ± SD (95% confidence level). [b] Significant difference for Main Effect. [c] Significant difference for Interaction.

Two-Legged Stance

Bilateral, Anterior/Posterior, Root Mean Square, Center of Pressure, Velocity.

Analysis of BAPrmsCOP_vel data demonstrated main effects for Previous Injury History, Vision and Intervention, as well as a statistically significant interaction between Previous Injury History and Vision (see Table 14).

The Previous Injury History statistics from BAPrmsCOP_vel demonstrated the mean for the condition of Previous Injury History was 0.014 m/s (SD=0.004), which was significantly larger than the mean for the condition of No Previous Injury History, at 0.009 m/s (SD=0.004).

Analysis of Vision demonstrated the mean for the condition of Eyes Closed was 0.013 m/s (SD=0.004), which was greater than the mean for the condition of Eyes Open, at 0.010 m/s (SD=0.004).

The Intervention statistics from BAPrmsCOP_vel demonstrated the mean for the condition of After Intervention was 0.012 m/s (SD=0.003), which was greater than the mean for the condition of Before Intervention, at 0.01 m/s (SD=0.004). A post hoc test using Tukey's HSD showed that all of the groups differed significantly at *p* < .05. However, meaningfulness was found between:

1. *No Previous Injury : Eyes Open and No Previous Injury : Eyes Closed*
2. *No Previous Injury : Eyes Open and Previous Injury : Eyes Open*
3. *No Previous Injury : Eyes Clsoed and Previous Injury : Eyes Closed*
4. *Previous Injury : Eyes Open and Previous Injury : Eyes Closed*

Figure 6: Bilateral, A/P, Root Mean Square, COP Velocity Interaction

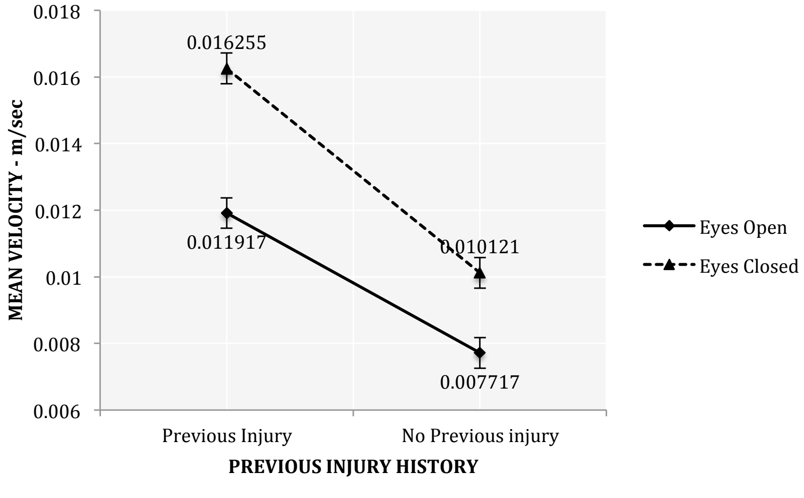


Figure 6: Bilateral, Anterior/posterior, Root Mean Square, Center of Pressure, Velocity interaction of Previous Injury History (previous injury and no previous injury) and Vision (eyes open and eyes closed).

As illustrated in Figure 6, the significant interaction between Previous Injury History and Vision showed that the mean velocity for the condition of Previous Injury History, with Eyes Closed was greater than the mean velocity for the condition of Eyes Open. Post hoc testing showed that all of the means differed significantly at $p < .05$.

Table 14 illustrates there was no significant effect was between Previous Injury History and Intervention; Vision and Intervention; or among Previous Injury History, Vision and Intervention.

Bilateral, Medial/Lateral, Root Mean Square, Center of Pressure, Velocity.

Analysis of BMLrmsCOP_vel demonstrated a significant main effect for Intervention (see Table 14). The mean for the condition of After Intervention was 0.0041 m/s (SD=0.001), which was less than the mean for the condition of Before Intervention, at 0.0056 m/s (SD=0.002).

Table 14 also demonstrates that no other main effects were statistically significant for Previous Injury History, Vision, or any interactions (Previous Injury History and Vision; Ankle Injury History and Intervention; Vision and Intervention; or among Previous Injury History, Vision and Intervention).

Bilateral, Anterior/Posterior, Root Mean Square, Center of Pressure.

Analysis of BAPrmsCOP data did not demonstrate a main effect for Previous Injury History, Vision or Intervention, nor were there any significant effects with any interactions (Previous Injury History and Vision; Ankle Injury History and Intervention; Vision and Intervention; or among Previous Injury History, Vision and Intervention) (see Table 14).

Bilateral, Medial/Lateral, Root Mean Square, Center of Pressure. As seen in Table 14, analysis of BMLrmsCOP demonstrated a significant main effect for Previous Injury History and Intervention, but no main effects were statistically significant for Vision.

The significant main effect for Previous Injury History indicated that with the presence of a Previous Injury History the BMLrmsCOP was 0.0017 m (SD=0.0008), which was less than the group with No Previous Injury History, which was 0.0146 m (SD=0.0007).

The main effect for Intervention from BMLrmsCOP displayed the mean for After Intervention was 0.0018 m (SD=0.0008), which was greater than the mean Before Intervention, which was 0.0013 m (SD=0.0006).

No significant effects were found between Previous Injury History and Vision; Previous Injury History and Intervention; Vision and Intervention; or among Previous Injury History, Vision and Intervention (see Table 14).

Bilateral, Anterior/Posterior, Center of Pressure, Median Frequency.

Analysis of Bfmed_APCOP did not demonstrate a main effect for Previous Injury History or Intervention, but did demonstrate a main effect for Vision (See Table 14). The main effect for Vision displayed that for Bfmed_APCOP, the mean for the condition of Eyes Closed was 0.39 Hz (SD=0.15), which was greater than the mean for the condition of Eyes Open, at 0.29 Hz (SD=0.11).

In Table 14 it was also evident that no significant interaction was demonstrated between Vision and Intervention; Previous Injury History and Vision; Previous Injury History and Intervention; or among Previous Injury History, Vision and Intervention.

Bilateral, Medial/Lateral, Center of Pressure, Median Frequency.

Analysis of Bfmed_MLCOP data did not demonstrate a main effect for any conditions (Previous Injury History, Vision or Intervention), nor significant effect with any interactions (Previous Injury History and Vision; Previous Injury History and Intervention; Vision and Intervention; or among Previous Injury History, Vision and Intervention) (see Table 14).

Single Leg Stance

All anterior/posterior (A/P) and medial/lateral (M/L) single leg analyses were completed with each ankle being viewed as an independent "participant". The rationale for this was to evaluate ankles according to its injury history, regardless of left or right leg/foot dominance. For the purpose of the current research objectives, the left and right ankle are not being compared, but rather the independent variables of Ankle Injury History. Therefore, N=38 for the single leg stance analyses.

Anterior/Posterior

Table 15: Summary Table of Postural Stability - A/P Single Legged Stance

COP Dependent Measures		Main Effects						*p-values* Main Effect			*p-values* Interactions			
		Intervention		Previous Injury History		Vision		INT	PIH	VIS	INT:PIH	INT:VIS	PIH:VIS	INT:PIH:VIS
		Before	After	No Previous Injury	Previous Injury	Eyes Open	Eyes Closed							
Postural Stability Anterior-Posterior Single Leg Stance (Velocity: Meters/second) (COP: Meters) (Median Frequency: Hz)	APrmsCOP_vel N=33	0.067 ± 0.095	0.057 ± 0.046	0.064 ± 0.083	0.057 ± 0.032	0.034 ^{b} ± 0.012	0.091 ^{b} ± 0.096	.46	.64	< .001 ^{b}	.94	.62	.62	.94
	APrmsCOP N=35	0.012 ± 0.006	0.013 ± 0.006	0.013 ± 0.006	0.011 ± 0.005	0.009 ^{b} ± 0.003	0.016 ^{b} ± 0.006	.98	.26	< .001 ^{b}	.09	.99	.97	.56
	fmed_APCOP N=33	0.9 ^{b} ± 0.23	0.79 ^{b} ± 0.2	0.83 ± 0.23	0.9 ± 0.21	0.768 ^{b} ± 0.2	0.795 ^{b} ±0.22	.009 ^{b}	.18	.001 ^{b}	.8	.79	.64	.33

Summary Table of Postural Stability [a]
INT=Intervention; PIH=Previous Injury History; VIS=Vision; B=bilateral; AP=anterior /posterior; ML=medial/lateral; rms=root mean square; vel=velocity; COP=center of pressure; fmed=median frequency; [a] Values are presented as mean ± SD (95% confidence level). [b] Significant difference for Main Effect. [c] Significant difference for Interaction.

Anterior/Posterior, Root Mean Square, Center of Pressure, Velocity.

Analysis of APrmsCOP_vel data did not demonstrate a significant main effect for Previous Injury History or Intervention, but there was a significant main effect for Vision (see Table 15). The mean for the condition of Eyes Closed was 0.09 m/s (SD=0.09), which was greater than the mean for the condition of Eyes Open, at 0.03 m/s (SD=0.01).

In Table 15 it can be seen that there were no significant effects with any interactions for MLrmsCOP (Previous Injury History and Vision; Previous Injury History and Intervention; Vision and Intervention; or among Previous Injury History, Vision and Intervention).

Anterior/Posterior, Root Mean Square, Center of Pressure

There were no significant main effects for Previous Injury History or Intervention, but there was a significant main effect for Vision (see Table 15). The mean for the condition of Eyes Closed was 0.018 m (SD=0.018), which was greater than the mean for the condition of Eyes Open, at 0.009 m (SD=0.003).

Table 15 also showed that there were no significant effects with any interactions for MLrmsCOP (Previous Injury History and Vision; Previous Injury History and Intervention; Vision and Intervention; or among Previous Injury History, Vision and Intervention).

Anterior/Posterior, Center of Pressure, Median Frequency.

There was no significant main effect for Previous Injury History, however, both the main effect for Vision and Intervention were significant (see Table 15). The mean for the condition of Eyes Closed for median frequency was 0.795 Hz (SD=0.22), which was significantly greater than the mean for the condition of Eyes Open, which was 0.768 Hz (SD=0.2).

Further, the mean for median frequency for Before Intervention was 0.9 Hz (SD=0.23), which was greater than the mean for After Intervention, which was 0.79 Hz (SD=0.2).

Table 15 also showed that there were no significant effects with any interactions for MLrmsCOP (Previous Injury History and Vision; Previous Injury History and Intervention; Vision and Intervention; or among Previous Injury History, Vision and Intervention).

Medial/Lateral

Table 16: Summary Table of Postural Stability - M/L Single Legged Stance

COP Dependent Measures		Main Effects						*p-values* Main Effect			*p-values* Interactions			
		Intervention		Previous Injury History		Vision		INT	PIH	VIS	INT:PIH	INT:VIS	PIH:VIS	INT:PIH:VIS
		Before	After	No Previous Injury	Previous Injury	Eyes Open	Eyes Closed							
Postural Stability Medial-Lateral Single Leg Stance (Velocity: Meters/second) (COP: Meters) (Median Frequency: Hz)	MLrmsCOP_vel N=33	0.05 ± 0.023	0.05 ± 0.032	0.05 ± 0.029	0.05 ± 0.026	0.34^{b} ±0.007	0.73^{b} ± 0.02	.48	.79	< .001^{b}	.23	.24	.97	.24
	MLrmsCOP N=33	0.009 ± 0.003	0.01 ± 0.005	0.01 ± 0.005	0.01 ± 0.003	0.007^{b} ±0.001	0.01^{b} ± 0.005	.43	.79	< .001^{b}	.22	.93	.58	.18
	fmed_MLCOP N=33	0.97$^{b\,c}$ ±0.24	0.86^{b} ±0.2	0.9^{c} ± 0.23	0.095^{c} ± 0.228	0.83$^{b\,c}$ ± 0.22	1.0$^{b\,c}$ ± 0.21	.01^{b}	.29	.001^{b}	.87	.28	.68	.01^{c}

Summary Table of Postural Stability ^{a}
INT=Intervention; PIH=Previous Injury History; VIS=Vision; B=bilateral; AP=anterior /posterior; ML=medial/lateral; rms=root mean square; vel=velocity; COP=center of pressure; fmed=median frequency; ^{a} Values are presented as mean ± SD (95% confidence level). ^{b} Significant difference for Main Effect. ^{c} Significant difference for Interaction.

Medial/Lateral, Root Mean Square, Center of Pressure, Velocity.

Analysis of MLrmsCOP_vel data did not demonstrate a main effect for Previous Injury History or Intervention, but there was a significant main effect for Vision (see Table 16). The mean for the condition of Eyes Closed was 0.73 m/s (SD=0.02), which was greater than the mean for the condition of Eyes Open, which was 0.34 m/s (SD=0.007).

Table 16 also showed that there were no significant effects with any interactions for MLrmsCOP (Previous Injury History and Vision; Previous Injury History and Intervention; Vision and Intervention; or among Previous Injury History, Vision and Intervention).

Medial/Lateral, Root Mean Square, Center of Pressure.

Analysis of MLrmsCOP data did not demonstrate a main effect for Previous Injury History or Intervention, but there was a significant main effect for Vision (see Table 16). The mean for the condition Eyes Closed was 0.01 m (SD=0.005), which was greater than the mean for the condition Eyes Open, which was 0.007 m (SD=0.001).

It was also evident in Table 16 that there were no significant effects with any interactions for MLrmsCOP (Previous Injury History and Vision; Previous Injury History and Intervention; Vision and Intervention; or among Previous Injury History, Vision and Intervention).

Medial/Lateral, Center of Pressure, Median Frequency.

As seen in Table 16, the main effect for Previous Injury History was not significant. However, the main effects for Vision and Intervention were both significant. The mean for the condition Eyes Closed was 1.0Hz (SD=0.21), which was greater than the mean for Eyes Open, which was 0.83 Hz (SD=0.22). The mean for the condition After Intervention was 0.86 Hz (SD=0.2), which was less than the mean for the condition Before Intervention, which was 0.97 Hz (SD=0.24). Table 16 does show that no significant effect was demonstrated with Previous Injury History and Vision; Previous Injury History and Intervention; as well as Vision and Intervention. However, there was a significant three-way interaction among Previous Injury History, Vision and Intervention. Figure 6 and Figure 7 illustrate the significant interaction with Vision, before and after intervention, for previously non-injured ankles and ankles previously injured, respectively.

Figure 7: M/L, COP, Median Frequency - No Previous Injury History

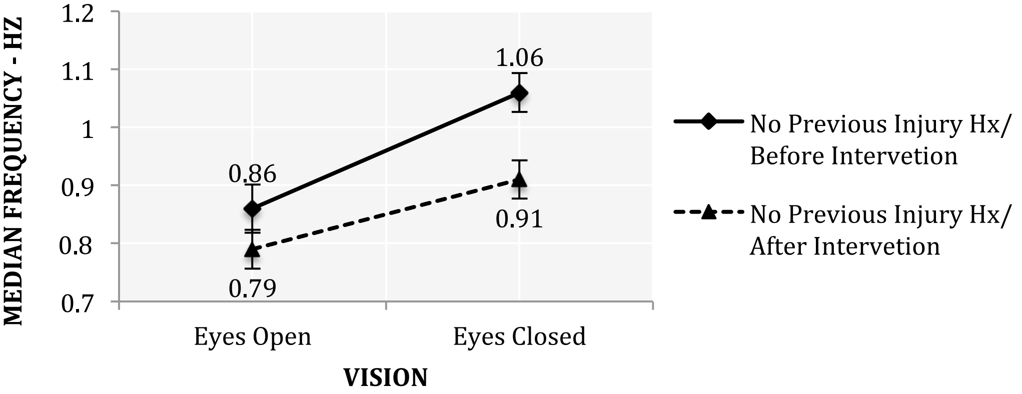


Figure 7. Postural stability interaction for medial/lateral center of pressure median frequency among Vision (eyes open and eyes closed) and Intervention (before and after intervention) for ankles with No Previous Injury History.

Figure 8: M/L, COP, Median Frequency - Previous Injury History

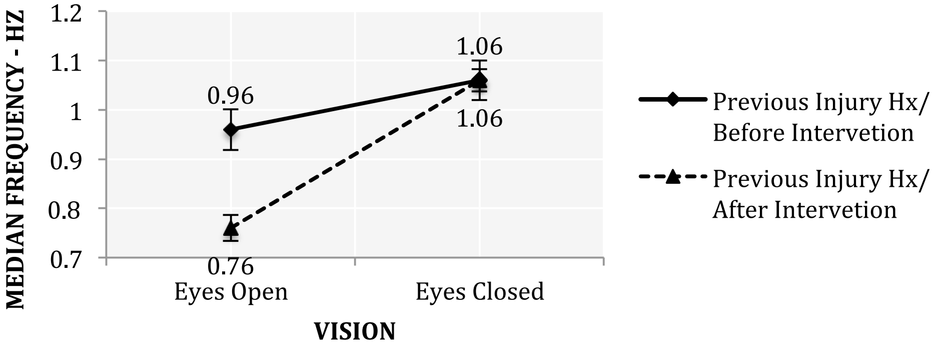


Figure 8. Postural stability interaction for medial/lateral center of pressure median frequency among Vision (eyes open and eyes closed) and Intervention (before and after intervention) for ankles with a Previous Injury History.

Chapter 4 - Discussion

The aim of the present study was to investigate how cryokinetics, and associated changes in sensory perception (tactile acuity), relate to range of motion and postural stability of ankles with and without previous history of injury, while currently asymptomatic. In addition to the reported statistical significance, additional focus was placed on evaluating the clinical significance or relevance of the results from the current study. Clinically relevant changes in outcomes refer to the smallest change in an outcome score that is considered important by a practitioner, that could result in a change in injury management (Page, 2014).

While the initial intent of this thesis was to compare the impact of cryokinetics with acute ankle injuries, in the end, there were no acute injuries involved in the current study. Following preliminary analysis indicating an effect for a history of ankle injury, the independent variable of ankle injury *status* was replaced with the independent variable injury *history*. Ankle injury history was established though discussion with each participant at intake. The inclusion of this independent variable allowed for evaluation of the dependent variables as a result of ankle injury history. All participants were asymptomatic in accordance with inclusion criteria, with nine participants having reported a history of ankle injury and the remaining ten reporting no previous injury of either ankle. In addition to Ankle Injury History (no previous injury history and previous injury history), the independent variables, Vision (eyes open and eyes closed) and Intervention (before intervention and after intervention) were also assessed. The dependent variables in the current study included: sensation, range of motion, and postural stability. Thus, I investigated the relationship of an intervention of cryokinetics with ankles that had no history of injury and ankles that had previous history of injury.

The effects of sensation, as a result of intervention was evaluated as proof of concept that the cryokinetic intervention indeed altered sensation. It was anticipated and demonstrated in the current study that decreased localized, superficial sensation followed an intervention of cryokinetics. It was also predicted that ankle range of motion would decrease following intervention, however, that decrease was only observed for ankles with no previous history of ankle injury. In contrast, range of motion of ankles with previous ankle injury, despite being asymptomatic at the time of testing, increased following the cryokinetic intervention.

Significant results were also noted for postural stability in single leg and double leg stance in both eyes open/closed conditions. COP values from single and double leg quiet stance demonstrated significant findings during: anterior/posterior COP velocity; anterior/posterior and medial/lateral COP; anterior/posterior and medial/lateral median frequency. Double-legged stance for anterior/posterior COP and medial/lateral median frequency were the only two conditions that did not demonstrate any significant main effects.

In addition to the main effects, an interaction was observed between cryokinetics and injury history, during functional range of motion testing. During double legged-stance, velocity values in the anterior/posterior plane were significant between ankles with previous injury and vision (eyes open/eyes closed). And finally, during single-legged stance, the median frequency in the medial/lateral plane was significant among all three independent variables (intervention, previous injury history and vision). The following sections discuss the pattern and meaning of the findings for the three categories of dependent measures.

Sensation

This study evaluated sensation through two-point discrimination and monofilament testing. Two-point discrimination and monofilament tests evaluate the receptors of the skin through light pressure. Two-point discrimination was used to determine sensitivity of sensation (difference between one or two points of contact), while monofilament testing was used to detect level of pressure at a specific superficial area of the body. The use of these clinical methods was done as a "proof of concept" that the cryokinetic intervention did alter localized sensation.

Somatosensation includes a variety of sensory information from the skin and musculoskeletal systems that is processed both consciously and non-consciously (Lundy-Ekman, 2013). Somatosensory input includes a variety of touch receptors located in the skin that respond to mechanical deformation of the receptor by touch and pressure, while pain and cooling at the superficial level affects nociceptors and thermoreceptors respectively (Prentice, 2014; Lundy-Ekman, 2013; Deleo, 2006). When a palpable sensation is detected on the skin, like that of the two-point discrimination test or the monofilament test, the signal is sent to the CNS and is processed (Cashin & McAuley, 2017). The evaluation of sensation from this study demonstrated that decreased skin perception after cryokinetics was accurately predicted.

Regardless of the ankles' previous injury history, both the two-point discrimination and monofilament sensation testing on the lateral ankle revealed a statistically significant main effect for intervention. In other words, regardless of previous injury history there was decreased sensation for two-point discrimination and light touch after the cryokinetic intervention. This result provided confirmation that the cryokinetic intervention affected sensation with a level of analgesia in the targeted area.

The range of monofilaments used in this study were between 0.07 grams and 300 grams. The ankle of some participants was at a level of numbness, after the cryokinetic protocol, where the 300-gram monofilament was needed to stimulate conscious perception of light touch. The results demonstrated that after intervention, there was an increased level of analgesia at the tested area. The direction of results for both the two-point discrimination and monofilament tests support the hypothesis that sensation to light touch will decrease following cryokinetic protocol, regardless of ankle injury history.

Range of Motion

This study utilized active, passive and functional range of motion testing, which are standard therapy/clinical methods of evaluating a joint range of motion (dorsiflexion from neutral/90 degrees). According to Prentice (2014), active range of motion (AROM), performed solely by the participant, is typically limited by swelling, joint effusion, muscle tightness, muscle weakness, or structural changes within the joint. In contrast, passive range of motion (PROM) is initiated and performed by the therapist while the participant's ankle is completely relaxed (Prentice, 2014). PROM of the ankle may be limited by swelling, joint effusion, muscle tightness, structural changes within the joint, or reflexive resistance of the calf musculature, as a result of injury (Magee, 2014). In contrast to AROM and PROM, functional range of motion

(FROM) testing is more dynamic in nature and is typically performed as a closed chain movement with the use of gravity and the participants body weight during the movement evaluation (Magee, 2014). Range of motion testing can be summarized as: AROM evaluates the musculature that acts on that particular joint; PROM evaluates the joint mobility without muscular involvement; and FROM evaluates the typical functional ability of the joint. Magee (2014) and Prentice (2014) agree that during a clinical physical exam, active, passive and functional joint evaluations are used together to evaluate specific aspects of the joint and surrounding structures in determining the limitations and potential pathologies related to an injury.

Flowers & Michlovitz (1988) suggested that passive range of motion can be of greater importance, clinically, than active range of motion in athletes who are experiencing pain and that passive range of motion may serve as a more valid indicator of change within connective tissues of the joint because the tissue is “relaxed” and therefore not actively moving the joint through that range of motion.

AROM and PROM testing in this study produced similar results before and after cryokinetics, whereas FROM changed as a function of injury history. Flowers and Michlovits (1988) reported AROM and PROM of acute ankle injuries may respond differently to cryokinetics following injury due to the inflammatory and pain responses brought on through trauma. Miklovic, Donovon, Protzuk, Kang, Feger (2018) summarized that patients with acute lateral ankle sprain often exhibit similar ROM, and functional activity deficits when compared to those with chronic ankle instability. Clinicians should be aware of potential clinical presentation (decreased ROM, decreased strength, decreased postural control and altered movement strategies) shared between clients with an acute lateral ankle sprain or chronic ankle instability (Miklovic et al , 2018;

Donovan and Hertel, 2012). The current study evaluated the effect of cryokinetics on ankles that were not acutely injured. Over the past nine years the author of this thesis had frequently observed increased range of motion of injured ankles at the conclusion of a single session of cryokinetics, but was unable to determine which type of range of motion was affected the most. This study demonstrated that AROM and PROM of the ankle was not affected by an intervention of cryokinetics, regardless of ankle injury history. However, FROM was affected in a manner that depended on the presence or absence of an ankle injury.

Prentice (2014) and Lundy-Ekman (2013) stated that the nerve fibers that conduct temperature change have a very slow conduction velocity and small diameter compared to the fibers that sense touch. In opposition, the nerve fibers that carry the signal of change in the range of motion at the ankle joint, during the functional range of motion testing, all have a faster conduction velocity and larger diameter than that of the fibers that conduct temperature change. These nerves appear to have been affected by the cryokinetic intervention such that functional range of motion of ankles with a previous history of injury was greater, compared to a decreased functional range of motion displayed in the ankles without injury history.

The functional range of motion test results supported the hypotheses that range of motion of an uninjured ankle will decrease following a cryokinetic protocol. However, the test results for functional range of motion of a previously injured ankle increased following a cryokinetic protocol. The direction of the effect for the previously injured ankles was not expected.

The greater FROM, in the absence of any difference for AROM and PROM may be explained by the aid of gravity and body weight with FROM. More force would have been generated through the ankle joint during the FROM evaluation to produce a greater range of motion of the ankles with injury history. The increase in FROM of ankles with injury history, following intervention was more evident compared to that of AROM and PROM. Although pain was not a factor at the time of testing for any of the participants, there could still be a perceived threat to the tissue of the previously injured ankle, by nociceptors. The result of increased FROM, of previously injured ankles, may be due to the inhibition of the nociceptors (to detect a threat to the tissue) receiving information from thermoreceptors (numbing the area) and reduced information from mechanoreceptors (mechanical changes) producing the inability to stop the movement during the test. Thus, when compared to active and passive range of motion alone, functional range of motion testing may provide more relevant information in a therapeutic/clinical setting when evaluating ankles and making return-to-sport decisions following ankle sprains. Physical activity goals as part of the rehabilitation process include dynamic and functional movement when compared to the clinical assessment of AROM and PROM. Given the pattern of results found here, functional range of motion testing is recommended as it better emulates the ankle requirements of sport and activities of daily living.

Postural Stability

This study included evaluation of Center of Pressure (COP) through trials of quiet standing during single and double leg support. A number of statistically significant findings during double and single leg stance were found. COP, measured with the force plate, was recorded during two-foot, quiet stance (bilateral); single leg (left foot) stance; and single leg (right foot) stance. Each of these conditions was repeated with the participants' eyes open and eyes closed, as well as, before and after the cryokinetic intervention. The independent variables included: Previous Injury History (No Injury History and Injury History); Intervention (Before Cryokinetics and After Cryokinetics); and Vision (Eyes Open and Eyes Closed). Postural stability results will be discussed systematically starting with two-legged stance, followed by the single leg stance (anterior/posterior and medial/lateral) findings.

Two-legged Stance

A greater anterior/posterior directional velocity of movement was observed when comparing previously injured ankles to those with no previous injury history, as well as during the comparison of eyes closed to eyes open. These results can be taken as evidence that, in the anterior/posterior plane, ankles with previous injury led to less postural stability than the ankles without previous injury, and participants were more unstable with their eyes closed compared to when their eyes were open, during two-legged stance.

Peterka (2002) and Horak (2006) stated that people change how they weight their sensory environment relative to the dependence of their senses. Peterka (2002) reported that vision accounts for 10% of one's ability to "re-weight" their environment. The removal of vision would then require the somatosensory and vestibular information to maintain stability. If somatosensory represents 70% (Peterka, 2002) of an individuals' ability to stabilize, and in this current study having a history of previous ankle injury affected quiet standing, then a participant with a history of ankle injury who closes their eyes would experience changes in both their vision and the somatosensory systems to the extent of demonstrating less stability in a two-legged quiet stance.

After the cryokinetic intervention two-legged stance velocity values were greater in the anterior/posterior direction, but were less in the medial/lateral direction. Anatomy at the ankle dictates that more movement occurs in the anterior/posterior direction when compared to the medial/lateral direction. As Horak (2000) suggests, when standing on a stable surface humans use an ankle strategy where the body moves at the ankle to maintain balance for small amounts of sway. More velocity following intervention in the anterior/posterior direction could be a result of the somatosensory system being altered through inhibition of the sensory receptors and anterior/posterior stabilizers being called upon to stabilize more than medial/lateral stabilizers, after intervention. Velocity in the medial/lateral plane was also significant, but because the velocity was greater before cryokinetics, compared to after, one may consider the result to be not clinically significant, regarding the ankle. However, the two-legged velocity results could suggest that the intervention affected the medial/lateral movement at the ankle in opposition to the anterior/posterior movement at the ankle because the demand for stability is greater in the anterior/posterior plane during a quiet stance.

Overall, the pattern of results is consistent with the interpretation that individual ankles with a previous injury were less stable than ankles with no injury history. Evidence of greater postural instability was also found in the results after cryokinetic intervention. This interpretation aligns with the findings of Douglas and colleagues (2013), with their conclusion that cryotherapy intervention impairs medial/lateral standing balance (Douglas, Bivens, Pesterfield, Clemson, Castle, Sole, Wassinger, 2013).

Vision was the only independent variable that demonstrated significance through the evaluation of median frequency during the two-foot stance, in the anterior/posterior plane. Greater values were observed with the eyes closed compared to the eyes open condition. This would align with the expectations of Lundy-Ekman (2013), due to the loss of visual cues and the additional demand on somatosensory system to maintain postural stability, and the research of Hazime, Allard, Ide, Siqueira, Amorim and Tanaka (2011), who demonstrated an increased reliance on visual information during balance. Individuals that had a previous injury history, while their eyes were closed, were relatively more unstable which suggests that those individuals may rely more heavily on vision to maintain postural stability.

Single-leg Stance

All values of the dependent variables were greater with eyes closed compared to eyes open. Similar to the double-legged stance, the loss of visual cues increased the demand on somatosensory system during single-leg stance, which resulted in relatively more difficulty maintaining postural stability.

Cryokinetics was shown to affect median frequency in the anterior/posterior and medial/lateral plane, but similarly to two-legged velocity in the medial/lateral plane, the frequency was greater before cryokinetics, compared to after. These results suggest that cryotherapy at the ankle caused the participants to rely on the knee musculature to provide stability for the lower leg.

Previous evaluation of median frequency for quiet standing with one and two-legged stance suggested that closing the eyes and cryokinetics caused disruption in postural stability. Evaluation of the interaction of single leg, median frequency in the medial/lateral plane could be summarized in three aspects. Firstly, that previously injured and non-previously injured ankles were both affected before and after intervention by closing the eyes. The removal of visual stimulus could have affected the somatosensory systems to the extent of demonstrating less stability in the single leg stance. However, following cryokinetics, with the eyes closed, the uninjured ankles demonstrated less instability, perhaps due to a change in lower leg stability strategy, utilizing the musculature of the knee to stabilize the leg in the medial/lateral plane. Secondly, participants with previously injured ankles, while having their eyes closed, demonstrated changes in postural stability compared to the uninjured ankles with eyes open before and after CK. Following cryokinetics, there was an increased instability demonstrated with previously injured ankles with the eyes closed. The removal of visual cues would call upon the somatosensory system to provide stability, which affected by the intervention, would have less ability to stabilize the ankle in the medial/lateral plane. While in comparison, following cryokinetics, there was less stability noted for the uninjured ankles while the eyes were open. Since the eyes were open (no disruption to the visual cues), there may have been an altered stability strategy for the lower leg that utilized the knee musculature rather than the ankle musculature. And thirdly, the instability was greater in the medial/lateral plane with the eyes closed-before intervention compared to eyes open-after intervention, for previously injured and non-previously injured ankles which reinforces of the importance of visual cues for postural stability. This study has shown that when evaluating postural stability, vision is a primary contributor during quiet stance. We can conclude that the absence of vision had a larger impact on postural stability when compared to any somatosensory changes associated with the cryokinetic intervention.

Based on the interaction of vision, intervention and ankle history from this study, closing the eyes during a two-legged quiet stance demonstrated decreased velocity of root mean square, center of pressure in the anterior/posterior plane; and closing the eyes during single-legged quiet stance demonstrated decreased postural stability in the medial/lateral plane when evaluating the median frequency. Vision affected postural stability more than the cryokinetic intervention or previous injury ankle history.

Chapter 5 – Limitations, Future Directions and Conclusion

Limitations

The current study had 19 participants across three sports. A larger sample size and additional sports would provide an opportunity to generalize the results across sports and/or athletes;

Despite the benefits of consistency for having the same rater measuring all ROM's, due to the nature of the intervention the investigator was not blind throughout the data collection process. Also, despite one leg being more dominant than the other for each participant, the use of each leg as an independent variable did not take in to account for common neural drive to each separate limb. From an application standpoint, while the results indicate value in assessing postural stability using a force platform, access to one in an athletic therapy environment is not common. Bartlett, Ting and Bingham (2014) suggested that a Wii balance board would be an inexpensive, portable device that may be useful for measuring center of pressure during a quiet stance, but not to the accuracy of laboratory-grade force plates. Based on the quiet standing results of this study, in comparison to the results from Bartlett, Ting and Bingham (2014), the Wii balance board could be used in a clinical setting to gather postural stability (low frequency movements – 0.01-10 Hz) information before or after ankle injury.

Future Opportunities

A number of future opportunities were identified throughout this study. The results help to set the groundwork to investigate the effects of cryokinetics on acute care injury management of ankle sprains with further expansion to study the relationship between cryokinetics and ligamentous or other soft tissue injuries at joints other than the ankle. Additional avenues for research could also include the effects of cryokinetics on dominant versus non-dominant limbs; gait; vertical jump; sex; and specific sport/position demands.

To aid in therapy/clinical research, the use of a Wii balance board, to provide affordable and accurate therapy/clinical evaluation of postural stability following injury, could be investigated further; or evaluation of goniometer applications in comparison to a manual or digital goniometer for ease and reliable application.

Conclusion

The results of the present study provide an initial investigation into how and why cryokinetics may affect sensory perception, range of motion and postural stability. Sensory perception of the skin decreased following the application of a cryokinetic protocol, which is similar to the results following cryotherapy alone. Tactile sensation was not affected by injury history.

Functional range of motion testing consistently demonstrated greater range of motion values than active and passive range of motion tests, both before and after cryokinetics. In addition, functional dorsiflexion of ankles with a history of previous injury increased following a cryokinetic intervention. In contrast, uninjured ankles demonstrated decreased functional dorsiflexion after a cryokinetic intervention. Following an ankle injury, proprioception appears to be used to a greater extent to control ROM. Thus, an increase in dorsiflexion during functional movement was permitted with the somatosensory receptors (nociceptors and thermoreceptors) numbed by a cryokinetic intervention.

This study also demonstrated that at some level, medial/lateral and anterior/posterior stability at the ankle were both affected by either cryokinetics, ankle injury history or removal of vision, while standing on one or both legs. However, postural stability was most affected when participants were asked to close their eyes, regardless of injury history or the use of cryokinetics.

Clinically, the author would recommend incorporating a cryokinetic intervention to address ankle range of motion deficits early in the rehabilitation process. Frequent use of proprioceptive exercises (with eyes open, progressing to eyes closed) during therapy sessions would also be recommended to enhance their ankle strategy to control sway. Postural stability can be evaluated prior to returning a client back to their previous level of activity by executing a stork stand test, comparing eyes open and eyes closed. A Wii balance board could also be an affordable tool, in a clinical setting, to provide evidence to aid in making an objective decision when returning an athlete to activity. Finally, functional range of motion and symmetry in single leg postural stability should be components of the return to play criteria following an ankle injury. Cryokinetics is recommended as a safe and affordable method to use in a therapy/clinical setting to improve functional range of motion.

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Appendices

Appendix A Coach Consent Letter

[To be printed on University of Manitoba Letterhead]

Dear Coach (name of coach):

I am conducting a study titled: How changes in sensory perception associated with cryokinetics relate to motor performance of injured and uninjured ankles. I am writing to request if one of the student research assistants helping with the project (Byron Bahniuk) may spend 15 minutes at the beginning or end of one of your practices or team meetings to present an opportunity for your student athletes to participate in this research study, conducted in the Faculty of Kinesiology and Recreation Management.

For this project, we are interested in learning how changes in sensory perception relate to motor performance of injured and uninjured ankles. Information from this study could help to decrease athlete absence from the field of play following an ankle injury. During this two-part study, student athletes will be asked to perform ankle dorsiflexion, single and two leg balance as well as sensation testing before and after the application of a therapeutic technique entitled cryokinetics. Prior to the evaluation, participants will be asked to fill out a brief demographics questionnaire that will inquire about your age, gender, footedness, years of experience at the U-sport level, and previous ankle injury history. A standardized history and ankle assessment will be performed. Measurements and evaluation of the ankle will be obtained with a manual goniometer, high-density surface electromyography, force platform, two-point wheel, and dull filament. Ice will be applied to the lateral ankle in an interval, alternating with simple ankle movements. The whole procedure will take approximately 75-90 minutes to complete. Each participant's name will be entered for a prize draw at the completion of the study.

This research has been approved by the Education/Nursing Research Ethics Board. If you have any concerns or complaints about this project you may contact any of the above-named persons or the Human Ethics Coordinator (HEC) at 474-7122 or humanethics@umanitoba.ca.

If you feel that this is an opportunity you would like your student athletes to be made aware of, please contact me and I will have one of the student research assistants arrange a convenient time with you. Many thanks for your time and consideration.

Sincerely,

Dr. Cheryl Glazebrook. MSc(PT), PhD
Associate Professor - Faculty of Kinesiology and Recreation Management

Appendix B Scripts

[Script 1]

When an experimenter presents this research opportunity to student athletes in a classroom the following script will be read aloud:
"I am Byron Bahniuk a student research assistant in the Faculty of Kinesiology and Recreation Management at the University of Manitoba. I am helping Dr. Glazebrook and Dr. Scribbans to carry out research examining the effect of cryokinetics when applied to injured and uninjured ankles. Information from this study could help to decrease athlete absence from the field of play following an ankle injury. If you feel like you would be interested in participating, please stay for a few minutes and I will tell you more about the experiment."
[Give students who want to leave a few movements to leave] *"We are interested in understanding how changes in sensory perception relate to motor performance of injured and uninjured ankles. In this study we are particularly trying to determine how the effects of cryokinetics affects an uninjured ankle compared to an injured ankle. The experiment will take approximately 75-90 minutes of your time, and is on a strictly voluntary basis.*
If you choose to participate, you would be looking at, receiving the cryotherapy treatment (crushed ice application and specific ankle movements). Following the cryokinetic treatment, you will be tested for local sensation, ankle range of motion, and balance. To evaluate this, we will use a two-point wheel, sharp and dull sensation testing, a manual goniometer, high-density surface electromyography, and a force plate, respectively.
The ice application will result in a mild numbing sensation on the skin that is in direct contact with the ice. Aside from the above, there is no other known risk, although you may experience mild muscle fatigue in the calf you are moving during the protocol. If, during the course of your season, you sustain an ankle sprain, you would contact the research assistant directly to arrange for a post injury assessment and repeat of the protocol you had completed earlier. This would include daily treatments and re-evaluation. There are no fees or charges associated with participating in this study. Restrictions to participate include: ankle sprain or ankle surgery within the past 6 months or 1 year respectively. If you choose to participate, you will be asked to sign an informed consent form before you begin and your name will be entered in to a draw for a prize for your time. This will be drawn at the conclusion of the study. Your personal information will be accessed by the student research assistants only and kept in strict confidence, with any data being coded by an arbitrary participant number. Identifying information (i.e., consent forms and receipts for gift cards) will only be accessed by the student research assistants, and will be destroyed seven years after the completion of the study (June 2025) by student research assistants under Dr. Glazebrook's direction and supervision. You are free to withdraw from the study at any time, for any reason, without consequence."

"If you are interested in participating, I can schedule you for a convenient time, or if you have any questions I would be happy to answer them. You may contact me at 204-474-6956 or

Byron.bahniuk@umanitoba.ca [Telephone number and email will be written on the board]. *Please contact me if you have any questions about the experiment. If I am unavailable, you may leave a message at the same number and I will contact you as soon as possible".*

***"This research has been approved by the Education/Nursing Research Ethics Board. If you have any concerns or complaints about this project you may contact any of the above-named persons or the Human Ethics Coordinator (HEC) at 474-7122 or humanethics@umanitoba.ca"* [Telephone number and email will be written on the board].**

[Script 2]

After the participants have signed the consent form, and demographic information is collected, the following script will be read aloud:

[If selected for experiment]- *"What you will be doing for this experiment, following EMG application, is receiving a cold compress of crushed ice on your ankles. After 15 minutes of ice application, sensation (on the skin under the ice) will be evaluated every minute. When skin sensation has been altered sufficiently, the ice will be removed and you will be asked to perform a walking movement for 3 minutes. Ice will be re-applied for approximately 5 minutes (or until the area is "numbed" appropriately). Followed by a modified squat (3 minutes), ice application (approximately 5 minutes), lunge movement (3 minutes), and a final ice application (approximately 5 minutes). Upon completion of the cryokinetic protocol, further evaluation of your sensation, ankle range of motion and balance will take place. An electric goniometer will be used to measure your range of motion while a force platform will be used to determine your balance. Do you have any questions before we begin?"*

[If an ankle sprain is sustained]- *"What you will be doing for this experiment, following EMG application, is receiving a cold compress of crushed ice on your ankles. After 15 minutes of ice application, sensation (on the skin under the ice) will be evaluated every minute. When skin sensation has been altered sufficiently, the ice will be removed and you will be asked to perform a walking movement for 3 minutes. Ice will be re-applied for approximately 5 minutes (or until the area is "numbed" appropriately). Followed by a modified squat (3 minutes), ice application (approximately 5 minutes), lunge movement (3 minutes), and a final ice application (approximately 5 minutes). Upon completion of the cryokinetic protocol, further evaluation of your sensation, ankle range of motion and balance will take place. An electric goniometer will be used to measure your range of motion while a force platform will be used to determine your balance. Do you have any questions before we begin?"*

[Script 3]

Following the experiment, participants will be debriefed about the purpose of the study and our general findings to date. The following script will be read:

"*Thank you for participating in this study. To date, research has neglected to investigate the effect of how changes in sensory perception relate to motor performance of injured and* *uninjured ankles. For instance, does the application of a cryokinetic protocol affect range of motion of an uninjured ankle differently than an injured ankle? In this experiment, we are interested in learning how changes in sensory perception relate to motor performance of injured and uninjured ankles. If you have any questions later on, please feel free to contact me – my contact information is on your consent form. Thank-you again for participating, and have a great day."*

"This research has been approved by the Education/Nursing Research Ethics Board. If you have any concerns or complaints about this project you may contact any of the above-named persons or the Human Ethics Coordinator (HEC) at 474-7122 or humanethics@umanitoba.ca. **[Telephone number and email will be written on the board]."**

Appendix C Informed Consent

How changes in sensory perception associated with cryokinetics relate to motor performance of injured and uninjured ankles

Principal Investigator:	Dr. Cheryl Glazebrook Faculty of Kinesiology & Recreation Management University of Manitoba (204) 474-8773 cheryl.glazebrook@umanitoba.ca
Co-investigator:	Dr. Trisha Scribbans Faculty of Kinesiology & Recreation Management University of Manitoba (204) 272-1699 Trisha.Scribbans@umantioba.ca
Student Research Assistants:	Byron Bahniuk, McKenna Brown, Jacqueline Ladwig-Davidson, Niyousha Mortaza, Carrie Peters, Jessica Sutton, Stephanie Tomy, Brad Bergan, Zach Henderson, Faculty of Kinesiology & Recreation Management

This consent form, a copy of which will be left with you for your records and reference, is only part of the process of informed consent. It should give you the basic idea of what the research is about and what your participation will involve. If you would like more detail about something mentioned here, or information not included here, you should feel free to ask. Please take the time to read this carefully and to understand any accompanying information.

PURPOSE: We are interested in learning how changes in sensory perception relate to motor performance of injured and uninjured ankles.

DESCRIPTION: During this two-part study, you will be asked to perform ankle dorsiflexion, single and two-leg balance as well as sensation testing before and after the application of a therapeutic technique entitled cryokinetics. Prior to the evaluation, you will be asked to fill out a brief demographics questionnaire that will inquire about your age, gender, footedness, years of experience at the U-sport level, and previous ankle injury history. A standardized history and ankle assessment will be performed. Measurements and evaluation of the ankle will be obtained with a manual goniometer, high-density surface electromyography, force platform, two-point wheel, and dull filament. Ice will be applied to the lateral ankle in an interval, alternating with simple ankle movements. The whole procedure will take approximately 75-90 minutes to complete.

RISKS AND BENEFITS: There are minimal risks inherent in the tasks you will perform as cryokinetics involves therapeutic application of crushed ice. A bag of crushed ice will be applied to the ankle for up to 25 minutes, prior to the ankle movement protocol. This will result in a change in skin temperature, local sensation and appearance (redness). These are typical responses to the application of a cold compress in a clinical setting. High-density surface electromyography collects the electrical information from your muscles using electrode grids that stick onto the surface of your skin. These grids will be secured to the skin using adhesive disposable matrices filled with conductive paste that may be uncomfortable to remove from the skin. If you experience discomfort, de-hesive will be available for grid removal. We may be required to shave small areas on the lower leg with a disposable razor, which could result in irritation to the skin, however, shaving will only be performed in the direction of the hair to minimize this risk.

Your participation in this study will help us to investigate the role or impact of cryokinetics on injured and uninjured ankles.

COSTS AND PAYMENTS: There are no fees or charges to participate in this study. However, for your participation, your name will be entered into a draw to win a prize, at the completion of the study.

CONFIDENTIALITY: Your information will be kept confidential. Once you begin the study your name, information, and results will be referred to by a code number. All files containing identifying information will be stored in a locked cabinet separate from data with your code number. Your files will only be accessible by the investigators and will be destroyed by Dr. Glazebrook seven years after the completion of the study (approximately June, 2025). All papers containing personal information will be shredded. All electronic files will be permanently deleted. Any CDs or DVDs containing data will be physically destroyed. Only Dr. Cheryl Glazebrook and the student research assistants listed will have access to any lists that contain identifying information. Dr. Glazebrook will only access the lists to destroy them or if required by ethics.

Results will be presented at academic conferences, invited presentations, and published in peer-reviewed academic journals. In almost all cases only group means will be presented. This data contains no identifiable information and therefore your anonymity will be maintained.

DEBRIEFING: Upon completion of the study the experimenter will describe the research questions being considered. If the participant would like to know the results of the study please indicate ‘yes’ on the consent form where indicated and the student research assistant will contact you with a summary of the findings in approximately 4 months (approximately September 2018).

VOLUNTARY CONSENT: If you do not wish to participate in the study, or wish to withdraw from the study, you are free to leave without consequence at any point in time and we thank you for your consideration.

Your signature on this form indicates that you have understood to your satisfaction the information regarding participation in the research project and agree to participate as a subject. In no way does this waive your legal rights nor release the researchers, sponsors, or involved institutions from their legal and professional responsibilities. You are free to withdraw from the study at any time, and /or refrain from answering any questions you prefer to omit, without prejudice or consequence. Your continued participation should be as informed as your initial consent, so you should feel free to ask for clarification or new information throughout your participation. If you choose to withdraw from the study you will still have your name entered into the draw for the gift card. The University of Manitoba may look at your research records to see that the research is being done in a safe and proper way.

This research has been approved by the Education/Nursing Research Ethics Board. If you have any concerns or complaints about this project you may contact any of the above-named persons or the Human Ethics Coordinator (HEC) at 474-7122 or humanethics@umanitoba.ca.

A copy of this consent form has been given to you to keep for your records and reference.

Participant’s Signature________________________________ Date______________

(Or)

Parent/Guardian Signature for Participant___________________________________

Relationship__________________________________ Date______________

Researcher/ Delegate’s_________________________ Signature Date____________

Appendix D Assent

How changes in sensory perception associated with cryokinetics relate to motor performance of injured and uninjured ankles

Principal Investigator:	Dr. Cheryl Glazebrook Faculty of Kinesiology & Recreation Management University of Manitoba (204) 474-8773 cheryl.glazebrook@umanitoba.ca
Co-investigator:	Dr. Trisha Scribbans Faculty of Kinesiology & Recreation Management University of Manitoba (204) 272-1699 Trisha.Scribbans@umantioba.ca
Student Research Assistants:	Byron Bahniuk, McKenna Brown, Jacqueline Ladwig-Davidson, Niyousha Mortaza, Carrie Peters, Jessica Sutton, Stephanie Tomy, Brad Bergan, Zach Henderson, Faculty of Kinesiology & Recreation Management

WHY ARE YOU HERE? We are interested in learning how changes in sensory perception relate to motor performance of injured and uninjured ankles. This form will explain the study and your role as a participant. If there is anything you do not understand, please ask your parent, your guardian, or the study staff.

WHY ARE YOU DOING THIS STUDY? We are doing this study to see how a therapeutic technique like cryokinetics affects the ankle before and after an ankle sprain. Information from this research may assist therapists with the management of acute ankle sprains. You can choose to do one, more, or none of the activities that we tell you about.

WHAT WILL HAPPEN? If you participate in this study the following will happen:

During this two-part study, you will be asked to perform ankle dorsiflexion, single and two leg balance as well as sensation testing before and after the application of a therapeutic technique entitled cryokinetics. Prior to the evaluation, you will be asked to fill out a brief demographics questionnaire that will inquire about your age, gender, footedness, years of experience at the U-sport level, and previous ankle injury history. A standardized history and ankle assessment will be performed. Measurements and evaluation of the ankle will be obtained with a manual goniometer, high-density surface electromyography, force platform, two-point wheel, and dull filament. Ice will be applied to the lateral ankle in an interval, alternating with simple ankle movements. The whole procedure will take approximately 75-90 minutes to complete. Parents/guardians may be present for the study.

WHAT IF YOU HAVE ANY QUESTIONS? You can ask questions at any time before, during or after the study.

WHO WILL KNOW WHAT I DID IN THE STUDY? All of the information you give to the study staff will be kept confidential. Only the researchers will be able to look at any of the information you provide to us. After today your personal information will be referred to by a participant number so your information and results will be kept confidential.

DO YOU HAVE TO BE IN THE STUDY? If at any point in time you decide that you do not want to participate in this study please let us know.

Have we answered all of our questions?

Participation Assent for Research Study

I want to take part in this study and understand that I can change my mind at any time.

Name of participant (print):__________________________ Verbal assent given Yes ☐

Signature of Participant______________________________ Age________ Date________

I confirm that I have explained the study to the participant to the extent compatible with the participants understanding, and that the participant has agreed to be in the study.

Printed name of research staff obtaining assent_______________________

Signature______________________________ Date_______________

Appendix E Demographic Information Sheet

Participant Number: ___________________________

Age of Participant: _________

Height ______ Weight ______

Preferred leg for kicking a ball (check one): Right ☐ Left ☐

Preferred leg for single leg jump (check one): Right ☐ Left ☐

Which team do you compete with?:

Women's Volleyball ☐ Women's Basketball ☐ Men's Volleyball ☐ Men's Basketball ☐
Women's Soccer ☐

How many years have you competed at U-sport level (circle one): 0 1 2 3 4 5
Zero = rookie

Is there any history of neurological or orthopedic ankle injury in the last 6 months?
Yes☐ No ☐

If yes, are you currently asymptomatic?
Yes☐ No ☐

Is there any history of neurological or orthopedic surgeries in the last year?
Yes ☐ No ☐

Appendix F Cryokinetic Assessment Form

Name:	Number:	Treatment date:	Injury date:
Team: WVB WBB MVB MBB			Injured side: R L
Hx:			

Pre-Cryokinetics:

		Right ankle				Left ankle			Comments
		Trial 1	Trial 2	Trial 3		Trial 1	Trial 2	Trial 3	
AROM:	Dorsiflexion: (from 90°)								
PROM:	Dorsiflexion: (from 90°)								
Dynamic:	Lunge: (90° @ knee/hip)								

Centre of Pressure:	Bilateral (eyes open)		Left leg (eyes open)		Right leg (eyes open)		Comments:
	Bilateral (eyes closed)		Left leg (eyes closed)		Right leg (eyes closed)		

2-Point: right	left
Monofilament: right	left

Cryokinetics:	Time	"cold"	"burning"	"achiness"	"numb"
Initial ice application (15'+)					

2-Point: right	left
Monofilament: right	left

Mini-squat (3')		
Ice (5")		
Fwd walk (3')		
Ice (5')		
Side lunge (3')		
Ice (5')		

2-Point: right	left
Monofilament: right	left

Post-Cryokinetics:		Right ankle				Left ankle			Comments
		Trial 1	Trial 2	Trial 3		Trial 1	Trial 2	Trial 3	
AROM: (NWB)	Dorsiflexion: (from 90°)								
PROM: (NWB)	Dorsiflexion: (from 90°)								
Dynamic:	Lunge: (90° @ knee/hip)								

Centre of Pressure:	Bilateral (eyes open)		Left leg (eyes open)		Right leg (eyes open)		Comments:
	Bilateral (eyes closed)		Left leg (eyes closed)		Right leg (eyes closed)		

Comments:

Appendix G Post Injury Assessment/Treatment Form

Name:	Number:	Assessment date:	Injury date:
Team: WVB WBB MVB MBB			Injured side: R L
Hx:			

Observation:	*Figure 8 measure:*	Right:	Left:	
	Static stand:	Anterior:		
		Right lateral:		
		Left medial:		
		Posterior:		
		Left lateral:		
		Right medial:		
	Supine:			

Function:	Can perform	Can perform w/ compensation	Cannot perform	Why:
Standing calf raise:				
Mini-squat:				
Kneeling lunge:				
Gait *(heel strike, midfoot stance, toe off, swing phase)*:				

		Right ankle			Left ankle			Comments
		Trial 1	Trial 2	Trial 3	Trial 1	Trial 2	Trial 3	
AROM: (from neutral)	*Dorsiflexion*:							
	Plantarflexion:							
	Inversion:							
	Eversion:							
PROM: *(from neutral)*	*Dorsiflexion*:							
	Plantarflexion:							
	Inversion:							
	Eversion:							

IRT:	***Right*** *Plantar flexion:*	/5	*Dorsiflexion:*	/5	*Inversion:*	/5	*Eversion:*	/5	
	Left *Plantar flexion:*	/5	*Dorsiflexion:*	/5	*Inversion:*	/5	*Eversion:*	/5	
Comments:									

Ortho:	*Anterior drawer:*(ATF)	+ -	
	Talar tilt:(CF & ATF)	+ -	
	Kleiger test:(high ankle &/or deltoid)	+ -	

Palpation:	*Fibula:* (head-malleolus)		*Lateral malleolus:*		*PTF:*		*CF:*		*ATF:*		*Talus:*	
Peroneal tendons:		*Base of 5th:*		*Anterior Jt. line:*		*Deltoid ligament:*		*Sustantaculum tali:*		*Sinus Tarsi:*		
Comments:												
2-POINT:												
Assessment Findings:												

Appendix H Standardized Ankle Assessment

History questions relevant to the injury (i.e., mechanism of injury, pain levels, current function).

Observation
  Figure-8 Ankle Measurement for Swelling
  Standing (Bilateral anterior, right lateral, left medial, bilateral posterior, left lateral, right medial)
  Supine (bilateral anterior, medial and lateral)
Functional Testing
  Standing calf raise (bilateral)
  Mini Squat
  Kneeling lunge test
  Gait (heel strike, mid foot stance, toe off, swing phase)
Active Range of Motion
  Plantarflexion
  Dorsiflexion
  Inversion
  Eversion
Passive Range of Motion
  Plantarflexion
  Dorsiflexion
  Inversion
  Eversion
Isometric Resisted Tests
  Plantarflexion
  Dorsiflexion
  Inversion
  Eversion
Orthopedic Testing
  Anterior Drawer (lateral ankle – ATF ligament)
  Talar Tilt (lateral ankle – CF ligament and AFT ligament)
  Kleiger Test (high ankle sprain and/or medial deltoid ligament)
Palpation
  Distal fibula (from the head to the malleolus)
  Lateral malleolus
  Lateral ligaments (PTF, CF, ATF)
  Talus
  Peroneal tendons
  Base of the 5th metatarsal
  Anterior joint line
  Dome of talus
  Medial ligament (deltoid)
  Sustentaculum tali
  Sinus tarsi

Brunkner and Khan (2009); Magee (2008)

Appendix I Orthopedic Tests

Figure-8 Ankle Measurement for Swelling (Magee, 2008, pp 895)
Client positioned in long sitting with ankle and lower leg beyond the end of the examining table – ankle at 90°. Using a 6mm wide plastic tape measure, the examiner places the end of the tape measure midway between the tibialis anterior tendon and the lateral malleolus, drawing the tame medially across the instep just distal to the navicular tuberosity. The tape is then pulled across the arch of the foot just proximal to the base of the fifth metatarsal, across the tibialis anterior tendon, and then around the ankle joint just distal to the tip of the medial malleolus, across the achilles tendon, and just distal to the lateral malleolus, returning to the starting position. The measurement is repeated three times and an average is taken.

Anterior Drawer (Magee, 2008, pp 888)
Client lies supine with the foot relaxed. Therapist stabilizes the tibia and fibula, holds the clients' foot in 20° of plantar flexion, and draws the talus forward in the ankle mortise. Sometimes, a dimple appears over the area of the anterior talofibular ligament on anterior translation if pain and muscle spasm are minimal. In the plantar-flexed position, the anterior talofibular ligament is perpendicular to the long axis of the tibia. Anterior translation and pain laterally (at the ATF) demonstrate a positive test.

Talar Tilt (Magee, 2008, pp 890)
Client lies in the supine or side-lying position with the foot relaxed. The clients' gastrocnemius muscle may be relaxed by flexion of the knee. The foot is held at 90°, which align the calcaneofibular ligament perpendicular to the long axis of the talus. The talus is then tilted into adduction. Adduction tests the calcaneofibular ligament. Excessive translation and pain demonstrate a positive test.

Kleiger (Magee, 2008, pp 890)
The client is seated with the leg hanging over the examining table with the knee at 90°. The therapist stabilizes the leg with one hand. With the other hand, the examiner holds the foot at 90° and applies a passive lateral rotation stress to the foot and ankle. The test is positive for syndesmosis ("high ankle sprain") injury if pain is produced over the anterior or posterior tibiofibular ligaments and the interosseous membrane.

Appendix J Lower Extremity Functional Scale (L.E.F.S.)

The Lower Extremity Functional Scale

We are interested in knowing whether you are having any difficulty at all with the activities listed below **because of your lower limb problem** for which you are currently seeking attention. Please provide an answer for **each** activity.

Today, *do you* or *would you* have any difficulty at all with:

	Activities	**Extreme Difficulty or Unable to Perform Activity**	**Quite a Bit of Difficulty**	**Moderate Difficulty**	**A Little Bit of Difficulty**	**No Difficulty**
1	Any of your usual work, housework, or school activities.	0	1	2	3	4
2	Your usual hobbies, re creational or sporting activities.	0	1	2	3	4
3	Getting into or out of the bath.	0	1	2	3	4
4	Walking between rooms.	0	1	2	3	4
5	Putting on your shoes or socks.	0	1	2	3	4
6	Squatting.	0	1	2	3	4
7	Lifting an object, like a bag of groceries from the floor.	0	1	2	3	4
8	Performing light activities around your home.	0	1	2	3	4
9	Performing heavy activities around your home.	0	1	2	3	4
10	Getting into or out of a car.	0	1	2	3	4
11	Walking 2 blocks.	0	1	2	3	4
12	Walking a mile.	0	1	2	3	4
13	Going up or down 10 stairs (about 1 flight of stairs).	0	1	2	3	4
14	Standing for 1 hour.	0	1	2	3	4
15	Sitting for 1 hour.	0	1	2	3	4
16	Running on even ground.	0	1	2	3	4
17	Running on uneven ground.	0	1	2	3	4
18	Making sharp turns while running fast.	0	1	2	3	4
19	Hopping.	0	1	2	3	4
20	Rolling over in bed.	0	1	2	3	4
	Column Totals:					

Minimum Level of Detectable Change (90% Confidence): 9 points SCORE: _____/ 80

Source: Binkley et al (1999): The Lower Extremity Functional Scale (LEFS): Scale development, measurement properties, and clinical application. Physical Therapy. 79:371-383.

Appendix K Numeric Pain Scale

[Script]

"On a scale of 0-10, with 0 being no pain and 10 being severe pain, what number would best represent your pain level at the time of injury? ...right now?"

This numerical value will be recorded during the history portion of each assessment.

Appendix L Classification of Sprains

Classification of Sprains			
	First degree	**Second degree**	**Third degree**
Damage to ligament	Few fibers of ligament are torn	Nearly half of the fibers are torn	All ligament fibers are torn (rupture)
Distraction with stress test	<5 mm distraction	5-10 mm distraction	>10 mm distraction
Weakness	Mild	Mild to moderate	Mild to moderate
Muscle spasm	None	None to minor	None to minor
Loss of function	Mild	Moderate to severe	Severe (instability)
Swelling	Mild	Moderate	Moderate to severe
Pain on contraction	None	None	None
Pain with stretching	Yes	Yes	No
Range of motion	Decreased	Decreased	May increase or decrease depending on swelling; dislocation or subluxation possible

Summarized from Anderson, M., Parr, G., & Hall, S. (2009).

Appendix M Sensation Statistical Results

Dependent Measures		Main Effects				*p-values* Main Effect		*p-values* Interactions
		Intervention		Previous Injury History				
		Before	After	No Previous Injury	Previous Injury	INT	PIH	INT:PIH
Sensation (TPD: millimeters)	Two-point Discrimination N=38	10.4 ± 3.65[b]	15.8 ± 5.41[b]	14 ± 5	11 ± 6	< .001[b]	.15	.9

Summary Table of Sensation[a]
INT=Intervention; PIH=Previous Injury History; VIS=Vision; TPD=Two-Point Discrimination
[a] Values are presented as mean ± SD (95% confidence level). [b] Significant difference for Main Effect.
[c] Significant difference for Interaction.

Appendix N Range of Motion Statistical Results

Dependent Measures		Main Effects				*p-values* Main Effect		*p-values* Interactions
		Intervention		Previous Injury History				
		Before	After	No Previous Injury	Previous Injury	INT	PIH	INT:PIH
Range of Motion (Degrees)	Active N=38	11.3 ± 4.99	10.8 ± 5.36	10 ± 5	13 ± 5	.18	.1	.24
	Passive N=38	16.3 ± 5.52	17.3 ± 6.2	16 ± 6	18 ± 6	.49	.4	.47
	Functional N=38	28.7[c] ± 6.1	28.1[c] ± 6.2	28[c] ± 5	30[c] ± 9	.67	.25	.036[c]

Summary Table of Range of Motion[a]
INT=Intervention; PIH=Previous Injury History; VIS=Vision; TPD=Two-Point Discrimination
[a] Values are presented as mean ± SD (95% confidence level). [b] Significant difference for Main Effect.
[c] Significant difference for Interaction.