ABSTRACT

Effects of Prophylactic Lace-Up Ankle Braces on Kinetics and Kinematics of the Lower Extremity During a State of Fatigue

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Prophylactic lace-up braces are commonly used on athletes regardless of ankle injury history to reduce lateral ankle sprains (LAS). However, their ability to limit ankle sagittal range of motion has the potential to alter knee kinematics and is linked to chronic knee pathologies. Thirteen college-aged (6 males) and (7 females) experienced in landing/cutting sports completed a random crossover design study consisting of a 90° cutting task and a 15m beep test fatigue protocol. Braced conditions elicited a significant reduction in ankle sagittal displacement (ASD) in both pre-fatigue (-10.08°) and post-fatigue (-9.51°). Also, w/brace increased in time to peak knee flexion pre-fatigue (3.26fps) and post-fatigue (1.74fps) and peak knee flexion pre-fatigue (6.14°) and post fatigue (10.92°). Prophylactic ankle braces limiting ASD appear to alter knee mechanics that are associated with chronic knee pathologies. Clinicians should use other prophylactic measures of hinge ankle braces or prevention programs to reduce LAS.

Effects of Prophylactic Lace-up Ankle Braces on Kinetics and Kinematics of the Lower Extremity During a State of Fatigue

by

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A Thesis

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CHAPTER ONE

Introduction

Prophylactic ankle braces are commonly used by youth, recreational, collegiate, and professional athletes with the primary aim to prevent LAS. Over 50% of injuries during athletic events involve the lower extremities, where the vast majority occur at the ankle, followed by the knee (Schroeder et al., 2019). Lateral ankle sprains predominantly occur after initial foot contact while running, cutting, or landing from a jump. During cutting momentum must rapidly reduce and the reverse into a new direction. This rapid shift may lead to the body to inappropriately attenuate forces yielding increases in non-contact ankle sprains. The primary mechanism of injury for LAS is excessive inversion and plantarflexion which is common sports involving cutting and jumping accounting for 58% of basketball injuries and 63% of volleyball injuries (Shaw et al., 2018). In NCAA sports the highest proportion of LAS occur in high impact sports including men's basketball (15%), women's basketball (14.5%), women's volleyball (10.7%), and women's lacrosse (10.2%) (Delahunt et al., 2019). Prevention of acute LAS is crucial since ankle sprains can have a lasting impact on functional performance and reinjury rates.

The three primary lateral ligaments that stabilize the talocrural joint of the ankle are the anterior talofibular ligament (ATFL), posterior talofibular ligament (PTFL), and calcaneofibular ligament (CFL). The weaker of the three ATFL provides restraint for excessive anterior glide and is injured the most during LAS. The PTFL is rarely injured during LAS but damage to the PTFL is often accompanied with a fracture or dislocation. The CFL is hardly the only ligament damaged but accompanies PTFL sprains 25% of the time (Medina McKeon et al., 2019). Ankle sagittal range of motion consist of plantarflexion and dorsiflexion at the talocrural joint. Ankle frontal range of motion consist of inversion (supination) and eversion (pronation).

Traumatic ankle sprains are one of the most common musculoskeletal injuries in athletic populations and lead to higher recurrence rates and the development of chronic ankle instability (CAI) (Herzog et al., 2019). First-time LAS can develop into CAI up to 40% of the time and are marked by having symptoms 12 months post-injury. Enduring symptoms of CAI consist of recurrent ankle sprains, perceived ankle instability, ankle weakness, and signs of inflammation (Hertel et al., 2019). Prophylactic ankle braces are used in conjunction with other preventative and rehabilitation techniques to minimize ankle inversion and plantarflexion range of motion to reduce ankle injury rates (Dewer, 2019). Athletes with CAI go through ankle prevention programs, use prophylactic ankle braces, and dynamic stability programs to mitigate symptoms and limit further sprains. Patients with CAI commonly develop anterior ankle impingement (AAI) from the production of soft tissue osteophytes. Commonly, AAI symptoms are due to the promotion of intraarticular fibrous scars or tibiotalar spurs from repetitive or traumatic sprains (Talusan et al., 2014). Soft tissue development of AAI occurs in 63% of patients with CAI and 12% of patients develop anterior bony (osteophyte) induced impingement (Odak et al., 2015). The Long-term impacts of LAS and their potential to develop into chronic conditions of CAI and AAI have made ankle bracing and preventative programs very popular.

Prophylactic ankle braces are designed to limit excessive joint motion in both the frontal and sagittal plane due to LAS mechanism of injury (excessive inversion and plantarflexion). The most used prophylactic ankle braces are semi-rigid braces (lace-up and hinge braces) and elastic/compression braces. Both elastic and semirigid braces can restrict ankle dorsiflexion. However, semi-rigid ankle braces are used more since they limit ankle sagittal range of motion and inversion more effectively (Wu et al., 2018). Both lace-up and hinge ankle braces limit ankle inversion and eversion however lace-up braces limit ankle sagittal plane motion of dorsiflexion and plantarflexion. Lace-up brace's ability to limit ankle dorsiflexion is unnecessary in reducing ankle sprain injury rates and may have a detrimental upstream effect on the knee kinematics (Klem et al., 2016). These restrictions are critical for athletes and clinicians to understand when choosing the best ankle support for performance and injury prevention.

When selecting a brace, the ability to limit ankle range of motion, the athlete’s perceived comfort, functionality, and ability to perform without impairments are heavily considered. This is apparent since different athletes are comfortable with different braces. For instance, soccer players and runners prefer compression braces while volleyball players preferred semi-rigid braces (Janssen et al., 2017). This is primarily due to soccer and running athletes running for long periods of time leading to athletes to favor comfort. Semi-rigid ankle braces reduce the anterior tibial shear force of the subtalar joint and can also reduce ankle injuries by improving proprioception (Klem et al., 2016). Semi-rigid ankle braces provide support and cutaneous sensory input aimed to increase mechanical stiffness, reduce ankle range of motion, and improve ankle proprioception for adults with CAI after an injury (Webster et al., 2017).

Athletes using lace-up braces while participating in cutting and landing sports have lower incidences of acute ankle injuries without affecting severity. However, for athletes, there are no differences in acute knee and other lower extremities injury rates (McGuine et al., 2011). Current research supports the use of external ankle supports since they consistently limit ankle injury rates in various athletic settings (Newman et al., 2017, Dizon et al., 2007; Thacker et al., 1999). Since prophylactic lace-up ankle braces are commonly used in athletics due to their ability to prevent inversion ankle sprains (Mcguine et al., 2011, Pedowitz et al., 2008) clinicians, teams, and physically active individuals use them regardless of individuals past ankle injury history (Bellows et al., 2018 and Henderson et al., 2019).

Restriction of ankle range of motion during landing and cutting can be problematic since past studies have indicated alterations in knee mechanics connected to chronic knee pathologies (Distefano et al., 2008 and Klem et al., 2016). Two recent systematic reviews have observed changes in knee kinematics due to prophylactic ankle braces specifically caused by reductions in dorsiflexion (Mason-MacKay et al., 2016 and Mason-MacKay et al., 2017). Attenuation of VGRF during landing and cutting is primarily through eccentric controlled dorsiflexion and knee flexion (Devita et al, 1992). If ankle dorsiflexion and plantarflexion is restricted this may lead to an increase in knee flexion to allow consistent VGRF. Plantarflexion restriction may also alter knee kinematics since the gastrocnemius and soleus might have less eccentric control to absorb landing and cutting forces. Furthermore, since athletes commonly perform during states of fatigue it is important to observe if braced conditions are affected differently than non-braced conditions following a fatigue protocol.

Purpose

The purpose of this study was to observe effects ankle bracing may have on knee kinematics during a 90° cutting maneuver before and after a state of fatigue in physically active athletes with no ankle injury history. Specifically, any changes (increases in PKF, T2PKF, and KFD) associated with chronic knee pathologies were investigated.

Hypotheses

Ho: There will be no sig difference in ankle and knee kinematics during cutting task between w/brace and w/o brace conditions

Ho: There will be no sig difference in ankle and knee kinematics during cutting task between pre-fatigue and post-fatigue conditions

Ho: There will be no sig interaction in ankle and knee kinematics during cutting task between fatigue protocol and brace conditions

Delimitations

1. Males and females between the ages of 18-25 and participate in moderate to vigorous activity at a minimum of 150 minutes a week.

2. No previous diagnosis or self-reported ankle injury over the last 6 months (e.g., sprain, fracture, tendonitis).

3. No previous significant knee injuries.

4. No current/previous heart conditions or under physician's recommendation not to participate in activities leading to maximal exertion or heart rate max.

5. Do not currently wear ankle braces during activities.

6. Have a history of competitive sports focused on cutting and landing (football, basketball, volleyball, soccer, hockey, baseball, softball, tennis, etc.)

Limitations

1. Patients not pushing themselves in the fatigue protocol enough to elicit fatigue effects.

2. Learning effect of the fatigue protocol from the first session to the second session.

3. Study outcomes may only be relevant for the chosen population.

4. The study doesn't have enough subjects.

5. The fatigue task may not effectively elicit enough muscle damage replicating a full athletic competition.

Assumptions

1. All research team members will be adequately trained in all necessary study protocols.

2. All necessary equipment will function properly and produce valid results.

3. All subjects will restrain from physical activity within 72 hours before their sessions.

Definition of Terms

Anterior Ankle Impingement (AAI) – Chronic anterior ankle pain typically caused by bone spurs or osteophytes developed from repetitive ankle trauma

ATFL – Anterior Talofibular Ligament

ASD – Ankle Sagittal Displacement

Chronic Ankle Instability (CAI) – Condition characterized by recurring symptoms of ankle pain, weakness, and episodes of instability following an acute ankle sprain.

CFL – Calcaneofibular Ligament

Electromyography (EMG) – Diagnostic test using electrodes that assess muscle to nerve signal transmission and their electrical signals eliciting muscle contractions.

ICPF – Initial Contact Plantarflexion

KFD – Knee Frontal Displacement

LAS – Lateral Ankle Sprain

Mechanoreception – Ability to respond to stimuli of touch, sound, pressure change, and posture due to sensory cells (mechanoreceptors).

Muscle Spindles – Skeletal muscle sensory receptors in the body of the muscle that detects a change in the length of a muscle. They contribute to central nervous system awareness of limb position and fine motor control.

Nociceptors – A sensory cell that responds to potentially damaging stimuli creating the sensation of pain.

PDF – Peak Dorsiflexion

PKF – Peak Knee Flexion

PPF – Peak Plantarflexion

PTFL – Posterior Talofibular Ligament

Prophylactic Ankle Braces – Ankle braces that are designed to prevent injuries in physically active populations.

T2PKF – Time Too Peak Knee Flexion

CHAPTER TWO

Literature Review

Introduction

There are various prevention strategies for reducing ankle sprains therefore it is important to understand which strategies are best for each athlete. Both prophylactic ankle braces and prevention programs are effective in reducing ankle sprain risk and, when combined, lead to the best outcomes (Bellow et al., 2018, Burger et al., 2018). Semi-rigid ankle braces can restrict ankle range of motion for up to 45 minutes while taped athlete's ankle range of motion stays limited for only 15 minutes (Forbes et al., 2013). Therefore, ankle bracing has increased since it can limit ankle range of motion for a longer duration. Due to their relatively low cost and ease of use, ankle braces have been used abundantly in athletics regardless of past injury history. Therefore, it is imperative to justify their use as a prophylactic measure while also reassuring their safety during long-term use without a history of an ankle sprain. Prevention programs and neuromuscular warmups with a focus on static and dynamic balance 3 or more days a week can also protect multiple joint systems (Kaminski et al., 2019). Prevention programs have no detrimental impact unless athletes sustain an injury during the exercise. However, prophylactic ankle braces may limit athletic performance and negatively alter knee mechanics.

Current literature aims to examine if ankle braces limit performance measures, limit ankle range of motion, compare braces vs. preventative rehab programs, and if ankle range of motion decreases can lead to changes at the knee or hip joint. However, current research lacks functional fatigue protocols comprising of the whole lower extremity which is needed to replicate fatigued athletes during competition.

Braces Effect on Athletic Performance

Using prophylactic ankle braces on non-injured athletes may have detrimental effects on athletic performance due to restriction of ankle range of motion altering cutting and landing mechanics. While few studies have shown no correlation in decreasing athletic performance and motion restricting ankle braces, a vast majority have shown negative impact on performance (Theodorakos et al., 2016). Current research indicates that soft-shell and semi-rigid ankle braces can reduce vertical jumping height (MacKean et al., 1995, Henderson et al., 2019, Newman et al., 2018, Smith et al., 2016, You et al., 2020) and impair agility performance (Newman et al., 2018, Beriau et al. 1994, Henderson et al., 2020). A decrease in performance from ankle lace-up braces can be partially attributed to a decrease in EMG activity of the soleus and gastrocnemius during vertical jumps (Henderson et al., 2019). Without the full ankle sagittal range of motion, the gastrocnemius and soleus can't contribute their full potential in producing power or eccentric control while landing and cutting. This is a possible explanation for the need for an increase in knee flexion to compensate for shock absorption while landing and cutting. This increase in knee flexion critically alters landing mechanics that may lead to chronic knee pathologies.

During walking tasks, healthy ankle braced groups have shown a reduction in ankle power output leading to a redistribution of mechanical power generation from the hip. This can increase overall metabolic demand since the hip joint muscles and tendons can generate more strength but are less efficient metabolically than those of the ankle joint (Wutzke et al., 2012). Another study found similar results with an increase in redistributed workload, and the knee was found to compensate more for loss of plantarflexion (Huang et al., 2015). These changes indicate that plantarflexion restriction can redistribute mechanical workload from the ankle to the knee and hip which may lead to an increase in metabolic demand and redistribution of joint workload. This can negatively impact an athlete's performance by potentially increasing muscle fatigue. During a sub-maximal treadmill run female subjects had an increase in oxygen consumption and energy expenditure when wearing prophylactic ankle braces while also exhibiting decreased vertical jump height (Mackean et al., 1995). This suggests further negative implications of ankle braces on performance measures because there is an increase in metabolic demand and potential for increases in muscle fatigue.

Ankle and Knee Changes Due to Ankle Braces

Ankle bracing can significantly reduce ankle frontal plane inversion and eversion by 3.95 ± 3.74° compared to the standard conditions (Vanwanseele et al., 2014) and can further restrict every motion of the ankle (Willeford, 2018). Consistently, previously published studies have shown a range of motion restriction in all directions of the ankle when prophylactic ankle braces are applied (Cordova et al., 2000, Willeford, 2018). This has led researchers to investigate the impact reduced ankle ranges of motions can have not only on performance but also on how they can alter the kinematics of the knee and hip as well.

ASO ankle braces (semi-rigid lace-up) on the dominant ankle can reduce ankle inversion without influencing the contralateral leg's mechanics and force distribution (Dewar et al., 2019). Contralateral brace influence is an important factor in landing and cutting tasks since most athletes brace only one ankle. Recent research observes how ankle braces impact upstream biomechanical changes of the knee. Primary concerns include the role braces might play in increasing anterior cruciate ligament (ACL) ruptures during landing activities (McGuine et al., 2011). This link is primarily due to decreased ankle dorsiflexion as a significant predictor in athletes having non-contact ACL rates during landing and cutting activities (Amraee, 2015, Wahlstedt et al., 2014) partially due to less dissipation of ground reaction forces (Theisen, 2019). A common predictor for increases in ACL ruptures is poor postural control during athletic movements which is exacerbated by decreases in ankle dorsiflexion angles (Mallory et al., 2014). However, prophylactic lace-up ankle braces have been found to limit ankle sagittal motion while leading to increases in knee flexion at initial ground contact which is a potential protective measure for ACL ruptures (Teng et al., 2013, Bodendorfer et al., 2015). Lace-up ankle braces that effectively reduce dorsiflexion during landing tasks are associated with greater knee flexion angles allowing ground reaction forces (GRF) to remain consistent (DiStefano et al, 2008).

Investigation in altered knee kinetics during landing and cutting due to reduction in ankle dorsiflexion range of motion from lace-up braces are needed to ensure lace-up braces are an effective prophylactic measure without causing potential harm. Current literature focuses on ankle braces and ACL injury risk and lacks investigation into possible chronic knee pathologies. Furthermore, a functional fatigue protocol is needed to replicate physical activity since current research is lacking and fatigued athletes exhibit higher chances of acute and chronic lower extremity injuries due to altered mechanics from muscle fatigue.

Factors Leading to Chronic Knee Injuries

An increase in eccentric knee flexion, as well as knee valgus strain during landing tasks, is a major risk factor in the development of patellar tendinopathy and other chronic knee injuries (West et al., 2013). A known precursor to patellar tendinopathy is the thickening of the proximal portion of the patellar tendon. Patellar thickening is associated with loss of ankle dorsiflexion range of motion with less than 45°. These subjects were shown to have 1.8 to 2.8 times more likely to have abnormal findings on patellar imaging (Malliaras et al., 2006). Patellar tendinopathy presents as pain at the inferior patellar pole and quadriceps tendinopathy presents as pain at the superior patellar pole with increases in pain during deep knee flexion. The onset of symptoms is related to acute high levels of eccentric knee flexion and athletes with extensor mechanism pain 25% of the time experience pain at the superior pole (Sprague et al., 2019). Low dorsiflexion range of motion is a major risk factor in patellar tendinopathy where basketball players with dorsiflexion range less than 36.5° had a risk of 18.5% to 29.4% of developing patellar tendinopathy within a year (Backman et al., 2011). Ankle dorsiflexion is important in absorbing lower limb forces and has consistently been found in altering knee mechanics in landing and cutting sports (Malliaras et al., 2006, (Aiyegbusi et al., 2019).

Loss of ankle dorsiflexion increases initial landing forces primarily through inadequate eccentric contractions of the gastrocnemius and soleus. Restriction of frontal plane ankle motion due to prophylactic ankle braces and custom orthotics is associated with increased knee peak external rotation during vertical landing tasks (Greene et al., 2014) which is a factor leading to the development of chronic knee pathologies from altered knee loading. The most common chronic knee pathology in young and physically active females is patellofemoral pain (PFP) marked by anterior knee pain during squatting, jumping, and running with a strong relationship with increased knee abduction angles (Myer et al., 2014). Other chronic knee conditions, such as iliotibial band friction syndrome (ITBF) and synovial plica of the knee can be caused by altered knee mechanics including increases in knee flexion. The iliotibial band is a fascial continuation of the tensor fascia lata, gluteus medius, and gluteus maximus. The ITB functions as a knee extensor but becomes a knee flexor when the knee is flexed past 30 degrees (Hadeed et al., 2020). If braced conditions contribute to excessive knee flexion past athletes' normal limits then they may potentially negatively impact ITBF symptoms.

Muscle Fatigue Effect on Cutting and Landing Mechanics

Muscle fatigue has a negative impact on muscle spindles by activation of nociceptors and inflammatory by-products creating altered muscle spindle discharge patterns. Furthermore, fatigue plays a role in joint stability through altered neuromuscular control causing a reduced preparatory joint motion response and loading to restore joint stability during functional movements (Shaw et al., 2008). Landing mechanics may change during fatigue conditions due to neuromuscular protective mechanisms aimed to decrease impact force magnitude (Madigan et al., 2003). However, (Xia et al., 2017) observed constant vertical ground reaction forces (VGRF) but altered joint mechanics with increased hip and knee flexion during drop landing under a fatigue condition. Neuromuscular fatigue is strongly correlated with increases in injury rates including ACL ruptures primarily through altered mechanics during landing and cutting tasks (Liederbach et al., 2014 and Thomas et al., 2010 and Haddas et al., 2015) especially in female athletic populations (Liederbach et al., 2014).

Knee mechanics that typically change after fatigue tasks are greater knee flexion at initial contact, greater knee internal rotation angle, and maximal knee flexion angle (Haddas et al., 2015) which are all factors that lead to chronic knee pathologies. During bouts of muscular fatigue, participants show greater knee and ankle flexion angles at initial contact, greater peak ground reaction forces, and require a longer time to stabilize after landing tasks (Brazen et al., 2010). During drop landings, fatigue increases initial and peak abduction/adduction angles, peak knee internal rotation, and females have a further increase in peak knee abduction moments (Mclean et al., 2007). Although significant amounts of research have gone into fatigue altering knee kinematics most researchers have focused on variables leading to increased ACL risk especially knee and hip flexion. Some researchers have observed fatigued athletes displaying increased knee and hip flexion which is favorable in decreasing ACL risk (Bourne et al, 2019).

Cutting tasks immediately following a fatigue protocol elicits similar knee kinematic changes as landing tasks. Following a 60-minute treadmill jogging protocol replicating a game scenario participant performed side-step cutting tasks and had significant increases in knee flexion at initial contact and varus/valgus angles when compared to baseline (Savage et al., 2017). Peak knee valgus angles increase during a side cutting task immediately after fatigue protocol but can return to normal after 20 minutes of rest (Tsai et al., 2009). The is a lack of research studies on the effect fatigue on ankle and knee kinematics of cutting. An investigation into ankle braces during a fatigue condition is important to fully understand if and how they can influence knee mechanics during cutting and landing tasks.

How Ankle Braces Influence Ankle Injuries/Knee Injuries

Lace-up ankle braces are used in conjunction with other preventative and rehabilitation techniques to minimize ankle inversion range of motion (Dewer, 2019). Prophylactic ankle braces are designed to limit traumatic ankle injuries by limiting excessive ankle joint motions in the frontal plane, reducing the anterior tibial shear force of the subtalar joint, and improving proprioception by promoting mechanoreception (Klem et al., 2016). Prophylactic ankle bracing that limit dorsiflexion may have a detrimental impact on the knee joint particularly patellar tendinopathy due to increased knee flexion compensating for the decrease in ankle dorsiflexion (West et al., 2013). An increase in eccentric knee flexion and an increase in knee valgus strain during landing tasks is a major risk factor in the development of patellar tendinopathy and other various chronic knee injuries (West et al., 2013). Furthermore, this increase in knee flexion has been linked to ACL injury protection (Sheu et al., 2015) and ankle braces limiting dorsiflexion have been linked to decreasing ACL injury rates (Fong et al., 2011). Reductions in ankle dorsiflexion are also correlated with greater knee-valgus and knee flexion angles (Hansberger et al., 2018) which are also associated with chronic knee pathologies. The possible mechanism for a decrease in ACL rates is less anterior tibial shear force when the knee undergoes increases in knee flexion. Increased knee flexion decreases anterior tibial shear force by decreasing the patellar tendon-tibial shaft angle. This is increase in knee flexion enhances the hamstrings' ability to counteract anterior tibial shear force by producing more posterior tibial shear (Padua et al., 2009).

Conclusion of Literature Review

Prophylactic lace-up ankle braces have been shown to alter lower body landing mechanics and joint forces. It is important to identify the types of changes that occur due to prophylactic ankle braces while performing athletic movements (e.g., landing and cutting) because chronic exposure to these changes may ultimately lead to chronic knee pathologies. Athletes often wear braces during games under fatigue and non-fatigued states therefore observing how braces influences both states is crucial. Nevertheless, there is a lack of literature on the potential long-term effect of ankle brace during fatigue (Ihmels et al., 2020 Mason-Mackay et al., 2016 West et al., 2013).

CHAPTER THREE

Methods

Participants

There were 14 participants in the study (7 males and 7 females). Participants were physically active young adults between the ages of 18 and 25, who have a history of competitive landing and cutting sports. Subjects were recruited via email, class visits, and flyers. All participants met the following criteria.

- Perform at least 150 min of moderate to vigorous aerobic activity each week
- No previous diagnosis or self-reported ankle injury over the last 6 months (e.g., sprain, fracture, tendonitis)
- No previous significant knee injuries
- No current/previous heart conditions
- Not under doctor’s restrictions to participate in heart rate max activities.
- Cannot wear ankle braces during any activities.

Study Sites

All data collection and subject sessions took place in the Biomotion Lab located in Baylor Research Innovation and Collaboration (BRIC) at Baylor University, Waco, TX.

Independent and Dependent Variables

Independent variables are ankle brace conditions (w/brace and w/o brace). Dependent variables are Initial Contact Plantarflexion (ICPF), Peak Ankle Dorsiflexion (PDF), Peak Ankle Plantarflexion (PPF), Ankle Sagittal Displacement (ASD), Peak Knee Flexion (PKF), Time to Peak Knee Flexion (T2PKF), Knee Frontal Displacement (KFD).

Warm-up/Stretch Routine

After subjects completed documentation and marker set-up they performed a 10-minute light lower-body focused warm-up then the fatigue protocol. This not only allows an adequate warm-up for subjects but also gives subjects time to get used to the markers and investigators a chance to secure any markers if needed. Subjects performed a light 2-minute jog on the 15-meter track used for the fatigue protocol. The rest of the warm-up was also done on the track. The tasks include floor sweeps, backward hip open ups, high knees, butt kicks, lunge with trunk rotations. For any time left, the subjects could perform a self-warm-up approved by investigators.

Lactate Measurements/Borg Scale

A decrease in strength and endurance is associated with increases in blood lactate levels. The ability to tolerate and remove lactic acid is beneficial for performance (Giles et al., 2006). Intense exercise causes metabolic and ionic changes that disrupt muscle excitation-contraction coupling and leads to impaired skeletal force production. A major contribution to impaired muscle function is the accumulation of lactate and H+ during non-steady-state exercise lasting a couple of minutes (Hostrup et al., 2016). Lactate does have physiological benefits as a signaling molecule and fuel for neurons often linking it to a positive impact of exercise on diminishing neurodegeneration (Proia et al., 2016). Capillary (fingertip) blood lactate and rate of perceived exertion (RPE) on a BORG 6-20 scale were measured before and after the fatigue protocol on both days (Fig. 1.1). Capillary lactate was taken from the dominant arm index finger and was properly sanitized and covered with a bandage by an investigator using all proper personal protective equipment. The lactate supplies used is the Nova Biomedical Lactate Plus and lactate strips along with 23G McKesson safety lancets.

Table 1.1.

BORG Scale (6-20)

Rating	How Hard you are Exercising
6	No exertion at all
7	Very very light
8	
9	Very light
10	
11	Light
12	
13	Somewhat hard
14	
15	Hard
16	
17	Very hard
18	
19	Extremely hard
20	Maximal exertion

Biomotion Set-Up

Kinematics and kinetics were calculated based on motion capture and ground reaction force data that were measured at Baylor University's BRIC in Waco, Texas. The BRIC houses the Biomotion Lab complete with a motion capture system that utilizes high-speed cameras and force plates. The system consists of 14 Vicon Vantage cameras (300Hz) for motion capture, 2 Vicon Bonita cameras for video, and 3 ATMI force plates (1500Hz). Markers made of reflective plastic were placed on the subject using adhesive. Subjects wore clothing that does not block the motion capture markers during the collection. Males wore short shorts and females wore short shorts and a sports bra. Once the markers were in place static and range of motion poses were collected to serve as a baseline measure for the overall subject motion quality and to form the standard kinematic and kinetic model. These poses are standard for all data capture session at the Biomotion Lab.

Marker Set-Up

Markers were placed with double-sided tape based on the lower body plug-in-gait model. The lower body plug-in-gait model consists of 16 total markers on various locations on the pelvis, knee, leg, and ankle (Fig. 2.1). Furthermore, any reflective materials the subject was wearing researchers took off or covered with tape.

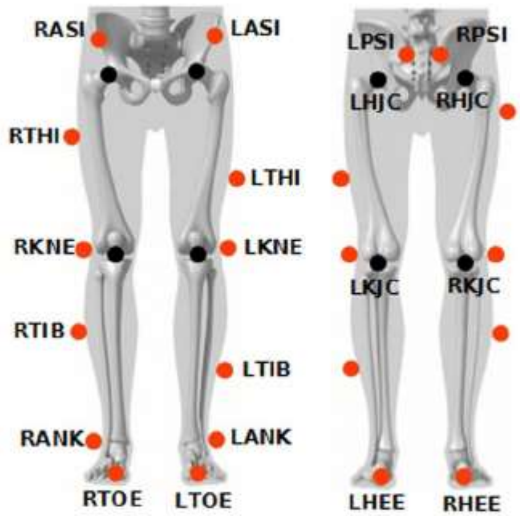

Figure 1.1. *Lower Body Plug-in Gait Marker Placement*

Ankle Brace Set-Up

Subjects were randomly assigned to wearing an ankle brace during their first session or second session. Subjects wore a semi-rigid ASO Ankle Stabilizer with Stays in sizes small, medium, large, or extra-large. To ensure comfort and same tightness through all subjects researchers tightened participants' shoes and the lace-up portion of the ankle brace. The lace-up portion of the ankle braces was tightened to 30lbs of force (measured with a handheld spring scale) and secured with buckle clamps throughout all participants (Figure 1.2.). Both researchers applying the brace are certified and licensed athletic trainers with experience in proper brace fitting.

Figure 1.2. *Scale Used for Proper Brace Tightness*

15-Meter Beep Test Fatigue Protocol

Participants performed a 15-meter beep test similar to the more commonly used 20-meter pacer test. The 15-meter test was chosen due to the size of the Biomotion lab. The accuracy of assessing VO2 max and aerobic capacity using the 15-meter beep test is a reliable measure (McClain et al., 2004). Subjects performed the test until they physically cannot continue, or they cannot make it to the line two times in a row before the beep. Immediately after the beep test, participants had their circulating lactate measured, BORG scale recorded, and any markers that had fallen were secured back on.

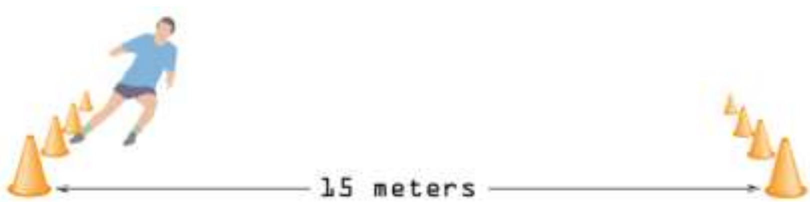

Figure 2.1. *15m Beep Test Set-Up*

90 Degree Cutting Task

A 90° angle task was chosen due to its ability to place more stress at both the ankle and knee joints. As the degree of the cut angles increase knee flexion angles will increase as well (Sheu et al., 2015). Ankle brace studies have predominantly used 45° tasks (Schroeder et al., 2019, Klem et al., 2017). However, 90° tasks have been used in different studies evaluating knee kinematics (Sheu et al., 2015, Havens et al., 2015 and Imwalle et al., 2009) and are a common maneuver used in sports requiring explosive movements like football, soccer, volleyball, basketball, etc. No previous studies on ankle braces and knee kinematics have used a 90° cutting task when subjects wore ankle braces. Subjects started their approach from 3 meters away and were instructed to plant on the force plate and explode out at a 90° angle off the force plate. Subjects were given a practice trial, so they were comfortable with the process and then completed 5 trials.

Visit 1 and 2 Visit Timeline

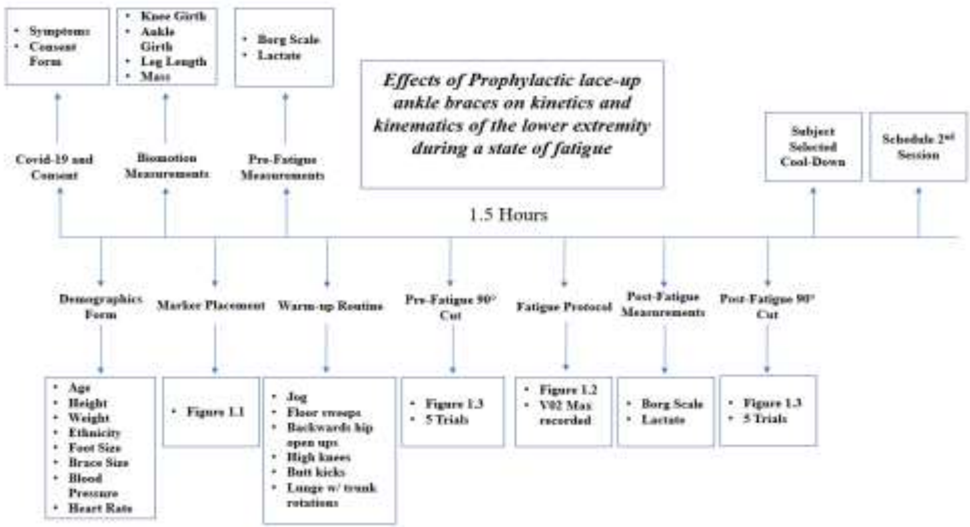

Figure 3.1. *Subject Visit Timeline*

Data Collection

Data collection variables of interest were taken during the deceleration phase of the cutting maneuver starting with dominant foot initial contact on the force plate. The collection took part over two sessions with 5 pre-fatigue 90° cuts and 5 post-fatigue 90° cuts during each session. The participants were informed they may be photographed and videoed during this data collection. Any photos/videos that are used in publication or presentation will be de-identified. All videos and photos are stored on a stand-alone computer in the collection lab that is not connected to the internet.

Statistical Analysis

All statistical analyses were performed using the IBM SSPS (IBM, Armonk, NY, USA). A 2 (Brace: w/ brace, w/o brace x 2 (Test: pre-fatigue, post-fatigue) analysis of variance (ANOVA) with repeated measures on both factors was performed. Means were considered significantly different when the probability of a type I error was .05 or less. If the sphericity assumption was violated, Huynh-Feldt corrections for the *p*-values were reported. Partial eta-squared (η_p^2) values were computed to determine the proportion of total variability attributable to each factor or combination of factors.

CHAPTER FOUR

Results

Subject Characteristics

In total, 14 subjects participated in the study, but one was a significant outlier (means beyond 2SD in kinematic analysis) therefore was excluded. Subject baseline characteristics are displayed in (Table 1.2).

Table 1.2 *Participant Baseline Characteristics (n=13)*

Variable	Mean ± SD
Age	23.5 ± 1.74
Foot Size	9.25 ± 1.55
Height (cm)	176.18 ± 6.98
Weight (kg)	46.65 ± 13.86
BMI	22.2 ± 2.25
Systolic BP (mmHg)	128 ± 11.65
Diastolic BP (mmHg)	79 ± 7.11
Heart Rate (bpm)	69.36 ± 11.01

Note: cm = centimeters; SD = standard deviation; kg = kilograms; bpm = beats per minute; mmHg = millimeters of mercury

Fatigue Measurements

The 15 Meter Beep test fatigue protocol elicited fatigue on all subjects while wearing the ASO ankle brace causing a significant increase in Borg scale results (pre-fatigue 6.14 ± 0.53, post-fatigue 15.93 ± 1.49) and lactate (pre-fatigue 1.81 ± 0.97, post-fatigue 10.65 ± 2.42). W/o brace conditions showed similar results in Borg scale (pre-fatigue 6.14 ± 0.53, post-fatigue 16.29 ± 1.33), and lactate (pre-fatigue 2.04 ± 1.05, post-fatigue 10.44 ± 1.93). Furthermore, the VO2 max results were not different between w/brace (41.75 ± 5.03) and w/o brace (41.75 ± 4.37). Overall, the fatigue protocol succeeded in creating a dynamic fatigue task causing all subjects to stay in a state of fatigue during their post-fatigue testing. Full subject's fatigue results are shown in (Table 1.3) as well as male and female comparison results are shown in (Table 1.4) with no significant differences.

Table 1.3 *All Subject Fatigue Measurements (n=13)*

Variable	Brace	No Brace
VO2 Max	41.75 ± 5.03	41.75 ± 4.37
Pre Borg Scale	6.14 ± 0.53	6.14 ± 0.53
Post Borg Scale	15.93 ± 1.49	16.29 ± 1.33
Pre-Lactate	1.81 ± 0.97	2.04 ± 1.05
Post-Lactate	10.65 ± 2.42	10.44 ± 1.93
Δ Borg	9.79 ± 1.48	10.14 ± 2.46
Δ Lactate	8.88 ± 2.45	8.41 ± 1.85

Note: SD = standard deviation

Table 1.4 *Male and Female Fatigue Measurements (n=13)*

Variable	Gender	Brace	No Brace
VO2 Max	Male	45.59 ± 3.38	44.69 ± 3.84
	Female	37.92 ± 3.00	38.82 ± 2.58
Pre Borg Scale	Male	6.00 ± 0.0	6.00 ± 0.0
	Female	6.29 ± 0.76	6.29 ± 0.76
Post Borg Scale	Male	16.29 ± 1.07	17.14 ± 6.48
	Female	15.57 ± 1.51	15.43 ± 0.98
Pre-Lactate	Male	2.07 ± 1.24	2.07 ± 1.07
	Female	1.54 ± 0.47	2.01 ± 0.91
Post-Lactate	Male	12.24 ± 2.04	11.20 ± 4.06
	Female	11.20 ± 4.06	9.06 ± 2.07
Δ Borg	Male	10.29 ± 1.07	11.14 ± 3.95
	Female	9.29 ± 1.38	9.67 ± 1.61
Δ Lactate	Male	10.40 ± 2.02	9.03 ± 3.28
	Female	7.37 ± 2.37	7.79 ± 1.55

Note: SD = standard deviation

Kinematics of the Ankle and Knee

Data related to all ankle and knee kinematic variables were analyzed using a 2 x 2 (Brace x Fatigue) ANOVA with repeated measures. Small non-significant interaction between brace and fatigue was found only in PKF ($F_{1, 12}$ =1.966, P = .186, η_p^2 = .141). There was no main effect on the brace for PDF, T2PKF, KFD (p > .05). However, there was an effect on the brace for ICPF, PPF, ASD, PKF, T2PKF (p < .05). Mean values ± standard deviations for all ankle variables and conditions are shown below in (Table 1.5) and knee variables (Table 1.6). A graph displaying the results on all variables and conditions are shown in (Figure 4.1) except T2PKF which is on (Figure 4.2)

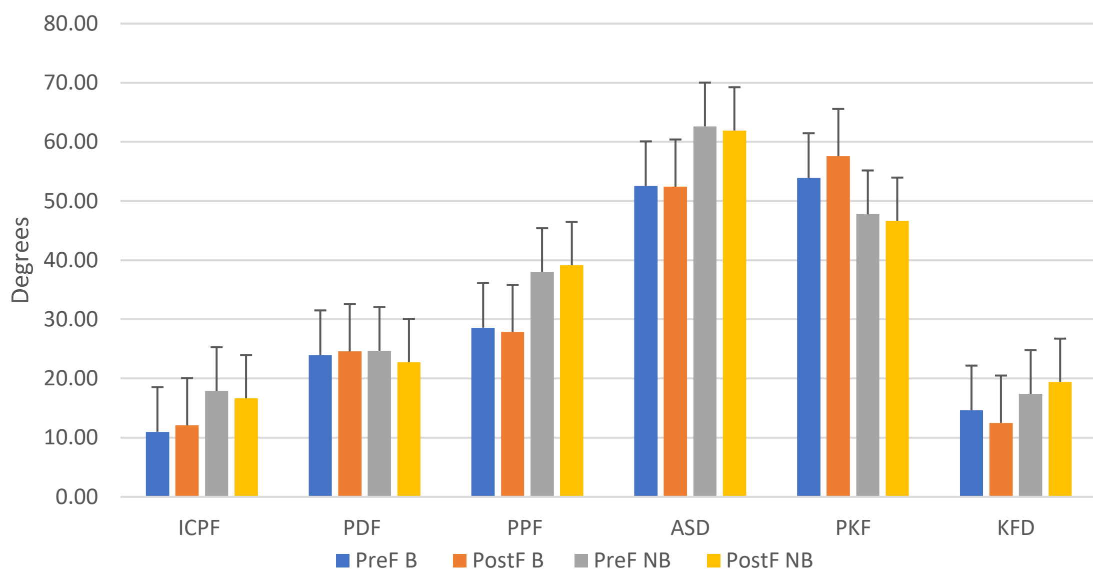

Figure 4.1 *Comparison of all Variables and Conditions*

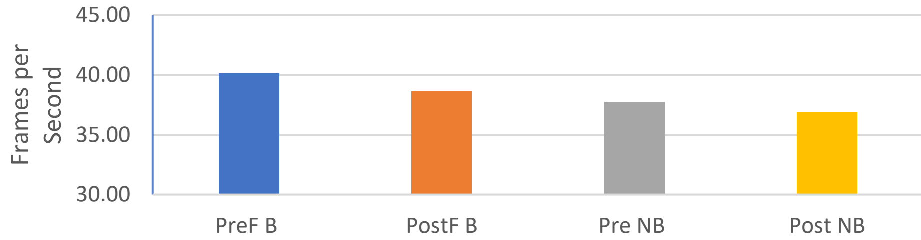

Figure 4.2 *Time to Peak Knee Flexion Values for All Subjects*

Table 1.5 *Descriptive Data of Ankle Kinematics*

Variable	Brace		No Brace	
	Pre-Fatigue	Post-Fatigue	Pre-Fatigue	Post-Fatigue
ICPF	10.99° ± 7.06°	12.09° ± 7.11°	17.88° ± 8.08°	16.66° ± 8.91°
PDF	23.95° ± 9.10°	24.59° ± 8.70°	24.68° ± 7.55°	22.77° ± 8.49°
PPF	28.59° ± 10.02°	27.84° ± 9.24°	38.00° ± 9.02°	39.15° ± 10.45°
ASD	52.54° ± 7.77°	52.42° ± 7.32°	62.62° ± 12.02°	61.93° ± 12.94°

Note: SD = standard deviation

Table 1.6 Descriptive Data of Knee Kinematics

Variable	Brace		No Brace	
	Pre-Fatigue	Post-Fatigue	Pre-Fatigue	Post-Fatigue
PKF	53.91° ± 10.7°	57.57° ± 8.43°	47.77° ± 11.62°	46.65° ± 13.86°
T2PKF	40.16 ± 7.97	38.64 ± 6.51	36.90° ± 6.68°	36.90° ± 8.47°
KFD	14.63° ± 8.16°	12.51° ± 7.45°	17.40° ± 8.60°	19.43° ± 8.99°

Note: SD = standard deviation, T2PKF = measured in frames per second (300fps)

Initial Contact Ankle Plantarflexion

On ICPF, there was a main effect on brace ($F_{1, 12}$ =5.69, P = .034, η_p^2 = .322). However, there was no effect on fatigue ($F_{1, 12}$ =.003, P = .956, η_p^2 = .000) and there was no significant interaction between the brace and the fatigue protocol ($F_{1, 12}$ =1.906, P = .193, η_p^2 = .137). Participants showed a decrease in ICPF from pre-fatigue w/ brace (10.99° ± 2.04°, to pre-fatigue w/o brace 17.88° ± 2.33°), as well as post fatigue, w/ brace (12.09° ± 2.05°, post fatigue w/o brace 16.66° ± 2.57). Overall, subjects showed a decrease in ICPF w/ brace in both pre and post fatigued states. The fatigue protocol increased ICPF w/ brace and decreased ICPF in the w/o brace but there was no interaction effect. Descriptive data of mean ± standard deviation as well as 95% confidence intervals for these variables are shown below in (Table 1.5). Mean subject results for ICPF are shown in (Figure 5.1) and ΔICPF from w/ brace to w/o brace in pre-fatigue test and the post-fatigue test is presented in (Figure 5.2)

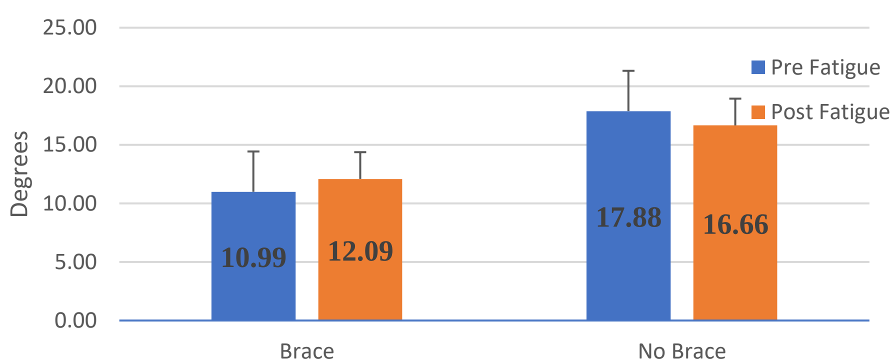

Figure 5.1. *Subject Mean ICPF*

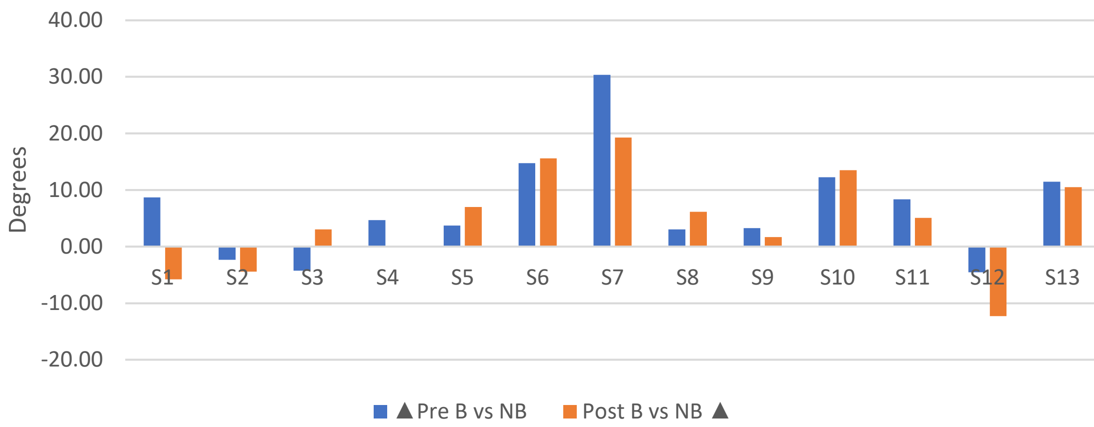

Figure 5.2. *ΔICPF – Pre w/ brace vs w/o brace and Post w/brace vs w/o brace*

Peak Ankle Dorsiflexion

On PDF, there was no main effect on the brace ($F_{1, 12}$ =.061, P = .809, η_p^2 = .005). Furthermore, there was no effect from the fatigue ($F_{1, 12}$ =.368, P = .556, η_p^2 = .030) and there was a small but not significant interaction between the brace and the fatigue protocol ($F_{1, 12}$ =2.760, P = .123, η_p^2 = .187). Overall, the brace did not affect PDF range of motion and the fatigue protocol did not alter w/ brace or w/o brace conditions as well. Descriptive data of mean ± standard deviation as well as 95% confidence intervals for these variables are shown below in (Table 1.5). Mean subject results for PDF are shown in (Figure 5.3).

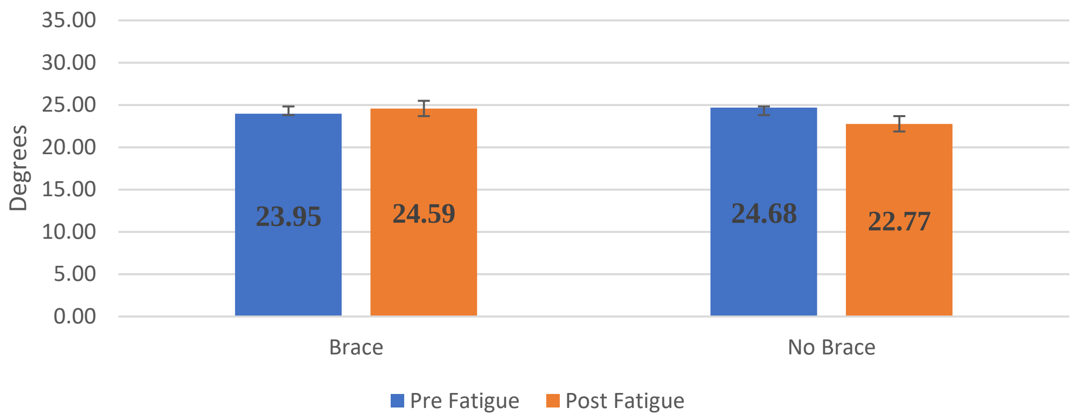

Figure 5.3. *Subject Mean PDF*

Peak Ankle Plantarflexion

On PPF, there was a main effect on the brace ($F_{1, 12}$ =14.411, P = .003, η_p^2 = .546). However, there was no effect from the fatigue ($F_{1, 12}$ =.035, P = .856, η_p^2 = .003) and there was not a significant interaction between the brace and the fatigue protocol ($F_{1, 12}$ =.846, P = .376, η_p^2 = .066). Participants showed a significant decrease in PPF (pre-fatigue w/ brace 28.59° ± 10.02°, to pre-fatigue w/o brace 38.00° ± 9.02°), as well as (post fatigue, w/ brace 27.84° ± 9.24°, post fatigue w/o brace 39.15° ± 10.45°). The fatigue protocol did not alter PPF in both w/ brace and w/o brace. Descriptive data of mean ± standard deviation as well as 95% confidence intervals for these variables are shown below in (Table 1.5). Mean subject results for PPF are shown in (Figure 5.4) and ΔPPF from w/ brace to w/o brace in pre-fatigue test and post-fatigue test are shown below (Figure 5.5).

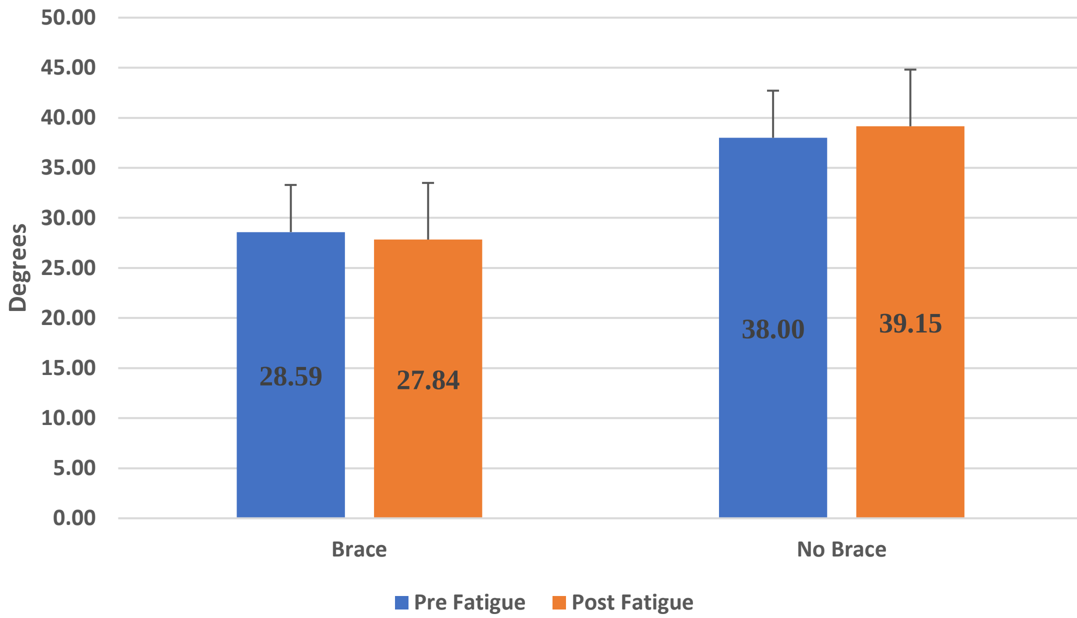

Figure 5.4. *Subject Mean PPF*

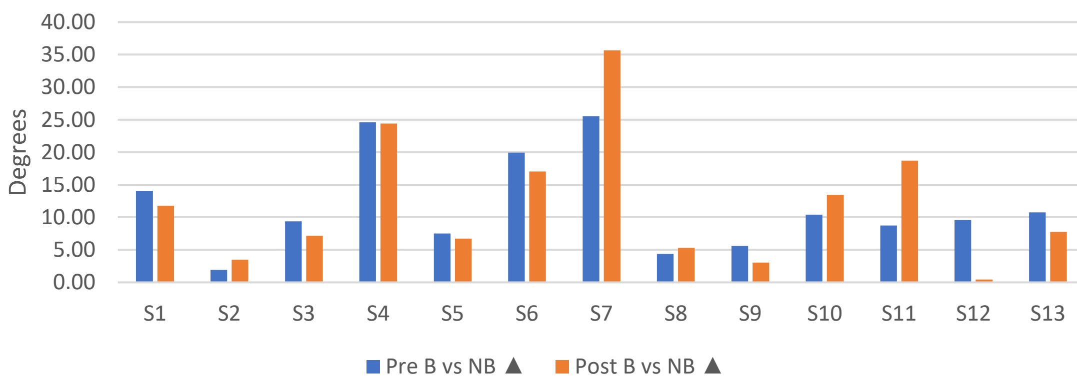

Figure 5.5. *ΔPPF – Pre B vs NB and Post B vs NB*

Ankle Sagittal Displacement

On ASD, there was a main effect on the brace ($F_{1, 12}$ =7.801, P = .016, η_p^2 = .394). However, there was not a significant effect from the fatigue protocol ($F_{1, 12}$ =.779, P = .779, η_p^2 = .007) and no significant interaction between the brace and the fatigue protocol ($F_{1, 12}$ =.140, P = .715, η_p^2 = .012). Participants showed a decrease in ASD from (pre-fatigue w/ brace 52.54° ± 7.77°, to pre-fatigue w/o brace 62.62° ± 12.02°), as well as (post fatigue, w/ brace 52.42° ± 7.32°, post fatigue w/o brace 61.93° ± 12.94°). The fatigue protocol did not alter ASD in both w/ brace and w/o brace. Descriptive data of mean ± standard deviation as well as 95% confidence intervals for these variables are shown below in (Table 1.5). Mean subject results for ASD are shown in (Figure 5.6) and ΔASD from w/ brace to w/o brace in pre-fatigue test and post-fatigue test are shown below (Figure 5.7).

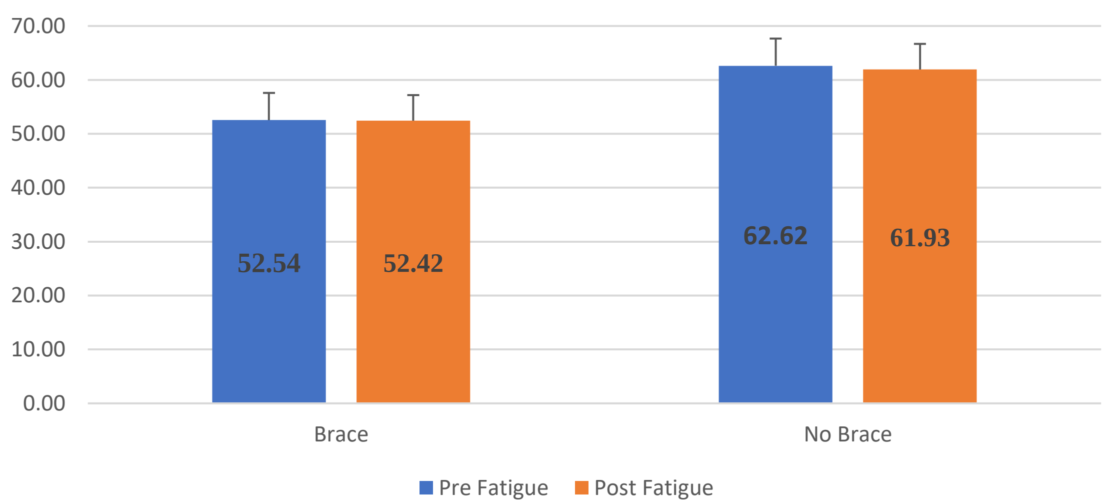

Figure 5.6. *Subject Mean ASD*

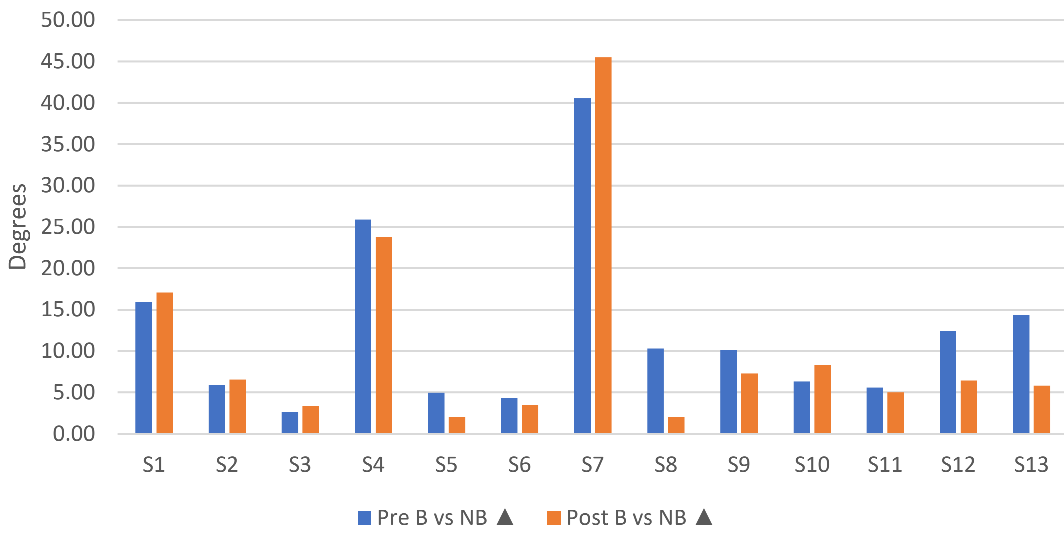

Figure 5.7. ΔASD – *Pre B vs NB and Post B vs NB*

Peak Knee Flexion

On PKF, there was a main effect on the brace ($F_{1, 12}$ = 6.229, *P* = .028, η_p^2 = .342). However, there was no effect from the fatigue protocol ($F_{1, 12}$ =.560, *P* = .469, η_p^2 = .045) and there was a small but non-significant interaction between the brace and the fatigue protocol ($F_{1, 12}$ =1.966, *P* = .186, η_p^2 = .141). Participants showed an increase in PKF from (pre-fatigue w/ brace 53.91° ± 10.7°, to pre-fatigue w/o brace 47.77° ± 11.62°), as well as (post fatigue, w/ brace 57.57° ± 8.43°, post fatigue w/o brace 46.65° ± 13.86°). The fatigue protocol increased PKF w/ brace and decreased PKF w/o brace but this was a moderate non-significant effect. Descriptive data of mean ± standard deviation as well as 95% confidence intervals for these variables are shown in (Table 1.6). Mean subject results for PKF are shown in (Figure 6.1). Furthermore, ΔPKF from w/ brace to w/o brace in pre-fatigue test and post-fatigue test are shown below (Figure 6.2).

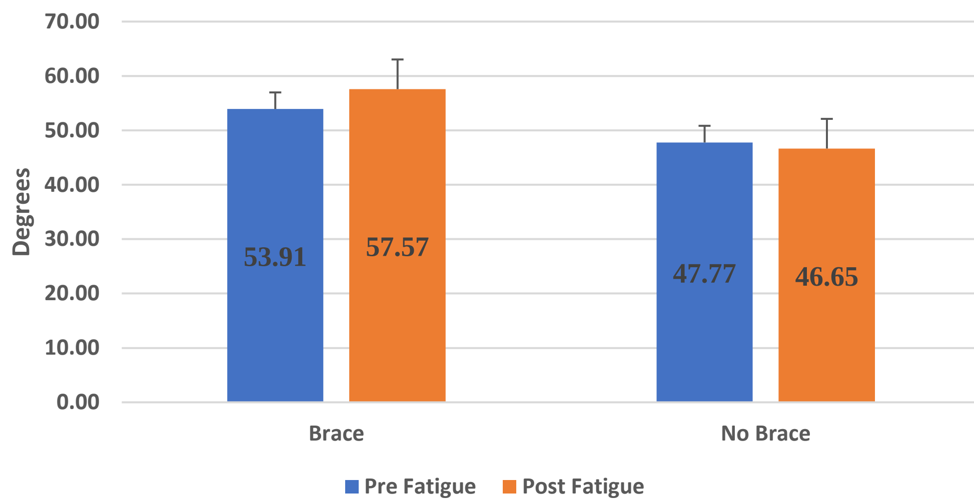

Figure 6.1. *Subject Mean PKF*

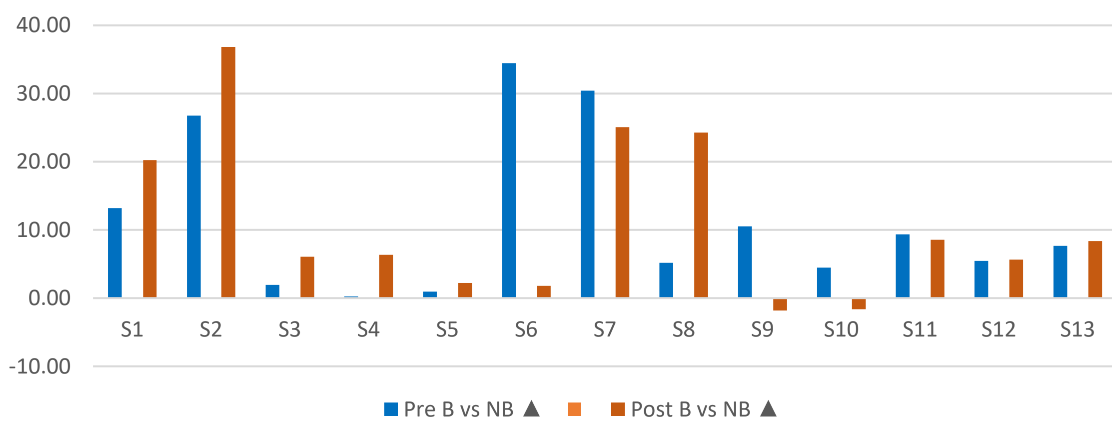

Figure 6.2. ΔPKF – *Pre w/ brace vs w/o brace and Post w/brace vs w/o brace*

Time to Peak Knee Flexion

On T2PKF, there was a main effect on the brace ($F_{1, 12}$ = 4.899, P = .047, η_p^2 = .290). However, there was small but not a significant effect from the fatigue protocol ($F_{1, 12}$ =2.379, P = .149, η_p^2 = .165) and there was a small but not-significant interaction between the brace and the fatigue protocol ($F_{1, 12}$ =.085, P = .776, η_p^2 = .007). Participants showed an increase in T2PKF from (pre-fatigue w/ brace 40.16 ± 7.97, to pre-fatigue w/o brace 36.90 ± 6.68), as well as (post fatigue, w/ brace 38.64 ± 6.51, post fatigue w/o brace 36.90 ± 8.47). The fatigue protocol decreased T2PKF in both w/ brace and w/o brace, but this was a moderate non-significant effect. Descriptive data of mean ± standard deviation as well as 95% confidence intervals for these variables are shown in (Table 1.6). Mean subject results for T2PKF are shown in (Figure 6.3) and ΔT2PKF from w/ brace to w/o brace in pre-fatigue test and post-fatigue test are shown below (Figure 6.4).

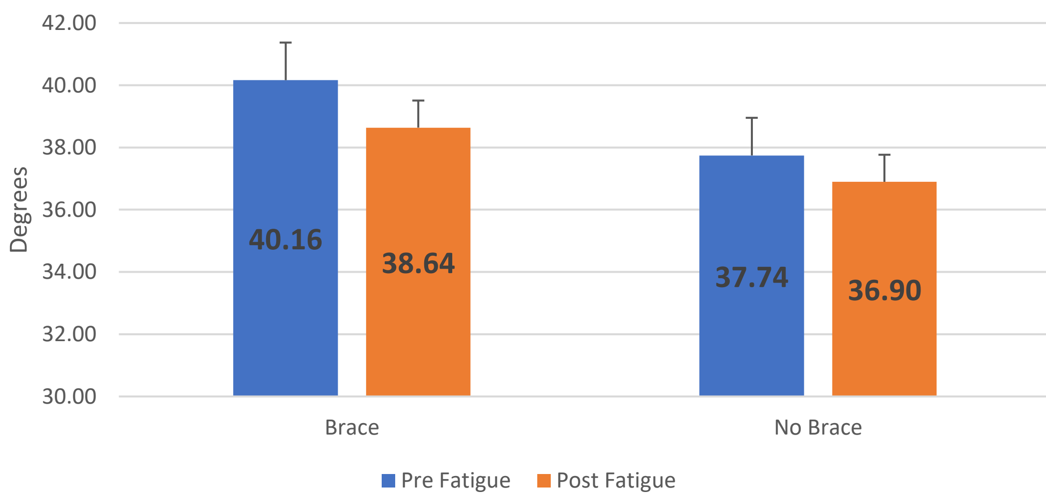

Figure 6.3. *Subjects Mean T2PKF*

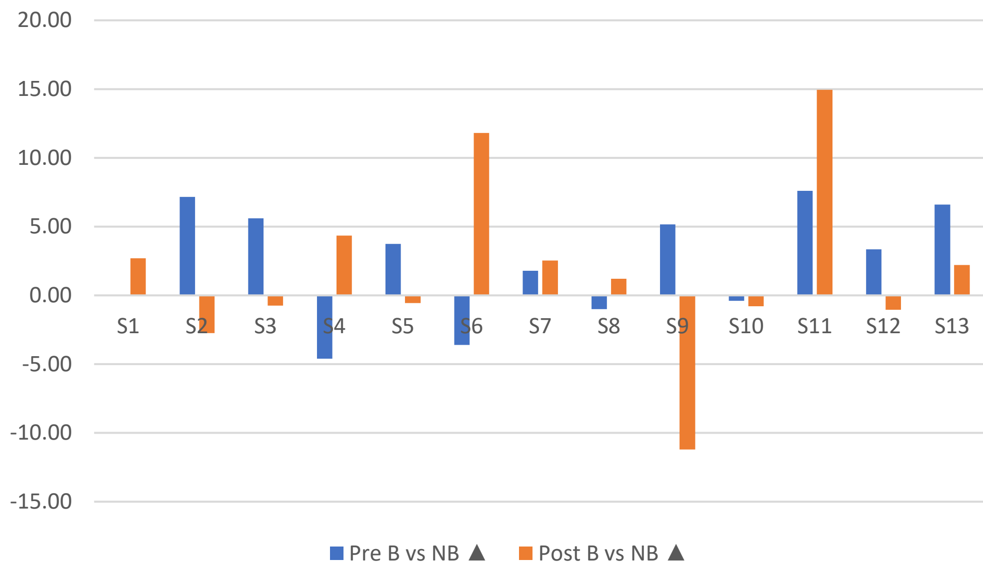

Figure 6.4 *ΔT2PKF – Pre w/ brace vs w/o brace and Post w/brace vs w/o brace*

Knee Frontal Displacement

On KFD, there was a main effect the brace ($F_{1, 12} = 6.586$, $P = .025$, $\eta_p^2 = .354$). However, there was a small but non-significant main effect in the KFD across participant w/brace and w/o brace ($F_{1, 12} = 3.165$, $P = .101$, $\eta_p^2 = .209$) and no significant effect from the fatigue protocol ($F_{1, 12} = .001$, $P = .971$, $\eta_p^2 = .000$). Overall, subjects showed an interaction from the brace and the fatigue protocol where the w/o brace increased (6.92°) compared to the w/ brace (2.77°) from the fatigue protocol. The braced seemed to decrease KFD more effectively when subjects were fatigued. Descriptive data of mean ± standard deviation as well as 95% confidence intervals for these variables are shown in (Table 1.6). Mean subject results for KFD are shown in (Figure 6.5).

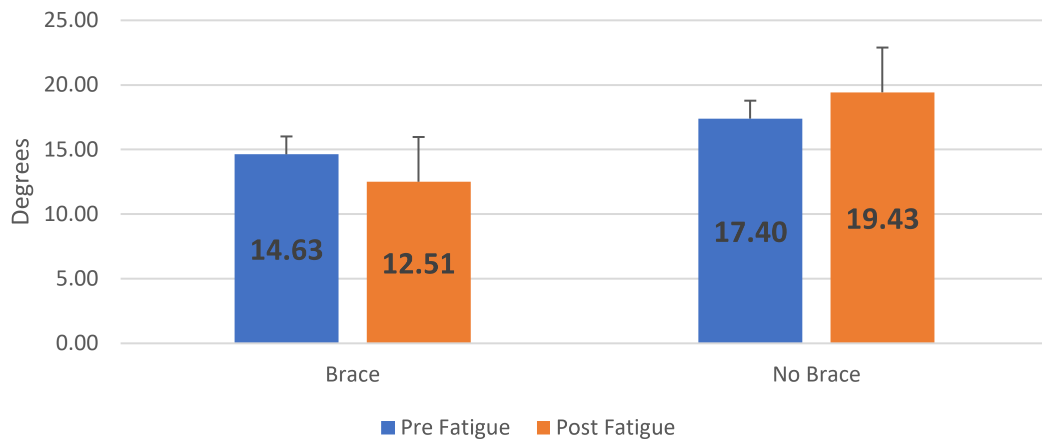

Figure 6.5. *Subjects Mean KFD*

CHAPTER FIVE

Discussion

This study assessed ankle sagittal range of motion restrictions of semi-rigid lace-up ankle braces and how they can influence knee kinematics before and after a state of fatigue. Participants were moderately active individuals with experience in landing and cutting sports. Previously published studies have consistently reported a range of motion restriction in all directions of the ankle when prophylactic ankle braces are applied (Cordova et al., 2000, Willeford et al., 2018, Greene et al., 2014). Ankle range of motion restriction is important in limiting ankle inversion ankle sprains. However, it is important to observe if this is necessary for the athlete without previous history of ankle sprains.

Our results showed statistically significant results in restriction of ICPF, PPF, and ASD during the cutting task when subjects were braced. Furthermore, PDF range of motion was restricted as well but this was not statistically significant in braced conditions. Interestingly, the fatigue protocol didn't significantly alter ankle mechanics when fatigue protocols have been found to increase knee flexion and ankle range of motion compared to non-fatigued conditions (Brazen et al., 2010, Haddaset al., 2015, Xia et al., 2017).

Overall, the participant's ankle range of motion was restricted in the sagittal plane which has been linked to altered knee mechanics (Klem et al., 2016 and Distefano et al, 2008). This is primarily due to less absorption of impact forces from the ankle leading to the knee joint having to take the load and increase knee flexion to compensate (Greene et al., 2014) (Malliaras et al., 2006). The brace caused subjects to shift from forefoot landing to more rearfoot landing at initial contact which could be the potential cause for increased knee flexion. Rearfoot landing is associated with increases in knee flexion during landing and cutting maneuvers (Xie et al., 2016).

Previous studies have shown a significant reduction in ankle sagittal plane range of motion when compared to standard conditions by 8.9° ± 2.4° (Greene et al., 2014). Peak dorsiflexion was only slightly decreased by braced conditions. However, knee flexion and frontal displacement were still altered most likely due to inadequate ankle plantarflexion at peak angles and initial ground contact. A previous study found similar results in a cutting task where participants displayed decreased plantarflexion angles at touchdown (Gudibanda et al., 2005). The ankle kinematic results from this study further demonstrate that ankle range of motion in the sagittal plane can be decreased during dynamic tasks while wearing a prophylactic lace-up ankle brace. This decrease in ASD creates a more neutral ankle during a cutting maneuver. As mentioned before this is linked to decreases in athletic performance and possible contributions to altered knee mechanics associated with chronic knee pathologies.

Knee kinematics when subjects were braced showed increases PKF while simultaneously taking longer to get to PKF causing an increase in the need for eccentric contractions of the quadriceps to maintain joint stability. Previous studies involving depth jumps have shown when ASD was restricted (brace = 56° ± 14°, no brace = 59° ± 16°, P = .001) the participants increased knee flexion (brace = 79° ± 16°, no brace = 82° ± 16°, P = .036) (DiStefano et al., 2008). Another study indicated that subjects showed 3° more knee flexion during landing positions (Simpson et al., 2013). Our greater changes in knee flexion compared to these studies is due to our participants' having greater ASD and we choose a cutting task instead of drop jumps. To our knowledge, we are the only study to evaluate participants during a 90° cutting task which is crucial in observing typical athletic maneuvers.

An increase in knee flexion has previously been identified in fatigued subjects however our results showed only a minor increase in PKF during the brace conditions after completing the fatigue protocol. This may be due to the fatigue protocol aerobically fatiguing subjects without eliciting enough muscle damage to disrupt muscle spindle discharge patterns which commonly causes athletes to have altered landing and cutting mechanics. Interestingly, braced conditions showed a possible trend in a protective mechanism for the knee since they showed a small difference in KFD. Excessive valgus and varus displacements are associated with multiple acute and chronic knee pathologies in physically active populations since they create a less stable knee joint.

Overall, results from the present study show restricted ankle sagittal range of motion especially dorsiflexion at ground contact during the deceleration phase of a 90° cutting task which negatively influenced knee flexion angles. Clinicians should consider the impact prophylactic lace-up ankle braces may have on non-injured athletes and initial injury prevention can be done through other means. Other prophylactic options to consider that are effective and have fewer complications are hinged ankle braces and various preventative rehab programs.

Hinge braces are not used as frequently as lace-up braces in physically active populations. Furthermore, hinge braces allow more ankle sagittal range of motion than lace-up braces making them less likely to decrease athletic performance or alter knee mechanics. Hinge braces can limit ankle inversion without altering knee flexion angles in a 45° cutting task (Schroeder et al., 2019) as well as decreased ankle and knee joint forces (Klem et al., 2016). Due to our results and other studies showing altered knee mechanics due to ankle restriction of a lace-up brace, hinge braces might be a better alternative since they allow more ankle sagittal range motion while still restricting ankle frontal range of motion.

Preventative programs require more compliance and typically can take 15-30 minutes with multiple sessions a week. However, they can easily be incorporated into warmup routines. Additionally, the preventative programs and their prophylactic effect extends past the ankle since they incorporate stretching, proprioception exercises, power, neuromuscular control, and agility which can benefit the whole lower extremity. A recent review including over 3,000 subjects found ankle preventative programs focusing on proprioception exercises are effective in reducing ankle sprains, including athletes without a previous history of an ankle injury (Rivera et al., 2017). A systematic review on the Prevent Injury and Enhance Performance (PEP) Program which is a commonly used prevention program for ACL and lower extremity injuries showed reductions in all lower extremities after athletes participated in the program for 3 months (Herman et al., 2012).

Our study used a novel approach to guaranteeing brace tightness from subject to subject (Figure 1.2). This is crucial for guaranteeing participants are equally restricted in in the sagittal and frontal plane. Future studies should adopt this approach to ensure adequate tightness and inter-subject consistency. Furthermore, we used a 90° cutting task which may be a better measurement for future kinematic analysis studies on the ankle and knee. This cutting task places greater stress on the ankle and knee while replicating a common sports movement pattern.

Conclusion

Results from this study show prophylactic lace-up ankle braces used by athletes without ankle injury history decrease ICPF, PPF, and ASD leading to the altered knee mechanic during a 90° cutting task. Our results showed the knee compensated for these changes by increasing PKF and concurrently taking more time to achieve peak knee flexion. Furthermore, we showed that the fatigue protocol did not significantly affect braced and non-braced conditions separately and the changes from the fatigue protocol were consistent between the conditions. Clinicians should consider the implications lace-up ankle braces can have on non-injured athletes and possibly implement other prophylactic measures instead. For future studies, implementation of a longer duration dynamic protocol should be considered to elicit more muscle damage while also replicating typical athletic activity.

BIBLIOGRAPHY

1. Aiyegbusi, A., Tella, B., & Okeke, C. (2019). Lower Limb Biomechanical Variables Are Indicators of the Pattern of Presentation of Patella Tendinopathy in Elite African Basketball and Volleyball Players. *Revista brasileira de ortopedia*, *54*(5), 540–548. https://doi.org/10.1055/s-0039-1693743

2. Backman, L. J., & Danielson, P. (2011). Low Range of Ankle Dorsiflexion Predisposes for Patellar Tendinopathy in Junior Elite Basketball Players. *The American Journal of Sports Medicine*, *39*(12), 2626–2633. https://doi.org/10.1177/0363546511420552

3. Bellows, R., & Wong, C. K. (2018). The Effect Of Bracing and Balance Training on Ankle Sprain Incidence Among Athletes: A Systematic Review with Meta-Analysis. *International Journal of Sports Physical Therapy*, *13*(3), 379–388. https://doi.org/10.26603/ijspt20180379

4. Beriau, M. R., Cox, W. B., & Manning, J. (1994). Effects of ankle braces upon agility course performance in high school athletes. *Journal of athletic training*, *29*(3), 224–230.

5. Bodendorfer, B., Stover, G., James, C. R., Arnold, N. R., Summerhays, B., Gray, A. D., & Sherman, S. L. (2015). Do Ankle Sleeves And Lace-Up Braces Effect Neuromuscular Control And Athletic Performance? *Orthopaedic Journal of Sports Medicine*, *3*(7_suppl2), 2325967115S0004. https://doi.org/10.1177/2325967115s00042

6. Bourne, M. N., Webster, K. E., & Hewett, T. E. (2019). Is Fatigue a Risk Factor for Anterior Cruciate Ligament Rupture? *Sports Medicine*, *49*(11), 1629–1635. https://doi.org/10.1007/s40279-019-01134-5

7. Brazen, D. M., Todd, M. K., Ambegaonkar, J. P., Wunderlich, R., & Peterson, C. (2010). The Effect of Fatigue on Landing Biomechanics in Single-Leg Drop Landings. *Clinical Journal of Sport Medicine*, *20*(4), 286–292. https://doi.org/10.1097/jsm.0b013e3181e8f7dc

8. Burger, M., Dreyer, D., Fisher, R. L., Foot, D., O’Connor, D. H., Galante, M., & Zalgaonkir, S. (2018). The effectiveness of proprioceptive and neuromuscular training compared to bracing in reducing the recurrence rate of ankle sprains in athletes: A systematic review and meta-analysis. *Journal of Back and Musculoskeletal Rehabilitation, 31*(2), 221–229. https://doi.org/10.3233/bmr-170804

9. Cordova, M. L., Ingersoll, C. D., & LeBlanc, M. J. (2000). Influence of Ankle Support on Joint Range of Motion Before and After Exercise: A Meta-Analysis. *Journal of Orthopaedic & Sports Physical Therapy*, *30*(4), 170–182. https://doi.org/10.2519/jospt.2000.30.4.170

10. Delahunt, E., & Remus, A. (2019). Risk Factors for Lateral Ankle Sprains and Chronic Ankle Instability. *Journal of Athletic Training*, *54*(6), 611–616. https://doi.org/10.4085/1062-6050-44-18

11. Devita, P., & Skelly, W. A. (1992). Effect of landing stiffness on joint kinetics and energetics in the lower extremity. *Medicine & Science in Sports & Exercise*, *24*(1), 108???115. https://doi.org/10.1249/00005768-199201000-00018

12. Dewar, R. A., Arnold, G. P., Wang, W., Drew, T. S., & Abboud, R. J. (2019). Comparison of 3 ankle braces in reducing ankle inversion in a basketball rebounding task. *The Foot*, *39*, 129–135. https://doi.org/10.1016/j.foot.2019.05.007

13. DiStefano, L. J., Padua, D. A., Brown, C. N., & Guskiewicz, K. M. (2008). Lower Extremity Kinematics and Ground Reaction Forces After Prophylactic Lace-Up Ankle Bracing. *Journal of Athletic Training*, *43*(3), 234–241. https://doi.org/10.4085/1062-6050-43.3.234

14. Dizon, J. R., & Reyes, J. B. (2007). The Effectiveness of External Ankle Supports in the Prevention of Inversion Ankle Sprains among Elite and Recreational Players. *JBI Library of Systematic Reviews*, *5*(Supplement), 1–12. https://doi.org/10.11124/jbisrir-2007-776

15. Fong, C.-M., Blackburn, J. T., Norcross, M. F., McGrath, M., & Padua, D. A. (2011). Ankle-Dorsiflexion Range of Motion and Landing Biomechanics. *Journal of Athletic Training*, *46*(1), 5–10. https://doi.org/10.4085/1062-6050-46.1.5

16. Forbes, H., Thrussell, S., Haycock, N., Lohkamp, M., & White, M. (2013). The Effect of Prophylactic Ankle Support During Simulated Soccer Activity. *Journal of Sport Rehabilitation*, *22*(3), 170–176. https://doi.org/10.1123/jsr.22.3.170

17. Giles, L. V., Rhodes, E. C., & Taunton, J. E. (2006). The Physiology of Rock Climbing. *Sports Medicine*, *36*(6), 529–545. https://doi.org/10.2165/00007256-200636060-00006

18. Greene, A. J., Stuelcken, M. C., Smith, R. M., & Vanwanseele, B. (2014). The effect of external ankle support on the kinematics and kinetics of the lower limb during a side step cutting task in netballers. *BMC Sports Science, Medicine and Rehabilitation*, *6*(1). https://doi.org/10.1186/2052-1847-6-42

19. Gudibanda, A., & Tai" Wang, Y. (2005). Effect of the Ankle Stabilizing Orthosis on Foot and Ankle Kinematics During Cutting Maneuvers. *Research in Sports Medicine*, *13*(2), 111–126. https://doi.org/10.1080/15438620590956115

20. Haddas, R., James, C. R., & Hooper, T. L. (2015). Lower Extremity Fatigue, Sex, and Landing Performance in a Population With Recurrent Low Back Pain. *Journal of Athletic Training*, *50*(4), 378–384. https://doi.org/10.4085/1062-6050-49.3.61

21. Hadeed A, Tapscott DC. (2020). Iliotibial Band Friction Syndrome. StatPearls Publishing]. Treasure Island (FL):; PMID: 31194342.

22. Hansberger, B. L., Acocello, S., Slater, L. V., Hart, J. M., & Ambegaonkar, J. P. (2018). Peak Lower Extremity Landing Kinematics in Dancers and Nondancers. *Journal of Athletic Training*, *53*(4), 379–385. https://doi.org/10.4085/1062-6050-465-16

23. Havens, K. L., & Sigward, S. M. (2015). Joint and segmental mechanics differ between cutting maneuvers in skilled athletes. *Gait & Posture*, *41*(1), 33–38. https://doi.org/10.1016/j.gaitpost.2014.08.005

24. Henderson, Z. J., Sanzo, P., Zerpa, C., & Kivi, D. (2019). Corrigendum to "Ankle bracing's effects on lower extremity iEMG activity, force production, and jump height during a Vertical Jump Test: An exploratory study" [Phys. Ther. Sport 37 (2019) 171–178]. *Physical Therapy in Sport*. https://doi.org/10.1016/j.ptsp.2019.04.021

25. Henderson, Z. J., Sanzo, P., Zerpa, C., & Kivi, D. (2020). Ankle bracing's effects during a modified agility task: analysis of sEMG, impulse, and time to complete using a crossover, repeated measures design. *Sports Biomechanics*, 1–15. https://doi.org/10.1080/14763141.2020.1778777

26. Herman, K., Barton, C., Malliaras, P., & Morrissey, D. (2012). The effectiveness of neuromuscular warm-up strategies, that require no additional equipment, for preventing lower limb injuries during sports participation: a systematic review. *BMC Medicine*, *10*(1). https://doi.org/10.1186/1741-7015-10-75

27. Hertel, J., & Corbett, R. O. (2019). An Updated Model of Chronic Ankle Instability. *Journal of Athletic Training*, *54*(6), 572–588. https://doi.org/10.4085/1062-6050-344-18

28. Herzog, M. M., Kerr, Z. Y., Marshall, S. W., & Wikstrom, E. A. (2019). Epidemiology of Ankle Sprains and Chronic Ankle Instability. *Journal of Athletic Training*, *54*(6), 603–610. https://doi.org/10.4085/1062-6050-447-17

29. Hostrup, M., & Bangsbo, J. (2016). Limitations in intense exercise performance of athletes - effect of speed endurance training on ion handling and fatigue development. *The Journal of Physiology*, *595*(9), 2897–2913. https://doi.org/10.1113/jp273218

30. Huang, T. . P., Shorter, K. A., Adamczyk, P. G., & Kuo, A. D. (2015). Mechanical and energetic consequences of reduced ankle plantar-flexion in human walking. *Journal of Experimental Biology*, *218*(22), 3541–3550. https://doi.org/10.1242/jeb.113910

31. Ihmels, W. D., Seymore, K. D., & Brown, T. N. (2020). Effect of Sex and Ankle Brace Design on Knee Biomechanics During a Single-Leg Cut. *The American Journal of Sports Medicine*, 036354652091104. https://doi.org/10.1177/0363546520911048

32. Imwalle, L. E., Myer, G. D., Ford, K. R., & Hewett, T. E. (2009). Relationship Between Hip and Knee Kinematics in Athletic Women During Cutting Maneuvers: A Possible Link to Noncontact Anterior Cruciate Ligament Injury and Prevention. *Journal of Strength and Conditioning Research*, *23*(8), 2223–2230. https://doi.org/10.1519/jsc.0b013e3181bc1a02

33. Janssen, K., Van Den Berg, A., Van Mechelen, W., & Verhagen, E. (2017). User Survey of 3 Ankle Braces in Soccer, Volleyball, and Running: Which Brace Fits Best? *Journal of Athletic Training*, *52*(8), 730–737. https://doi.org/10.4085/1062-2050-52.4.06

34. Kaminski, T. W., Needle, A. R., & Delahunt, E. (2019). Prevention of Lateral Ankle Sprains. *Journal of Athletic Training*, *54*(6), 650–661. https://doi.org/10.4085/1062-6050-487-17

35. Klem, N.-R., Wild, C. Y., Williams, S. A., & Ng, L. (2016). Effect of External Ankle Support on Ankle and Knee Biomechanics During the Cutting Maneuver in Basketball Players. *The American Journal of Sports Medicine*, *45*(3), 685–691. https://doi.org/10.1177/0363546516673988

36. Liederbach, M., Kremenic, I. J., Orishimo, K. F., Pappas, E., & Hagins, M. (2014). Comparison of Landing Biomechanics Between Male and Female Dancers and Athletes, Part 2. *The American Journal of Sports Medicine*, *42*(5), 1089–1095. https://doi.org/10.1177/0363546514524525

37. MacKean, L. C., Bell, G., & Burnham, R. S. (1995). Prophylactic Ankle Bracing Vs. Taping: Effects on Functional Performance in Female Basketball Players. *Journal of Orthopaedic & Sports Physical Therapy*, *22*(2), 77–81. https://doi.org/10.2519/jospt.1995.22.2.77

38. Madigan, M. L., & Pidcoe, P. E. (2003). Changes in landing biomechanics during a fatiguing landing activity. *Journal of Electromyography and Kinesiology*, *13*(5), 491–498. https://doi.org/10.1016/s1050-6411(03)00037-3

39. Malliaras, P., Cook, J. L., & Kent, P. (2006). Reduced ankle dorsiflexion range may increase the risk of patellar tendon injury among volleyball players. *Journal of Science and Medicine in Sport*, *9*(4), 304–309. https://doi.org/10.1016/j.jsams.2006.03.015

40. Malloy, P., Morgan, A., Meinerz, C., Geiser, C., & Kipp, K. (2014). The association of dorsiflexion flexibility on knee kinematics and kinetics during a drop vertical jump in healthy female athletes. *Knee Surgery, Sports Traumatology, Arthroscopy*, *23*(12), 3550–3555. https://doi.org/10.1007/s00167-014-3222-z

41. Mason-Mackay, A. R., Whatman, C., & Reid, D. (2016). The effect of ankle bracing on lower extremity biomechanics during landing: A systematic review. *Journal of Science and Medicine in Sport*, *19*(7), 531–540. https://doi.org/10.1016/j.jsams.2015.07.014

42. Mason-Mackay, A. R., Whatman, C., & Reid, D. (2017). The effect of reduced ankle dorsiflexion on lower extremity mechanics during landing: A systematic review. *Journal of Science and Medicine in Sport*, *20*(5), 451–458. https://doi.org/10.1016/j.jsams.2015.06.006

43. McClain, J. J., & Welk, G. J. (2004). Comparison of Two Versions of the PACER Aerobic Fitness Test. *Medicine & Science in Sports & Exercise*, *36*(Supplement), S5. https://doi.org/10.1249/00005768-200405001-00022

44. McGuine, T. A., Brooks, A., & Hetzel, S. (2011). The Effect of Lace-up Ankle Braces on Injury Rates in High School Basketball Players. *The American Journal of Sports Medicine*, *39*(9), 1840–1848. https://doi.org/10.1177/0363546511406242

45. Mclean, S. G., Felin, R. E., Suedekum, N., Calabrese, G., Passerallo, A., & Joy, S. (2007). Impact of Fatigue on Gender-Based High-Risk Landing Strategies. *Medicine & Science in Sports & Exercise*, *39*(3), 502–514. https://doi.org/10.1249/mss.0b013e3180d47f0

46. Medina McKeon, J. M., & Hoch, M. C. (2019). The Ankle-Joint Complex: A Kinesiologic Approach to Lateral Ankle Sprains. Journal of Athletic Training, 54(6), 589–602. https://doi.org/10.4085/1062-6050-472-17

47. Myer, G. D., Ford, K. R., Di Stasi, S. L., Foss, K. D. B., Micheli, L. J., & Hewett, T. E. (2014). High knee abduction moments are common risk factors for patellofemoral pain (PFP) and anterior cruciate ligament (ACL) injury in girls: Is PFP itself a predictor for subsequent ACL injury? *British Journal of Sports Medicine*, *49*(2), 118–122. https://doi.org/10.1136/bjsports-2013-092536

48. Newman, T. M., Gay, M. R., & Buckley, W. E. (2017). Prophylactic Ankle Bracing in Military Settings: A Review of the Literature. *Military Medicine*, *182*(3), e1596–e1602. https://doi.org/10.7205/milmed-d-16-00160

49. Newman, T. M., Vairo, G. L., & Buckley, W. E. (2018). The Comparative Effects of Ankle Bracing on Functional Performance. *Journal of Sport Rehabilitation*, *27*(5), 491–502. https://doi.org/10.1123/jsr.2016-0136

50. Odak, S., Ahluwalia, R., Shivarathre, D. G., Mahmood, A., Blucher, N., Hennessy, M., & Platt, S. (2015). Arthroscopic Evaluation of Impingement and Osteochondral Lesions in Chronic Lateral Ankle Instability. *Foot & Ankle International*, *36*(9), 1045–1049. https://doi.org/10.1177/1071100715585525

51. Padua, D. A., & DiStefano, L. J. (2009). Sagittal Plane Knee Biomechanics and Vertical Ground Reaction Forces Are Modified Following ACL Injury Prevention Programs: A Systematic Review. *Sports Health: A Multidisciplinary Approach*, *1*(2), 165–173. https://doi.org/10.1177/1941738108330971

52. Pedowitz, D. I., Reddy, S., Parekh, S. G., Huffman, G. R., & Sennett, B. J. (2008). Prophylactic Bracing Decreases Ankle Injuries in Collegiate Female Volleyball Players. *The American Journal of Sports Medicine*, *36*(2), 324–327. https://doi.org/10.1177/0363546507308358

53. Proia, P., Di Liegro, C., Schiera, G., Fricano, A., & Di Liegro, I. (2016). Lactate as a Metabolite and a Regulator in the Central Nervous System. *International Journal of Molecular Sciences*, *17*(9), 1450. https://doi.org/10.3390/ijms17091450

54. Rivera, M. J., Winkelmann, Z. K., Powden, C. J., & Games, K. E. (2017). Proprioceptive Training for the Prevention of Ankle Sprains: An Evidence-Based Review. *Journal of Athletic Training*, *52*(11), 1065–1067. https://doi.org/10.4085/1062-6050-52.11.16

55. Savage, R. J., Lay, B. S., Wills, J. A., Lloyd, D. G., & Doyle, T. L. A. (2018). Prolonged running increases knee moments in sidestepping and cutting manoeuvres in sport. *Journal of Science and Medicine in Sport*, *21*(5), 508–512. https://doi.org/10.1016/j.jsams.2017.07.007

56. Schroeder, L. E., & Weinhandl, J. T. (2019). Hinged ankle braces do not alter knee mechanics during sidestep cutting. *Journal of Biomechanics*, *84*, 191–196. https://doi.org/10.1016/j.jbiomech.2018.12.046

57. Shaw, M. Y., Gribble, P. A., & Frye, J. L. (2008). Ankle Bracing, Fatigue, and Time to Stabilization in Collegiate Volleyball Athletes. *Journal of Athletic Training*, *43*(2), 164–171. https://doi.org/10.4085/1062-6050-43.2.164

58. Sheu, C. L., Gray, A. M., Brown, D., & Smith, B. A. (2015). Sex Differences in Knee Flexion Angle During a Rapid Change of Direction While Running. *Orthopaedic Journal of Sports Medicine*, *3*(12), 232596711561793. https://doi.org/10.1177/2325967115617932

59. Simpson, K. J., Yom, J. P., Fu, Y.-C., Arnett, S. W., O'Rourke, S., & Brown, C. N. (2013). Does Wearing a Prophylactic Ankle Brace During Drop Landings Affect Lower Extremity Kinematics and Ground Reaction Forces? *Journal of Applied Biomechanics*, *29*(2), 205–213. https://doi.org/10.1123/jab.29.2.205

60. Smith, B., Claiborne, T., & Liberi, V. (2016). Ankle Bracing Decreases Vertical Jump Height and Alters Lower Extremity Kinematics. *International Journal of Athletic Therapy and Training*, *21*(2), 39–46. https://doi.org/10.1123/ijatt.2014-0143

61. Sprague, A., Epsley, S., & Silbernagel, K. G. (2019). Distinguishing Quadriceps Tendinopathy and Patellar Tendinopathy: Semantics or Significant? *Journal of Orthopaedic & Sports Physical Therapy*, *49*(9), 627–630. https://doi.org/10.2519/jospt.2019.0611

62. Talusan, P. G., Toy, J., Perez, J. L., Milewski, M. D., & Reach, J. S. (2014). Anterior Ankle Impingement. *Journal of the American Academy of Orthopaedic Surgeons*, *22*(5), 333–339. https://doi.org/10.5435/jaaos-22-05-333

63. Teng, P. S. P., Leong, K. F., Huang, P. Y., & McLaren, J. (2013). The Effect of a Knee-ankle Restraint on ACL Injury Risk Reduction during Jump-landing. *Procedia Engineering*, *60*, 300–306. https://doi.org/10.1016/j.proeng.2013.07.036

64. Thacker, S. B., Stoup, D. F., C.M Branche, Gilchrist, J., Goodman, R. A., & Weitman, E. A. (1999). The prevention of ankle sprains in sports. A systematic review of the literature. *American Journal of Sports Medicine*, *27*(6), 753–760. https://doi.org/10.1177/03635465990270061201

65. Theodorakos, I., Rueterbories, J., Lund, M. E., Andersen, M. S., de Zee, M., & Kersting, U. G. (2016). Ankle bracing effects on knee and hip mechanics during landing on inclined surfaces. *International Biomechanics*, *3*(1), 22–32. https://doi.org/10.1080/23335432.2015.1132638

66. Thomas, A. C., McLean, S. G., & Palmieri-Smith, R. M. (2010). Quadriceps and Hamstrings Fatigue Alters Hip and Knee Mechanics. *Journal of Applied Biomechanics*, *26*(2), 159–170. https://doi.org/10.1123/jab.26.2.159

67. Tsai, L.-C., Sigward, S. M., Pollard, C. D., Fletcher, M. J., & Powers, C. M. (2009). Effects of Fatigue and Recovery on Knee Mechanics during Side-Step Cutting. *Medicine & Science in Sports & Exercise*, *41*(10), 1952–1957. https://doi.org/10.1249/mss.0b013e3181a4b266

68. Vanwanseele, B., Stuelcken, M., Greene, A., & Smith, R. (2014). The effect of external ankle support on knee and ankle joint movement and loading in netball players. *Journal of Science and Medicine in Sport*, *17*(5), 511–515. https://doi.org/10.1016/j.jsams.2013.07.009

69. Wahlstedt, C., & Rasmussen-Barr, E. (2014). Anterior cruciate ligament injury and ankle dorsiflexion. *Knee Surgery, Sports Traumatology, Arthroscopy*, *23*(11), 3202–3207. https://doi.org/10.1007/s00167-014-3123-1

70. Webster, C. A., Nussbaum, M. A., & Madigan, M. L. (2017). Stiffness and proprioceptive contributions of ankle braces and the influence of localized muscle fatigue. *Journal of Electromyography and Kinesiology*, *34*, 37–43. https://doi.org/10.1016/j.jelekin.2017.02.009

71. West, T., Ng, L., & Campbell, A. (2013). The effect of ankle bracing on knee kinetics and kinematics during volleyball-specific tasks. *Scandinavian Journal of Medicine & Science in Sports*, *24*(6), 958–963. https://doi.org/10.1111/sms.12130

72. Willeford, K., Stanek, J. M., & McLoda, T. A. (2018). Collegiate Football Players' Ankle Range of Motion and Dynamic Balance in Braced and Self-Adherent–Taped Conditions. *Journal of Athletic Training*, *53*(1), 66–71. https://doi.org/10.4085/1062-6050-486-16

73. Wu, D., Zheng, C., Wu, J., Hu, T., Huang, R., Wang, L., & Fan, Y. (2018). Prophylactic Ankle Braces and the Kinematics and Kinetics of Half-Squat Parachute Landing. *Aerospace Medicine and Human Performance*, *89*(2), 141–146. https://doi.org/10.3357/amhp.4950.2018

74. Wutzke, C. J., Sawicki, G. S., & Lewek, M. D. (2012). The influence of a unilateral fixed ankle on metabolic and mechanical demands during walking in unimpaired young adults. *Journal of Biomechanics*, *45*(14), 2405–2410. https://doi.org/10.1016/j.jbiomech.2012.06.035

75. Xia, R., Zhang, X., Wang, X., & Fu, W. (2017). The Effects of Different Fatigue Protocols on Lower Extremity Kinematics and Impact Forces during Landings. *Medicine & Science in Sports & Exercise*, *49*(5S), 516. https://doi.org/10.1249/01.mss.0000518324.00735.8f

76. Xie, D., & Hong Qi, J. (2016). Rearfoot Landing Technique Increases Knee Loading during Sidestep Cutting Maneuvers by Basketball Players. *Journal of Athletic Enhancement*, *05*(02). https://doi.org/10.4172/2324-9080.1000226

77. You, D. Z., Tomlinson, M., Borschneck, G., Borschneck, A., MacDonald, M., Deluzio, K., & Borschneck, D. (2020). The Effect of Ankle Brace Use on a 3-Step Volleyball Spike Jump Height. *Arthroscopy, Sports Medicine, and Rehabilitation*, *2*(5), e461–e467. https://doi.org/10.1016/j.asmr.2020.04.015