ABSTRACT

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

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Prophylactic lace-up ankle braces are worn to prevent ankle sprains during states of fatigue, which may increase GRF and VLR during landings and increase risk of injury. Studies have not examined effects of wearing lace-up ankle braces while fatigued when completing functional sport movements. 15 subjects completed this study throughout two sessions. One session they wore a brace and the other they didn't. Kinetic data (Fz, Fy, Mz, Mx, VLR) was collected during a cutting task and drop landing both pre and post-fatigue each session. There were significant effects from brace on Fz and Fy (P=.004, P=.014), from fatigue on Fz, Fy, and VLR (P=.001, P=.023, P=.008), and interaction between brace and fatigue on Fz between sessions and comparing R and L during same session (P=<.001, P=.015). Significant interactions between brace and fatigue do not show increases in GRF and VLR, so wearing a brace during fatigue doesn't seem to put individuals at higher risk for injury. Lace-up ankle braces alone do however increase GRF.

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

by

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A Thesis

Approved by the Department of Health, Human Performance, and Recreation

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Dale Connally, Ph.D., Chairperson

Submitted to the Graduate Faculty of
Baylor University in Partial Fulfillment of the
Requirements for the Degree
of

Master of Science

Approved by the Thesis Committee

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May 2021

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ACKNOWLEDGMENTS

I would like to thank my committee member Dr. Darryn Willoughby for getting me started on this project. Next, Dr. Jonathan Rylander for working outside of his department and being a tremendous help the entire time. Also, my classmate Austin Hagan for persevering through this project with me. Lastly, I would like to thank my mentor Dr. Jaeho Shim for all of his help and direction on this project.

DEDICATION

To all the athletes whom I have had the pleasure to work with over the years.

CHAPTER ONE

Introduction

Overview

Athletic-related injuries are costly disturbances in today's world. Injuries are not only costly in the fact that they may have to be treated with medical procedures, but they are also costly in that they take away precious time that could be spent training or competing. The time out due to injury can also put athletes at a greater risk of losing scholarships and career benefits/promotions. In addition, injuries can lead to decreases in quality of life in any athlete, whether recreational or professional. Therefore athletes, coaches, and health care professionals strive to minimize the risk of athletic related injuries.

Lace-up ankle braces are a type of brace commonly worn prophylactically in athletics due to their ability to prevent inversion ankle sprains (Mcguine 2011; Pedowitz 2008), which are among the most common injuries experienced in athletics. It is not uncommon for teams to be required to use prophylactic lace-up ankle braces regardless of previous ankle injury history (Bellows 2018; Henderson 2019). Although lace-up ankle braces produce the desired effect of limiting motion in the frontal plane, sagittal plane movements such as dorsiflexion and plantar flexion may also be restricted with these devices. Restriction of dorsiflexion caused by these lace-up ankle braces does not reduce the occurrence of ankle sprains. This restriction of dorsiflexion may also have detrimental upstream effects on structures of the lower extremity due to decreased ability to absorb the force upon landing.

Restriction of dorsiflexion and plantar flexion has been examined by researchers due to the possibility of increased vertical GRF and vertical loading rate (VLR) during jump landings (West, 2013; Maeda, 2019; Schroeder, 2019; DiStefano, 2008). Redundantly increased GRF and VLR may put individuals at risk for injury to bone, cartilage, and soft tissue (Shaw 2008). Additionally, fatigue is often experienced while wearing lace-up ankle braces. Fatigue negatively affects landing patterns in that it causes a more erect landing posture, resulting in increases in peak vertical GRF (Cortes 2014). Increasing vertical GRF is considered a risk factor for lower extremity injuries such as anterior cruciate ligament tears (Zhang 2018).

While it may be beneficial to use prophylactic ankle braces to reduce the risk of inversion ankle sprains, it may not outweigh putting individuals at risk for what could lead to other more serious injuries, especially when requiring entire teams to wear them. Athletes are already susceptible to injuries during competitions due to their level of fatigue and high-velocity movements, so it is crucial to make the most educated decision on the risks and benefits of limiting motion with prophylactic ankle braces.

Purpose

The purpose of this study was to investigate the potential changes in GRF, VLR, and examine moments during functional sports movements (landing/cutting) due to the use of a lace-up brace with subjects in a state of physical fatigue. Secondarily, this study aimed to identify differences in landing patterns between the braced and unbraced leg upon drop landing. It is important to note that because this study incorporates a functional fatigue protocol, the findings of this study will more accurately portray the effects of using lace-up ankle braces during moderate to strenuous physical activity, such as in athletic competition. The findings of this study can then be used by researchers and healthcare professionals to better determine the risks of using prophylactic ankle braces for athletes undergoing fatigue

Hypothesis

H_0: There will be no significant difference between braced and unbraced conditions on GRF, VLR, and moments.

H_0: There will be no difference between fatigued and non-fatigued condition on GRF, VLR, and moments.

H_0: There will be no interaction between brace (brace and non-brace) and test (pre-test and post-test) on GRF, VLR, and moments.

H_0: There will be no difference between braced and non-braced leg during drop landing on GRF, VLR, and moments.

Limitations

1. Participants may not give full effort in the fatigue protocol each session.
2. Testing tasks and fatigue protocol were performed in a lab setting and not real competition situation.
3. Participants may be more comfortable in the later testing tasks than were in the earlier.
4. Subjects come from a variety of athletic backgrounds and some may be more comfortable with tasks than others.
5. Outcomes may only be relevant for chosen population.

Assumptions

1. All necessary equipment will function properly and provide accurate results.
2. Participants will comply with self-reporting for inclusion/exclusion criteria.

Definition of Terms

- GRF- the force exerted by the ground on a body in contact with it
- VLR- slope of initial part of the vertical GRF-time curve between foot strike and impact peak measured in BW/s. How fast GRF rises to impact peak (Figure 1.1).

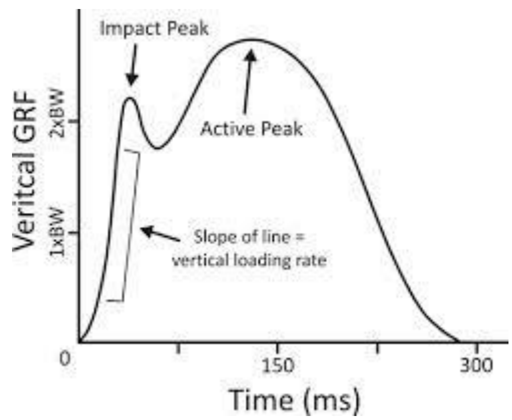

Figure 1.1. Example of Vertical GRF Curve.

- Moment- rotation around the x, y, or z axis
- Prophylactic ankle bracing- intended to prevent ankle injuries.
- ROM- range of motion
- Fz- peak vertical GRF. Second and largest peak on GRF curve when heel strike occurs upon landing. Active peak
- Fy- peak horizontal GRF
- Mz- measurement of moment of rotation around the Z axis (vertical)
- Mx- measurement of rotation of the foot around the X axis (anterior to posterior)

CHAPTER TWO

Literature Review

Prophylactic Ankle Bracing

As the demand in ways to decrease injury in sport increases, so does the research in the field of sports medicine. There are numerous studies done on the topic of prophylactic ankle bracing. However, the research findings often contradict as different types of braces are tested, thus limiting its practical application. There are various designs of ankle braces with a main intent to limit ankle inversion sprains. Among the most widely used types of prophylactic ankle devices are compression sleeves, hinged braces, and lace up braces. Athletes will often use compression devices for swelling control and their ability to give proprioceptive feedback, causing the athlete to feel more stable and supported. Hinged braces likewise can aid in giving proprioceptive feedback, but they also give more restriction of inversion and eversion with their rigid lateral and medial shells. The hinge lies under the heel to allow for normal ranges of motion in the sagittal plane. Hinge braces also give compression to the lateral and medial aspects of the ankle, making them a seemingly practical option for athletes with a history of ankle sprains. Though the hinge braces seem to prevent injury without compensating unwanted restrictions in range of motion, many athletes do not prefer them over lace-up braces due to their lack of comfort.

Lace-up braces prevent inversion sprains, provide proprioceptive feedback, give compression to the ankle, and are not rigid like the hinged braces therefore making them more comfortable, but do restrict some motion in the sagittal plane (Henderson 2019).

In a study done by Riemann et.al, (2002), semi rigid hinged braces were examined with motives of implementing functional sports movements as testing tasks during a period of fatigue. However, lace-up ankle braces have not been examined with these motives. Therefore, investigation on ASO lace-up braces would add to the literature and benefit the users as they are the most recommended type of ankle brace by clinicians to prevent inversion ankle sprains in athletics (Denton, 2015).

The ASO ankle brace consists of a lace-up boot, two nylon straps that cross on the dorsal aspect of the foot and fasten to the medial and lateral aspects of the shank, and an elastic cuff which is fastened around the circumference of the lower leg. The design of the ASO lace-up brace makes it easy for individuals to apply the brace to themselves in a way that feels most comfortable to them, which may be another reason why they are preferred over other types. More important, lace-up ankle braces are proven to successfully prevent inversion ankle sprains (Mcguine et al., 2011; Pedowitz et al., 2008); however, as stated previously, they simultaneously limit sagittal plane motion (Henderson et al., 2019) which may have detrimental effects when it comes to repetitive functional movement patterns in sports.

The literature is lacking regarding lace-up ankle braces, particularly the ASO type. It is important to fully understand the risks that might occur under different circumstances due to restriction of dorsiflexion these devices. With further investigation of ASO lace-up ankle braces, healthcare providers and clinicians who most frequently recommend the brace for their patients can have more confidence in their decisions to prescribe or to not prescribe lace-up ankle braces. Users of ASO ankle braces can also make better decisions for themselves on which device will most benefit them in the long run.

Effects of Ankle Bracing on Fatigue

Fatigue alone is known to cause changes to landing mechanics compared to non-fatigued conditions. GRF and VLR increase when the subjects are in a state of fatigue (Christina and White 2001; Brazen 2010). Neuromuscular fatigue associated with prolonged exercise puts athletes at greater risk of landing-related injuries. This type of fatigue is often coupled with the use of prophylactic lace-up ankle braces in athletic competitions, possibly doubling the risk of injury caused by adjustments in landing patterns. Additionally, athletes who wear ankle braces during states of fatigue often already experience repeated high impact landings from their sports. The accumulation of these high impact landings of can lead to overuse injuries (Macdermid 2017). Therefore, it is crucial to examine the use of lace-up ankle braces with the subject in a state of fatigue so that it can be determined to which extent excessive forces on the lower extremity could be attributed to the prophylactic lace-up brace.

Many researchers have separately examined the effects of ankle bracing on landings, as well as the effects of fatigue on landings. A systematic review done by Niu et al., (2016) extracted data on GRF during landings while wearing different types of ankle braces. Among 15 studies in the review, none of them incorporated a fatigue protocol before examining the effects of braces on landing kinetics. Riemann et al., (2002) conducted a study which incorporated a 20-minute treadmill exercise before gathering information on GRF while wearing semi-rigid braces, however the running was not intended to produce fatigue. This study did however find that the semi-rigid brace significantly decreased the time to reach peak impact forces after the treadmill running, but the design of this brace differs from the lace-up brace in the sense that it is more rigid, and since the treadmill running was not intended to produce fatigue it cannot be compared to sports activity. While previous independent research on bracing and fatigue may give reasonable insight on these two potential factors of injury, it is important to incorporate both lace-up braces and fatigue in current sports competition conditions.

Few studies have used fatigue protocols when examining the effects of bracing and fatigue on ground reaction forces. Shaw et al., (2008) conducted a study incorporating a fatigue protocol before testing tasks with participants in both lace up and hinged braces but focused more so on the joints and did not report GRF. They used a combination of modified agility drills, lunges, and running stations to achieve fatigue (Shaw et al., 2008). While this may accomplish the goal of the subject becoming fatigued, this method allows for more variability when it comes to the extent of fatigue. Also, the repetitive lunges are not commonly executed in athletic competitions. Another study examining effects of fatigue on kinetic variables in the absence of ankle support used two fatigue protocols. The first fatigue protocol consisted of constant speed running on a treadmill until the subjects could no longer run. The other consisted of subjects completing 6x10 m shuttles with maximal effort and repeat it until they could not jump more than 70% of their baseline vertical max jump for 5 consecutive trials (Xia et al., 2017). This type of fatigue is closely associated with the type of activity one participates in during sports. It would be beneficial for athletes and healthcare providers to gain insight on effects of this type of sport-related fatigue while wearing a lace-up ankle brace.

Ground Reaction Forces and Vertical Loading Rates

An identified risk factor for injury is the inability to dissipate energy from landing or rapidly changing directions. Specifically, ankle and knee injuries often occur when athletes perform high-impact landing movements. This undissipated landing energy is measured by assessing the ground reaction force (GRF) (Cacolice 2020). GRF is the force exerted by the ground on a body in contact with it. When a person is standing still, the GRF corresponds with the person's body weight. In a typical landing, GRF has two peaks: the first peak force (F1) is produced by the impact of the forefoot and is of lower magnitude than the second peak force (F2) which occurs when the heel strikes the ground (Riemann et al., 2002). GRF increases upon landing during dynamic activities, specifically in athletic events. Additionally, restriction of joint motion increases GRF (West et al., 2013).

Studies have disagreed as to whether GRF alone is the determining factor of injury occurrence, though many researchers have agreed that it is a useful measurement in observation of landing patterns due to its correlations with kinematics of the lower-extremity joints and related muscle activity (Niu et al., 2014). For example, smaller peaks of GRF in a soft landing correspond with greater flexion angles in the hip and knee joints, and more energy absorbed by the hip and knee than the ankle joint. The time to peak GRF is negatively correlated with peak GRF which means longer time to peak GRF increases buffering process to potentially reduce both chronic and acute injuries (Devita and Skelly 1992).

Vertical loading rate (VLR) is defined as the slope of the initial part of the vertical GRF-time curve between the foot strike and vertical impact peak. The VLR is an indication of how fast the vertical GRF rises to its first peak. While GRF and time to peak are often looked at separately from one another, VLR is calculated by using these two variables in the same equation. A meta-analysis concluded that faster vertical loading rates are significantly associated with the incidence of stress fractures (Zadpoor et al., 2011). The same meta-analysis showed no significant differences between the peak GRF of subjects experiencing lower-limb stress fractures and control groups. These results show the importance of measuring not only GRF alone, but also VLR. The impact attenuation mechanism also involves internal forces by muscles, tendons, bone, and ligaments which may place strain on one another and may cause injury. One study showed mechanical fatigue testing on bone samples, concluding that the ability of the bone to withstand forces is significantly less when the load is applied at a higher rate (Schaffler et al., 1989). Therefore, VLR correlates more specifically with internal loading since it is dependent on buffering done by the internal structures such as the muscles unlike GRF, which does not fully represent the load of the lower extremity on its own.

GRF gives valuable insight in determining risk factors of injury due to its correlations with kinematic data. Based on previous studies however, VLR may give more insight on loading of the tissues, as it was found that results of the meta-analysis for loading rate are consistent with data from bone samples, suggesting that a more rapid loading rate results in more severe damage to the bones (Schaffler et al., 1989; Zadpoor 2011). Increases in GRF and VLR may be caused by fatigue as well as reduction of ROM at the ankle in the sagittal plane, leading to a potential increase in risk of injury at other joints (Butler 2003; Devita and Skelly 1992; Zhang 2000). GRF is also associated with greater knee-valgus displacement upon landing, (Chun-Man Fong 2011) which is a risk factor of ACL injuries. Conversely, increased ROM allows for softer landings and therefore 19% more kinetic energy can be absorbed by muscular tissue. This reduces stress experienced by non-muscular tissue such as bone, cartilage, and ligaments (Devita and Skelly 1992).

Cutting Task and Drop Landing

The cutting movement, which involves a running start at high speed and change of direction immediately after landing, represents a dynamic movement that is commonly executed in athletics. Specifically, the short running approach to a 90-degree cut accurately represents a movement performed in a wide variety of sports. The demanding dynamic nature of the cutting movement combined with rapid inversion and plantar flexion are often a cause of lateral ankle sprains. Also, rapid and poorly executed cuts may be responsible for more serious injuries such as noncontact anterior cruciate ligament tears and other knee injuries and pathologies (Nagano et al., 2009; Greene et al., 2014). Most of the literature on ankle braces examined landing patterns during vertical movements such as drop or jump landings but failed to include horizontal/lateral movements.

Klem et al., (2016) collected kinematic and GRF data to quantify ankle and knee joint forces on semi-elite female basketball players that performed a cutting maneuver while wearing lace-up or hinged braces. Contrary to their expectation, the lace-up brace did not significantly restrict ROM in the sagittal plane during the cutting task. The lace-up brace did however result in greater GRF values compared to the hinged brace. These findings warrant additional research, as the evidence was inconclusive as to what could have caused the difference between the two braces when both caused no ankle restriction in sagittal plane.

The use of a lace-up ankle brace may also affect genders differently. Research has shown that females have mechanical disadvantages compared to males during cutting movements and jump landings because females display decreased knee flexion angles but increased knee abduction angles which places increased load on the ACL (Markolf et al., 1995; Pappas et al., 2007). Females tend to land in a more erect position due to the decreases in ROM during landing and cutting. As a result, females exhibit significantly greater injury risks compared to males (Agel et. al, 2005, McLean et al., 2005). It is important to understand the effects of lace-up ankle braces not only because they may put already mechanically disadvantaged females at higher risk for injury.

One study has been done to conclude that hinged braces do not alter knee mechanics for both males and females during sidestep cutting (Schroeder et al., 2019), but as mentioned before, hinged braces consist of a different design with more capability of allowing ROM in the sagittal plane than lace up braces. It is important to understand the risks of using a lace-up brace especially for females, but also males, during a cutting maneuver to determine if these devices might cause even more of a lack in ROM leading to increased risk of injury.

While not many studies have examined the cutting maneuver, the drop landing and variations of it have been used in many studies to collect data on the loading of the lower extremity with and without the use of ankle braces (Maeda 2019, DiStefano 2008, Venesky 2006, Chun-Man Fong 2011, Simpson 2013). Devita and Skelley (1992) were one of the first to examine the drop landing to standardize the vertical velocity during the descent phase and limit horizontal velocity when observing lower extremity landing kinetics and kinematics. This method has since been used by studies when observing kinetics and kinematics of the lower extremity while the subject is wearing an ankle brace (Riemann 2002; Simpson 2013).

In a meta-analysis done by Niu et al. (2016), 11 articles were pooled to conclude that using protective ankle support elevated peak GRF and reduced T1 and T2 (time to the first and second peaks on the GRF curve) during vertical landings. This meta-analysis included a variety of vertical landings, 7 of which were drop landings. Two of these studies examined kinetic parameters during vertical drop landings while wearing a lace-up ankle brace and found that GRF and/or VLR was significantly increased (Okamatsu et al., 2014; Simpson et al., 2013). This type of landing is similar to landings observed in sports and has resulted in valuable data on landing patterns which yielded clinical significance. However, controlled, drop landings while wearing a lace-up ankle brace must be studied with the participant in a state of fatigue to better understand the effects of lace-up braces in the athletic competition setting. More studies must be done to examine the effects of lace-up ankle braces during cutting maneuvers as well, especially with the athlete in a state of fatigue. Furthermore, these considerations should be carried out on both males and females to better understand the effects of the lace-up ankle brace.

Conclusion

Research has shown conflicting results as to whether prophylactic ankle bracing significantly alters landing mechanics during athletic activity. Some have concluded that prophylactic ankle bracing alters landing mechanics regarding GRF and VLR (Riemann et al., 2002; Simpson et al. 2008; Okamatsu et al., 2014), while others found no difference in

GRF in the braced conditions compared to non-braced conditions (Greene et al., 2014, Mason-Mackay et al., 2016, Vanwanseele et al., 2014). While there are numerous studies done on ankle braces, the conditions in which these studies were done vary greatly. Variations in type of brace, levels of fatigue, type of landing and cutting tasks, as well as differences in subject fitness and history are all important factors that may contribute to contradicting results and they must be taken into consideration when reviewing the current state of the literature.

From what has been found by previous studies, it can be concluded that ASO ankle braces may limit dorsiflexion (Henderson et al., 2019) and when coupled with fatigue cause more rigid landing patterns leading to increased GRF and VLR. The specific observation of ASO lace-up ankle braces and its effects on parameters of GRF and VLR during cutting maneuvers and drop landings with subjects in a state of fatigue has not yet been examined. Therefore, it is crucial to examine these conditions together to determine how lace-up ankle braces in these conditions might affect the dependent variables. The results of the present study will provide valuable information to practitioners in sports medicine when prescribing ASO lace-up brace to athletes. (Denton 2015).

CHAPTER THREE

Methods

Participants

There were 16 total participants in the study (8 males and 8 females). Each subject attended two sessions. At each session, the participants were randomly assigned to either the braced or non-braced condition at the beginning of their first visit. They switched conditions at the second session. Participants were required to read, comprehend, and sign a university-approved informed consent before engaging in any part of the study. All participants met the following criteria:

- 18-25 years old
- BMI under 30
- Participate in at least 150 minutes of moderate to vigorous activity a week
- Functionally stable ankles with no history of severe ankle sprain (Non-weight-bearing period of 3 days and restricted physical activity for at least 2 weeks).
- Do not currently use external ankle support during activity
- No diagnosed or self-reported ankle injury over the last 6 months (e.g., sprain, fracture, tendinitis)
- Not under doctor's recommendation to not exercise to heart rate max or Vo2 max
- No previous severe knee injuries
- No diagnosis of COVID-19 or symptoms in the past 14 days

Table 3.1 Subject Characteristics

Variable	Mean ± SD
Age	23.5 ± 1.74
Foot Size	9.25 ± 1.55
Height (cm)	176.18 ± 6.98
Weight (kg)	69.60 ± 13.86
BMI	22.2 ± 2.25
Systolic BP	128 ± 11.65
Diastolic BP	79 ± 7.11
Heart Rate (bpm)	69.36 ± 11.01

All data collection sessions took place at the Baylor Research and Innovation Collaborative (BRIC) on the campus of Baylor University in Waco, Texas.

Independent and Dependent Variables

Independent variables for the study included the treatment of wearing a prophylactic lace-up during a state of fatigue compared to the condition of not wearing a brace during a state of fatigue. Methods were also carried out on non-fatigued braced and unbraced conditions.

Dependent variables for the cutting task included peak ground reaction forces on the Z axis (Fz), peak moment on the the Z axis (Mz), and VLR. Dependent variables for the drop landing included peak GRF on the Z axis (Fz) and Y axis (Fy), peak moment on the X axis (Mx), and VLR.

Research Design

A single-group repeated-measures design was utilized. This study compares subjects' landing/cutting mechanics with and without the use of lace-up ankle braces during a state of fatigue. Subjects attended two sessions, one session involved the treatment of wearing a brace while the other session did not require the subject to wear the brace. Both sessions required the same protocol (refer to Figure 3.1) where subjects completed baseline testing before the fatigue protocol (90-degree angle cutting task and a 71-cm depth jump onto force plate), went through a fatigue protocol in the form of a beep test estimating a Vo2 max, followed by post-fatigue testing (same as baseline testing). Additionally, each trial of the drop landing compared the GRF, VLR, and moments on the braced side to the non-braced side during the visit in which they wore the brace.

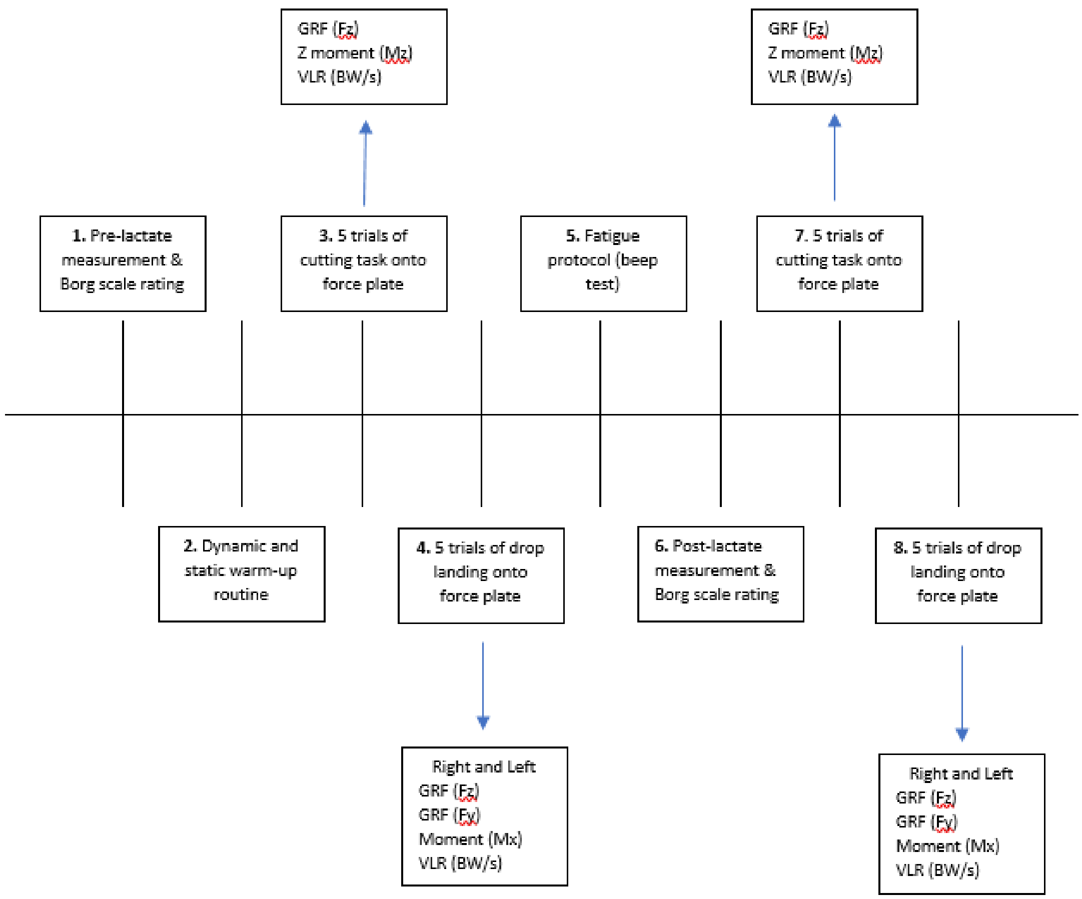

Figure 3.1 Summary of sessions.

Lactate Testing and Borg Scale

Subjects underwent baseline pre-fatigue lactate measurement before any physical activity as soon as they arrived. A post fatigue lactate was measured immediately after fatigue protocol but before the post fatigue tests. Increased blood lactate concentration is a normal physiological response to exertion. At rest, it is common to see lactate levels around 1-2 mM. In response to progressive and incremental exercise, blood lactate increases gradually at first then becomes more intense. In response to maximal exertion, values of blood lactate become elevated and the level at which they peak varies from person to person (Goodwin 2007). Subjects underwent these two tests during each testing session. Subjects were instructed to refrain from strenuous physical activity before coming to the testing sessions to ensure that they were not already fatigued. Blood lactate was measured by pricking a finger with a sterile lancet and using the Lactate Plus (Nova Biomedical, USA) meter which has been shown to display good reliability and accuracy compared with a criterion laboratory analyzer (Bonaventura 2015). The lactate meter gave measurements within 15 seconds.

Subjects were also asked to rate their perception of current fatigue before participating on the Borg scale at the same time as their blood lactate was being measured. The Borg scale uses a numeric rating system (6-20) along with descriptions of each numeric level to quantify perceptions of exertion. The Borg scale has been shown to provide valid and reliable estimates of physiologic measures of effort assessed during exercise in healthy children and adults. Strong linear relationships are reported between heart rate and rated perceived exertion, as well as intensity and rated perceived exertion (Penko 2017).

Pre- and Post-fatigue Testing Tasks

At the beginning of the first session, subjects randomly selected a paper out of a bag assigning them to group 1 (wears the brace during session 1 and not session 2) or group 2 (wears the brace during session 2 and not session 1). When the subject was required to wear the brace, they put it on immediately following lactate testing and Borg scale rating. The subject only wore the brace on their dominant leg due to the increased dynamic movement patterns and therefore increased risk of injury on the dominant leg (Niu 2011). The ASO braces were applied to subjects by certified athletic trainers who have education and training on how to properly apply the brace to patients. The tightness of the laces was regulated by using a fish scale with a weight of 30 lbs of tension, and then fixed in place for the duration of the study.

Subjects then began completing a short 5–10-minute dynamic and static stretching routine to minimize risk of muscular injury. Subjects began testing tasks following warm-up. They were given demonstration by researchers as well as verbal cues. The first testing task was the 90-degree angle cut off the force plate. Subjects approached the force plate (Advanced Mechanical Testing, Inc., Watertown, MA) from 3 meters away and planted their dominant foot directly on the force plate. Force plates were 400x600 mm and for both the cutting task and drop landing subjects foot was oriented along the width of force plate. After planting on their dominant foot, they exploded off the force-plate in a direction perpendicular to their approach, toward the side of their nondominant foot. Subjects were instructed to repeat this task 5 times and was instructed to plant the foot and make the cut as fast as possible but to a degree they had enough control to accurately plant on the force plate. If the subject's foot did not land directly on the force plate, the trial was discarded.

After the 5 consecutive trials of the cutting task, subjects immediately went into the next task: the drop landing. Subjects were also given visual demonstration and verbal cues for this task. We chose a drop landing where all the subjects walked off of a 28-inch box from a standardized takeoff position (DeVita and Skelly). This process also allowed for minimized horizontal motion. Researchers set a 71-cm box one-foot length (of the individual subjects) away from the force plate. The box was centered between two force plates. Subjects were instructed to land with one foot on each force plate to keep the dominant foot separate from the non-dominant foot, again with the foot oriented along the width. Subjects started on the box and took a step off onto the force plate, leading with their dominant foot as if they were walking off the box. Upon landing on the force plate, subjects were told to explode up as high as they could.

Fatigue Protocol

A 15-meter beep test estimating subjects Vo2 max was used to induce fatigue. The 15-meter beep test is comparable to sports in which athletes most commonly wear ankle braces, such as running up and down a basketball court or soccer field, running and cutting in football and volleyball, and a variety of other common sports. When completed properly, the beep test also accurately estimates Vo2 max (Paradisis 2014).

Verbal instructions and visual demonstrations from the researchers were given before the start of the fatigue protocol. A recording of verbal instructions was also used during each fatigue protocol session. The recording consisted of an explanation on the beeps and gave cues to when the subject should have started/completed each shuttle (15 m each shuttle). Subject started out at a low intensity jog, and every 10 shuttles intensity increased to a fast-paced run and sprint toward the end. When the subject reached the line to turn around at the end of a lap, they performed a cutting movement, facing the same direction to ensure the use of both legs for the cut to not fatigue one side more than another. Subjects were instructed to push themselves to complete as many shuttles as they could. They were done with the beep test when they either could not complete two consecutive shuttles or decided they could not continue.

Statistical Analysis

All statistical analyses were performed using IBM Statistical Package for Social Sciences (IBM, Armonk, NY, USA). The level of significance was set at $p < .05$ for all tests. A 2 x 2 repeated measures analysis of variance (Brace x Fatigue Test) was used to analyze any changes and differences in the dependent variables (Fz, Fy, Mx, Mz, VLR) between and within fatigued braced and non-braced groups. To find differences between the right and left leg during the drop landing, a 2 x 2 repeated measures analysis of variance (Side x Fatigue test) was used to analyze changes in dependent variables (Fz, Fy, Mx, VLR) between and within fatigued braced (R leg) and non-braced (L leg) groups.

CHAPTER FOUR

Results

Subject Characteristics

In total, the study included 16 participants. However, one participant was excluded due to not having sufficient data. Therefore, there were 15 participants in the analysis of the cutting tasks and drop landings. 8 of these participants were female and 7 were male.

Fatigue Results

Table 4.1. Results Pre and Post-Fatigue Protocol

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

Cutting Task: Peak GRF

Fz is the measurement of vertical GRF in the Z direction. The brace had no significant effect on Fz ($F_{1, 14}$ =.890, *P* =0.361 $\eta_{p}2$ =.060). Furthermore, there was no significant effect from fatigue ($F_{1, 14}$ =1.57 *P* =.231, $\eta_{p}2$ =.101) and there was not a significant interaction between brace and fatigue ($F_{1, 14}$ =0.781, *P* =0.392, $\eta_{p}2$ =.053). Values for descriptive statistics are shown in (Table 4.2).

Cutting Task: Peak Moment

Mz is the measurement of moment or torque about the Z axis. The brace had no significant effect on Mz ($F_{1, 13}$ =2.670, *P* =0.126 $\eta_{p}2$ =.140). Furthermore, there was no significant effect from fatigue ($F_{1, 13}$ =0.021 *P* =.886, $\eta_{p}2$ =.004) and there was not a significant interaction between brace and fatigue ($F_{1, 13}$ =0.382, *P* =0.547, $\eta_{p}2$ =.0.012). Subject 8 was excluded from data analysis due to being an outlier caused by incorrectly entered data. Mean values and standard deviations can be found in (Table 4.2).

Cutting Task: VLR

VLR is the slope of the initial part of the vertical GRF-time curve between the foot strike and vertical impact peak measured in BW/s. The VLR is an indication of how fast the vertical GRF rises to its first peak. The calculation used to find VLR was: $\frac{First\ peak\ Fz\ (N)/Body\ weight\ (N)}{Frames\ to\ reach\ first\ peak/300\ frames\ per\ second}$. The brace had no significant effect on VLR ($F_{1, 14}$ =1.264, *P* =0.280 $\eta_{p}2$ =.083). Furthermore, there was no significant effect from the fatigue ($F_{1, 14}$ =0.302 *P* =.591, $\eta_{p}2$ =.021) and there was not a significant interaction between the brace and the fatigue protocol ($F_{1, 14}$ =0.970, *P* =0.342, $\eta_{p}2$ =.0.065). Overall, the brace and fatigue did not have an effect on VLR, nor did the brace and fatigue protocol have an interaction during the cutting task. Descriptive values for VLR are shown below in (Table 4.2).

Table 4.2. Descriptive Data of Kinetics During Cutting Task Between Sessions

Variable	Brace		No Brace	
	Pre-Fatigue	Post-Fatigue	Pre-Fatigue	Post-Fatigue
Peak GRF FZ (N)	-1479.32 ± 316.84	-1494.69 ± 356.43	-1499.45 ± 260.56	-1547.89 ± 327.07
Peak Moment Mz (N·mm)	93036.28 ± 48705.19	107461.33 ± 64908.28	162245.64 ± 203388.60	138161.81 ± 129434.52
VLR (BW/s)	44.6913 ± 25.72	41.29 ± 19.47	46.81 ± 24.63	46.55 ± 22.39

Drop Landing: Peak GRF

When comparing the right foot braced in one session to the right foot non-braced in other session upon landing, there was no significant effect from the brace on Fz ($F_{1, 14}$ =.580, *P* =.459, η_{p}^{2} =.040). Furthermore, there was not a significant effect from the fatigue ($F_{1, 14}$ =2.284, *P* =.153, η_{p}^{2} =.140) and there was a significant interaction between the brace and the fatigue protocol ($F_{1, 14}$ =18.674, *P* = <.001, η_{p}^{2} = .572). Overall, subjects showed a decrease in vertical GRF with the brace after the fatigue protocol (1792.28 N to 1560.84 N) and showed an increase in vertical GRF after the fatigue protocol without the brace (1571.11 N to 1680.23 N). Descriptive data of mean ± standard deviation as well as 95% confidence intervals for these variables are shown below in (Table 4.3). Mean subject results for Fz are shown in (Figure 4.1).

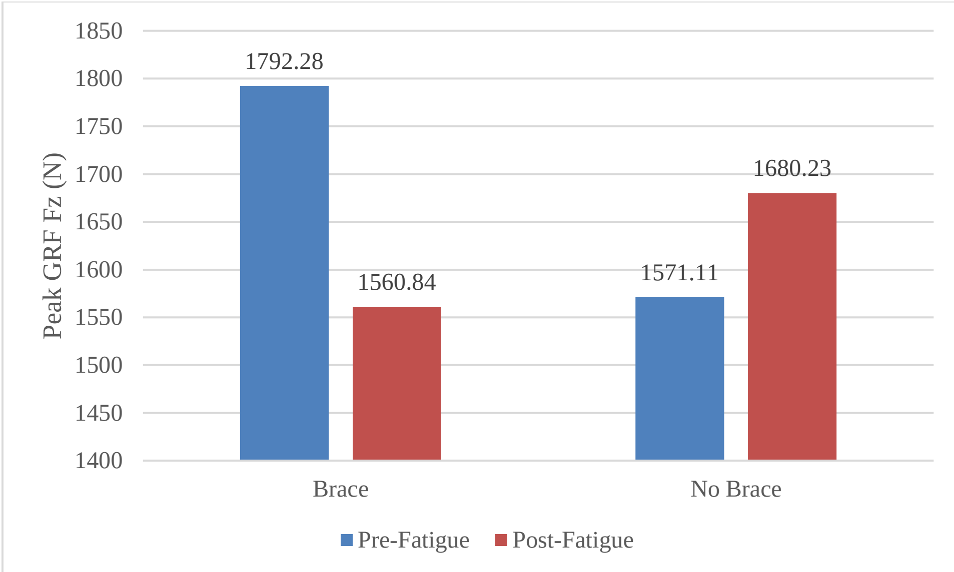

Figure 4.1. Peak Fz of Brace and No Brace conditions in Pre-Fatigue and Post-Fatigue

Fy represents the shear force that the foot imparts on the floor along the medial-lateral axis. When comparing the right foot braced in one session to the right foot non-braced in other session, there was no significant effect from the brace on Fy ($F_{1, 14}$ =.266, *P* =.614 $\eta_{p}2$ =.019). There was a significant effect from the fatigue ($F_{1, 14}$ =13.564, *P* =.002, $\eta_{p}2$ = .492) but there was not a significant interaction between the brace and the fatigue protocol ($F_{1, 14}$ =2.157, *P* = .164, $\eta_{p}2$ = .134). Overall, subjects showed a decrease in GRF on the Y axis due to the fatigue protocol with both the brace and no brace. Descriptive data of mean ± standard deviation as well as 95% confidence intervals for these variables are shown below in (Table 4.3). Mean subject results for Fy are shown in (Figure 4.2).

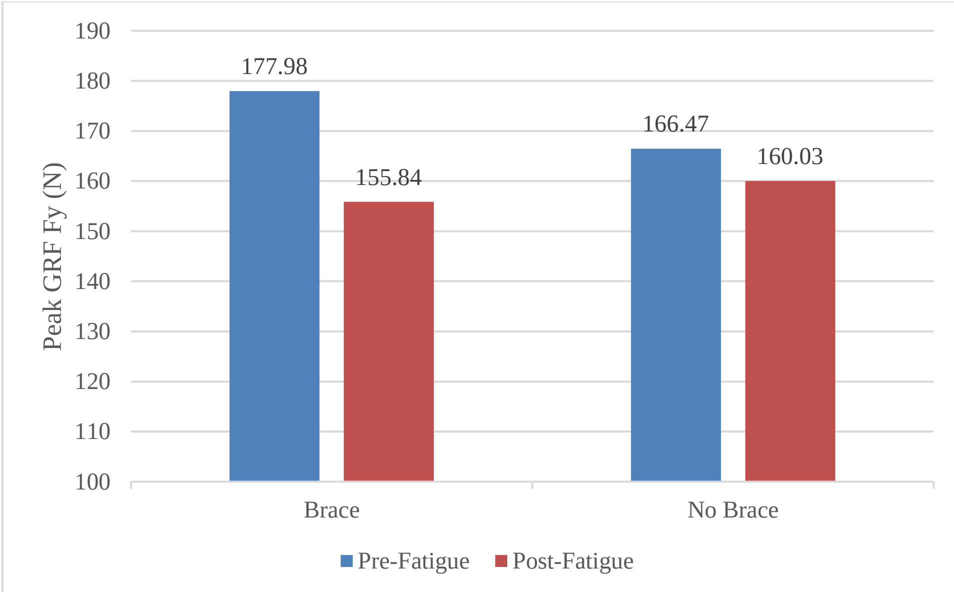

Figure 4.2 Fy Comparing the Right Foot Braced in One Session to the Right Foot Non-Braced in Other Session.

When comparing the right (braced) and left (unbraced) side during the same brace condition in pre and post-fatigue, there was a significant effect from the brace on Fz ($F_{1, 14}$ =11.475, *P* =0.004 $\eta_{p}2$ =.450). Furthermore, there was significant effect from the fatigue ($F_{1, 14}$ =16.309, *P* =.001, $\eta_{p}2$ =.538) and there was a significant interaction between the brace and the fatigue protocol ($F_{1, 14}$ =7.696, *P* =.015, $\eta_{p}2$ =.355). Overall, subjects showed an increased vertical GRF in the Z direction on the right foot which had the brace on it (1792.28 N vs 1287.54 N) compared to the left with no brace. Moreover, subjects showed decreased values for vertical GRF following the fatigue protocol (1792.28 N to 1560.84). Descriptive data of mean ± standard deviation as well as 95% confidence intervals for these variables are shown below in (Table 4.3). Mean subject results for Fz are shown in (Figure 4.3).

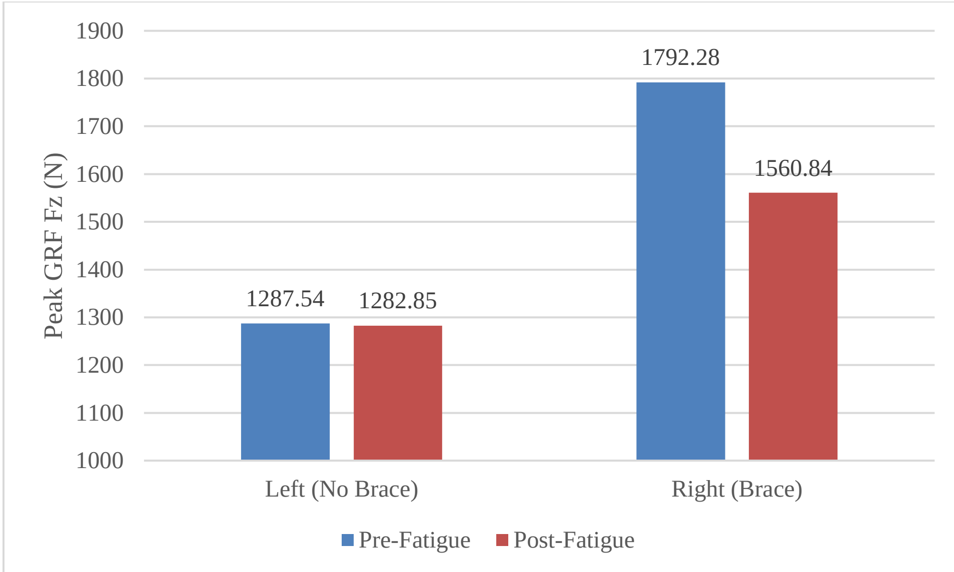

Figure 4.3. Peak Left and Right Peak Fz in Pre-Fatigue and Post-Fatigue

When comparing Fy of the left (unbraced) and the right (braced) side during the same brace session in pre and post-fatigue, there was a significant main effect on the brace ($F_{1, 14} = 7.797$, $P = .014$ $\eta_{p}2 = .358$). Furthermore, there was significant effect from the fatigue ($F_{1, 14} = 6.473$, $P = .023$, $\eta_{p}2 = .316$) but there was not a significant interaction between the brace and the fatigue protocol ($F_{1, 14} = 2.728$, $P = .121$, $\eta_{p}2 = .163$). Overall, subjects showed increased GRF on the Y axis with the right foot which had the brace on it compared to the left with no brace. Subjects showed decreased values for vertical GRF following the fatigue protocol on the side that had the brace, but the slightly larger GRF on the Y axis following the fatigue protocol on the side that did not wear the brace. Descriptive data of mean ± standard deviation as well as 95% confidence intervals for these variables are shown below in (Table 4.4).

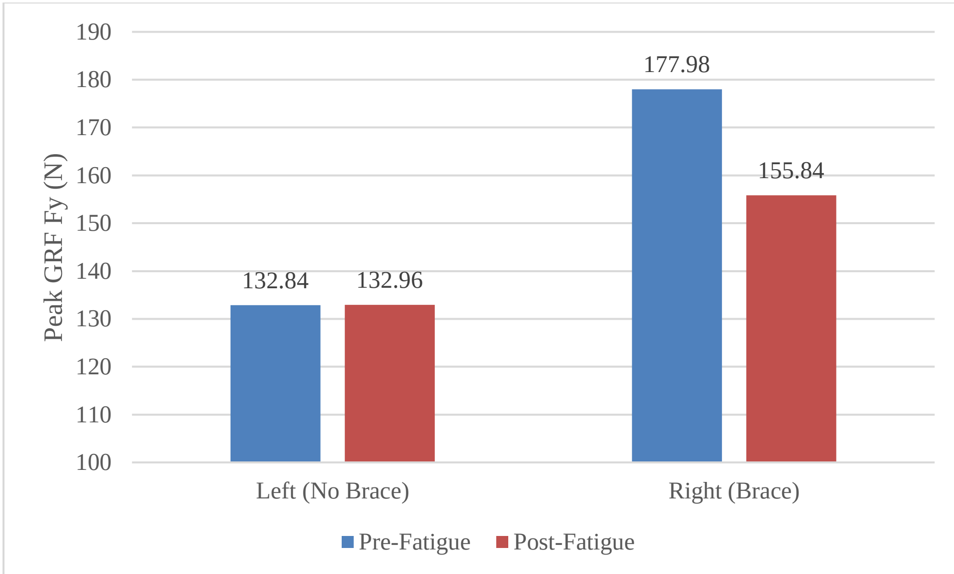

Figure 4.4. Fy Comparing Right and Left During Same Session

Drop Landing: Peak Moment

X moment is the rotation of the foot around the X axis which runs anterior to posterior from the direction of the jump. When comparing the right foot braced in one session to the right foot non-braced in other session, there was no significant effect from the brace on Mx ($F_{1, 14}$ =.063, P =0.806 $\eta_{p}2$ =.004). Furthermore, there was not a significant effect from the fatigue ($F_{1, 14}$ =0.391 P =.542, $\eta_{p}2$ =.492) and there was not a significant interaction between the brace and the fatigue protocol ($F_{1, 14}$ =3.766, P =0.073, $\eta_{p}2$ =.0.212). Overall, the brace and fatigue did not have an effect on Mx, nor did the brace and fatigue protocol have an interaction during the drop landing. Descriptive data of means and standard deviations for Mx are shown in (Table 4.3).

When comparing the right (braced) and left (unbraced) side during the same session pre and post-fatigue, on Mx, there was not a significant main effect from the brace ($F_{1, 13}$ =.206, P =.657 $\eta_{p}2$ =.123). Furthermore, there was a significant effect from the fatigue ($F_{1, 14}$ =3.834, P =<.001, $\eta_{p}2$ =.0.72) and there was not a significant interaction between the brace and the fatigue protocol ($F_{1, 14}$ =0.10, *P* =.923, η_{p2} =.032). Subject 4 was excluded from data analysis due to being an outlier caused by incorrectly entered data. Overall, the brace did not have an effect on Mx, nor did the brace and fatigue protocol have an interaction during the drop landing. Only the fatigue protocol influenced Mx in that it decreased values of Mx following fatigue. Data of means and standard deviations for Mx are shown in (Table 4.4), and mean subject results for Mx can be shown in (Figure 4.5).

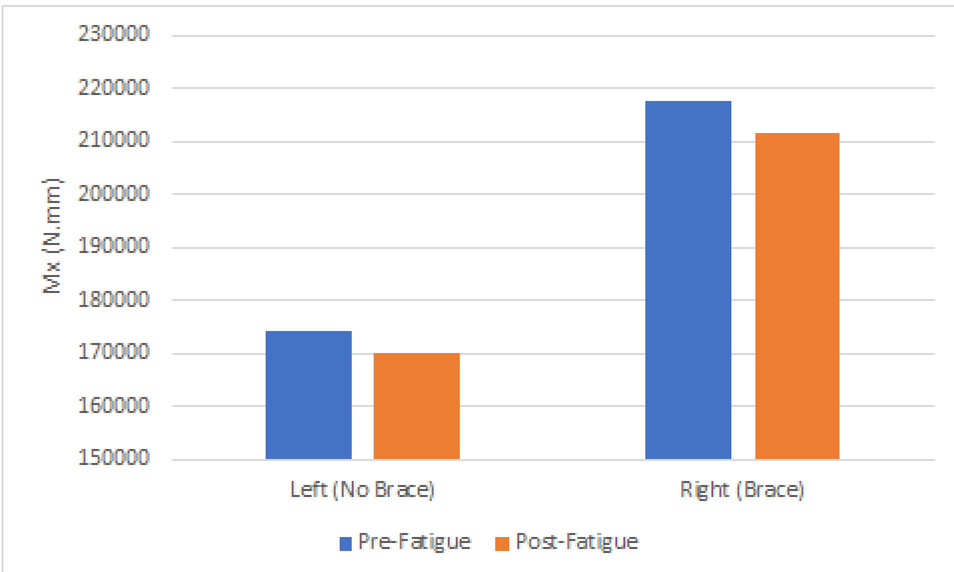

Figure 4.5. Mx Comparing Right to Left During Same Session

Drop Landing: VLR

When comparing the right foot braced in one session to the right foot non-braced in other session, there was not a significant effect from the brace on VLR ($F_{1, 14}$ =1.349, *P* =0.265 η_{p2} =.088). Furthermore, there was not a significant effect from the fatigue ($F_{1, 14}$ =01.420 *P* =.253, η_{p2} =.092) and there was a not significant interaction between the brace and the fatigue protocol ($F_{1, 14}$ =.349, *P* =0.564, η_{p2} =.0.024).

Overall, the brace and fatigue did not have an effect on VLR, nor did the brace and fatigue protocol have an interaction during the drop landing. These results are shown in (Table 4.3).

When comparing the right (braced) and left (unbraced) side during the same session pre-and post-fatigue, there was not a significant effect from the brace on VLR ($F_{1,14}$ =.393, *P* =.541 η_p^2 =.027). However, there was significant effect from the fatigue ($F_{1,14}$ =9.431, *P* =.008, η_p^2 =.402) but there was not a significant interaction between the brace and the fatigue protocol ($F_{1,14}$ =.906, *P* =.061, η_p^2 =.906). Overall, subjects showed lower values for VLR signifying decreased VLR following the fatigue protocol while wearing the brace. Descriptive data of mean ± standard deviation as well as 95% confidence intervals for these variables are shown below in (Table 4.4). Mean subject results for Fz are shown in (Figure 4.5).

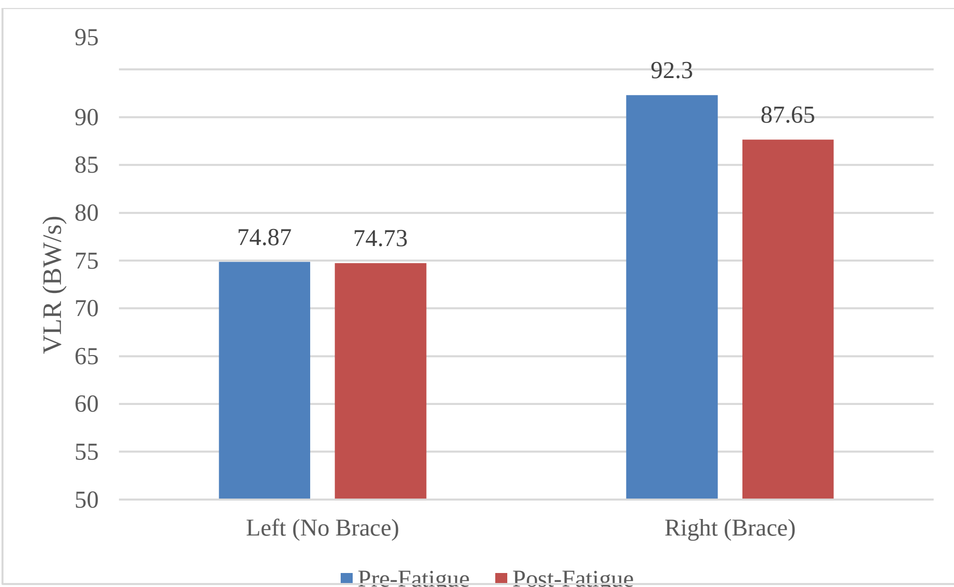

Figure 4.6. VLR Comparing Right to Left During Same Session

Table 4.3 Descriptive Data of Kinetics During Drop Landing Between Sessions

Variable	Brace		No Brace	
	Pre-Fatigue	Post-Fatigue	Pre-Fatigue	Post-Fatigue
Peak GRF Fz (N)	-1792.28 ± 533.35	-1560.84 ± 402.7	-1571.77 ± 550.26	-1680.23 ± 508.54
Peak GRF Fy (N)	-177.9768 ± 68.4	-155.8424 ± 69.1	-166.4650 ± 56.03	-160.0270 ±55.06
Peak Moment Mx (N·mm)	-210348.43 ± 83433.14	-192978.97 ± 85184.19	-200961.65 ± 94336.45	-207577.16 ± 85133.24
VLR (BW/s)	92.3 ± 26.24	87.65 ± 22.18	82.08 ± 30.48	80.94 ± 28.44

Table 4.4 Descriptive Data of Kinetics During Drop Landing for Right and Left Side Same Session

Variable	Pre-Fatigue		Post-Fatigue	
	Right Side (Braced)	Left Side (Not Braced)	Right Side (Braced)	Left Side (Not Braced)
Peak GRF Fz (N)	-1792.28 ± 533.35	-1287.54 ± 432.95	-1560.84 ± 402.69	-1282.85 ± 339.86
Peak GRF Fy (N)	177.97 ± 68.36	132.84 ± 31.84	155.84 ± 69.15	132.96 ± 37.16
Peak Moment Mx (N·mm)	217551.42 ± 81599.31	174233.37 ± 56282.72	211684.36 ± 87901.20	169992.87 ± 42651.66
VLR (BW/s)	92.2974 ± 26.24	74.87 ± 27.53	87.6497 ± 22.18	74.7311 ± 23.84

CHAPTER FIVE

Discussion

Overview

The aim of this study was to investigate the potential changes in GRF and VLR during functional sports movements (landing/cutting) due to the use of a lace-up brace with participants in a state of physical fatigue. Furthermore, this study aimed to identify differences in landing patterns between the braced and unbraced leg upon drop landings. Increased GRF has been cited in the literature as a concern for potential increase of injury risk to bone, cartilage, and soft tissue (Devita and Skelley. 1992; Shaw, 2008). GRF is often measured because it is a quick, noninvasive way to measure external loading of the lower extremities. Increased VLR has also been cited in the literature as a risk factor for injury to the lower extremity, specifically chronic pathologies such as stress fractures (Zadpoor et al., 2011), and can also be easily calculated. As described in chapter 1, prophylactic ankle braces that restrict dorsiflexion have been shown to cause increases in GRF and VLR (Hodgson 2003; Maeda, 2019; Simpson 2013). This has been thought to occur due to the restriction of dorsiflexion caused by the lace-up ankle braces and therefore reduce the ability to dissipate force.

Cutting Task: Peak GRF

During the cut, GRF was examined along the Z axis which is the vertical component of GRF. The results of this study found no significant effects of wearing the brace on Fz during the cutting task.

Average descriptive data for Fz during the cutting task can be found in Table 4.2. One possible explanation for the lack of significant results could be the non-uniform nature of the cutting task onto the force plate. Cutting tasks are performed differently by different body types and though this study required regular physical activity, the subjects came from a variety of athletic backgrounds where some may be more comfortable with cutting. Subjects were required to run at a high speed and change direction while landing their foot directly and entirely on the force plate Some subjects seemed to be more natural at this task than others. The fact that some may have been uncomfortable with the cut may have altered the natural occurrence of their cut, causing them to slow down or hesitate to make sure their foot hit the force plate. The surface on which they performed the cutting task was also slick for certain subjects due to their shoe type, potentially causing them to hesitate further. Ensuring a population from a common athletic background as well as an environment where the subject could focus on the task more than the force plate with less apprehension could potentially lead to more accurate results.

Cutting Task: Peak Moment

Moment was observed on the Z axis during the cutting task to determine if there was significant rotation of the foot during the cut caused by the brace, fatigue, or interaction between the two. Previous studies tend to focus on the moments between joints using kinematic data to draw conclusions on moment as it relates to injuries (Maeda et al,, 2019; McLean et al., 2005). However, this study only used kinetic data and were therefore only able to retrieve moment using force plate data. The goal in finding peak Z moment of the foot was to look at trends that could potentially be used in future research. All data for Mz during the cut yielded insignificant results, as shown in (Table 4.2). Again, the cut performed by subjects from a variety of athletic backgrounds be a possible explanation for lack of significance.

Cutting Task: VLR

The results pertaining to VLR (Table 4.2) were insignificant during the cutting task between sessions as well. There were no significant effects from the brace, fatigue, or interaction between the brace and fatigue. These results contrast with the conclusions made by Schroeder et al., which found that VLR is greater in braced conditions during cutting movements. As mentioned earlier, the cutting task might have yielded more significant results if the environment and subject similarities allowed for more uniform movements. The subjects in Schroeder's study were also provided with lab standard tennis shoes, which might have been more appropriate for the cutting task to avoid slipping.

Additionally, Hodgson et al. examined VLR during a drop landing while wearing a brace and found there to be an increase in VLR upon landing with the brace. Hodgson's subjects consisted of 12 division 1 female volleyball players. Using elite athletes would be ideal since they are more likely to be comfortable with the movement tasks to be performed. Moreover, Hodgson et al. may have gotten more accurate data regarding VLR upon landing. The fact that the subjects in the current study were faced with the cutting task that they may or may not have been comfortably performed by different individuals can potentially be a reason for insignificant results.

Drop Landing: Peak GRF

For the drop landing, GRF along the Z axis was examined as well as GRF along the Y axis which is the sideways frictional force exerted when one is pushing out with their feet. GRF on the Z axis is more commonly cited in the literature due to its implications for potential to increase injury (Devita and Skelley 1992; Riemann et al., 2002; West et al., 2013). GRF along the Y axis has not been thoroughly examined in the literature but was collected in this study to examine possible trends that may be used in future research when examining landing mechanics.

This study found insignificant results for effects of the brace on Fz as well as insignificant effects from the fatigue protocol when examining the drop landing between sessions. Mean descriptive data for Fz can be found in (Table 4.2). However, somewhat consistent with the hypothesis for this study, there was a significant interaction between the fatigue protocol and the brace. As shown in Figure 4.1, significantly larger GRF was produced while wearing the brace pre-fatigue than any other condition and it was expected that this trend would continue in post-fatigue, but it did not. A possible explanation for these results may be that the subjects involved in this study did not regularly use lace-up ankle braces and therefore were not used to the feeling of landing with them. This might have caused them to be more focused on the brace therefore landing harder with the braced leg, and after getting used to it following the fatigue protocol their values became closer to the non-braced condition. Selecting subjects who regularly use lace-up braces for prophylactic purposes might yield differing results.

When comparing the right (braced) side to the left (unbraced) side during the same session, values for Fz were significantly higher for the braced condition as demonstrated in (Figure 4.3). One possible explanation and also a limitation of this set of data may be that since all subjects wore the brace on their dominant foot which was their right foot, they could have been favoring landing on that foot. It was not expected that all subjects would have a dominant right foot going into the study. Furthermore, consistent with previous studies, another possible explanation for Fz being significantly larger in the braced condition can be due to the restriction of frontal plane motion, specifically inversion. Previous studies have confirmed that lace-up ankle braces successfully prevent inversion as intended (Mcguine 2011; Pedowitz 2008). Also, the brace may have restricted motion in the sagittal plane. The decrease in motion caused by the brace is likely the reason for a more rigid landing where the force cannot be absorbed by the joint, and therefore produced higher values for Fz. This is consistent with results from previous studies (Maeda, 2019; Simpson 2013).

Surprisingly, the fatigue protocol had a significant effect but contrary to what was expected. Values for Fz pre-fatigue were greater than those post-fatigue. As stated earlier, many subjects were not used to wearing lace-up braces prophylactically, and therefore may have been focused on the brace pre-fatigue causing them to land harder on it. Post-fatigue however, they may have gotten used to the brace or became more focused on their state of fatigue and forgot about it to possibly yield more accurate values. There was also a significant interaction between the brace and the fatigue protocol in this condition. Another potential reason that Fz did not increase post-fatigue might be that subjects may have landed with increased knee and hip flexion to perform a softer landing and therefore decrease GRF, in this case Fz. This reasoning is consistent with results from studies that show increased hip and knee flexion following fatigue protocols (DeVita and Skelley 1992; Xia 2017; Zhang 2000; Zhang 2018).

For the drop landing, Fy represents the shear force that the foot imparts on the floor along the medial-laterial axis. Fy can also be understood as the force vector of the floor pushing back against the foot, or how much sideways frictional force pushing out or pushing in with the subjects' feet exists. When comparing the right foot braced and unbraced between sessions for Fy, the data did not show significant effect from the brace but did show a significant effect from the fatigue (Figure 4.2) being that pre-fatigue values were higher than post fatigue values. As mentioned for the similar results of Fz, the fatigue may have caused increased knee and hip flexion absorb force at the hip and knee and decrease Fy.

When comparing the left and right side during the drop landing within the same session, the data shows significant effect from the brace on Fy, as well as significant effect from the fatigue on Fy. Again, fatigue yielded results that were inconsistent with the hypothesis for this study. As shown in (Figure 4.4), the brace and pre-fatigue conditions resulted in higher values for Fy. As mentioned for the results of Fz, the lace-up ankle brace restricts motion in the frontal plane and potentially sagittal plane and therefore causes the ankle to be in a more rigid position during landing and absorb less force through the ankle joint. Also similar to the results for Fz when comparing the right and left side during the drop landing, values of Fy were highest in the braced condition pre-fatigue, second highest in the braced condition post fatigue, and significantly lower in the non-braced condition. These results are consistent with the likely cause for higher GRFs being the lack of force absorbed by the ankle joint due to the brace making it more rigid upon landing from restricting ROM at the ankle joint.

Drop Landing: Peak Moment

Peak X moment of the foot has not been thoroughly examined in the literature regarding its effects on injury risk during landing. However, it was measured in this study to observe potential trends relating to GRF and VLR. X moment is related to the rotation of the foot around the X axis which runs anterior to posterior from the direction of the jump. This rotation was expected to correlate with inversion/eversion of the ankle joint. The results of this study, however, did not find any significant effects caused by the brace, or interaction between the two either between sessions or comparing right and left within the same session. Only the fatigue protocol influenced Mx on the drop landing when comparing right to left. Mean descriptive values for Mx can be found in (Table 4.3) and (Table 4.4). These results were not expected, as we know that the brace prevents inversion and therefore, we would have expected increased moment of the foot on the non-braced side compared to the braced side. However, these results may be due to potential favoring and leaning to the right side, because as mentioned before, the right braced foot was dominant for all subjects. The insignificant results for moment may also be a reason why X moment is typically not reported regarding landing mechanics of the foot and ankle.

Drop Landing: VLR

Results for VLR during the drop landing between sessions also yielded insignificant results. When comparing the right foot braced in one session to the right foot non-braced in other session, there was no significant effect of the brace, fatigue, or interaction between the brace and fatigue protocol on VLR as portrayed in (Table 4.2). As discussed earlier in this chapter, Hodgson et al., examined VLR during a drop landing while wearing a brace and found there to be an increase in VLR upon landing with the brace, making the findings of Hodgson's study inconsistent with the current study. The fact that Hodgson's study used subjects who were college volleyball players, might have been one of the reasons for the differences in results. Using collegiate volleyball players would have been ideal over a population that was used in the current study, because the volleyball players are much more comfortable with landing from jumps and likely are more used to wearing a brace. Their jumps are also likely more similar to one another, as opposed to the subjects used in the current study whose body types and athletic capabilities varied from one another (Table 3.1).

When comparing the right braced side to the left unbraced side during the same session, the only effect that showed significance was the fatigue protocol. As shown in (Figure 4.5), the fatigue protocol caused significantly lower values of VLR. These results are inconsistent with findings of a previous study by Zhang et al., which similarly examined VLR upon drop landings in collegiate athletes and found no differences in loading rate between pre-and post-fatigue conditions. The study done by Zhang et al. also examined kinematic data and showed a more flexed landing posture due to an increase in hip and knee flexion angles in the post-fatigue condition. The increased ROM in the landing mechanism was described as a possible protective strategy for preventing injury and potential reason for the hypothesis of this study to have been wrong. The significantly lower values for VLR following fatigue in this study might be due to potentially significant decreases of ROM at the ankle causing increases of ROM at the hip and knee.

Conclusion

Results from this study show that wearing a brace during a period of fatigue does not have significant effects regarding increase of GRF and VLR. However, the effects from the brace alone were significant in increasing GRF but not VLR compared to the non-braced condition. Furthermore, the effects from the fatigue alone were significant in decreasing VLR but not GRF. There were no significant effects from the brace, fatigue, or interaction between the two regarding moment.

Being that this study confirmed that the use of lace-up ankle braces results in higher values for GRF, healthcare providers and athletes should continue to be cautious when making decisions on when to use these braces. Though lace-up braces are successful in preventing inversion sprains, they may pose negative consequences to certain individuals. Not only may repeated high GRFs cause chronic knee pathologies and stress fractures/reactions, but acute injuries such as landing from a jump in basketball with altered landing mechanics can also occur during a high-impact landing force. Though this study did not examine whether lace-up ankle braces are a direct cause of these types of injuries, other studies have agreed that increased GRF may be a risk factor for injury (Butler 2003; Devita and Skelly 1992; Zhang 2018).

The significant interactions on Fz between the brace and fatigue that occurred were not consistent with the hypothesis of the study. For the drop landing that compared the braced condition to the unbraced condition between sessions, it was expected that braced fatigued would yield the highest values of Fz, when in fact braced-non-fatigued yielded the highest values of Fz. For the drop landing that compared right (braced) to left (unbraced), it was also expected that the braced-fatigued condition would yield the highest values of Fz. Though there was a significant interaction between the brace and fatigue protocol for this task, values of Fz decreased after the fatigue protocol. The fact that the significant interactions between wearing a brace and being in a state of fatigue do not show increases in GRF and VLR means that those who use lace-up ankle braces do not need to be concerned that wearing a brace during a state of fatigue might potentially put them at a higher risk for injury. Fatigue is an inevitable part of many sports. Fatigue can however be somewhat controlled through training, and therefore variations in VLR may be able to be somewhat controlled during athletic competitions through training as well.

The current study had some limitations as mentioned before regarding the fatigue protocol, environment, and population, especially during the cuts. Future studies should consider using populations from similar athletic backgrounds that are used to wearing ankle braces for prophylactic purposes to see if the results may differ.

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