The Impact of Unilateral Versus Bilateral Ankle Bracing on Lower Extremity Kinetics, Kinematics, and Performance in Volleyball Players

by

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In partial fulfillment of the requirements

for the degree of Master of Science in Kinesiology

SCHOOL OF KINESIOLOGY

LAKEHEAD UNIVERSITY

THUNDER BAY, ONTARIO, CANADA

August, 2022

Abstract

As athletes, volleyball players strive for optimal performance while avoiding the incidence of injury. Ankle braces, which are most commonly used by volleyball players to minimize the risk of injury are the Ankle Stabilizing Orthosis© EVO (ASO) lace up and Active Ankle© T2 (T2) rigid braces. Volleyball players wear ankle braces either unilaterally or bilaterally, but there no previous research has evaluated this comparison. It has been reported that ankle braces reduce the risk of initial and recurring injury, however, the impact that wearing ankle braces has on vertical jump height and agility time is inconclusive. The purpose of this study was to evaluate the impact that unilateral and bilateral ankle bracing has on kinetic and kinematic measures while wearing the ASO and T2 ankle braces. Competitive female and male volleyball players (n=22) from Lakehead University and Thunder Bay Competitive Volleyball League were recruited. Each participant attended two sessions; the first test day included either the vertical jump test or the agility T-test and the second test day included whichever test they did not complete the first session. During the each of these two testing sessions, the participants completed testing trials while wearing the ASO and T2 braces, unilaterally (UNI) and bilaterally (BI), as well as unbraced (UB). The 2D-kinematic analysis system recorded peak joint angles at the hip, knee, and ankle, while ground reaction forces (GRF) were collected with an Advanced Mechanical Technologies Incorporated® (AMTI) force platform. Vertical jump height was assessed utilizing the Vertec™ apparatus and agility times were measured using a Brower timing system. Data were analyzed using descriptive statistics and repeated measures ANOVAs.

Significant bracing effects were found between the braced and unbraced conditions for vertical jump height and agility time. UNI and BI ankle bracing produced statistically significant lower vertical jump heights and slower agility time when compared the UB condition,

respectively. Statistically significant interaction effects between brace type and bracing conditions were found in both ankle dorsiflexion and ankle plantarflexion. Furthermore, peak knee flexion angles were significantly lower in the ASO brace than the T2 brace. Lastly, peak hip flexion angle was significantly lower in the BI bracing condition when compared to the UB condition. Based on the findings of this study, both the ASO and T2 braces impact vertical jump and agility performance, however, wearing ankle braces UNI versus BI does not. From this, it is dependent on the individual athlete to determine if the injury prevention benefits which the ankle braces provide is worth the performance deficits experienced while wearing the braces.

Acknowledgements

Writing this part of the project is the hardest part as it alone, could probably be as long as the whole document. First and foremost, grad school is hard, but it has been particularly difficult over the past two years. From COVID lockdowns which forced us to Zoom, to ongoing restrictions which stopped us from being in person until almost Christmas of 2021, all while trying to fulfill all the requirements of a Master's degree. I would not have gotten to this point without the support of my parents, Mike and Linda, and siblings, Jason, and Lindsay, who may not know it but kept me going through all of the trials and tribulations. Whether it was hour long conversations over Skype, random game nights, family bonfires, hiking, or even spending time on the golf course with me, all of this helped keep my mind fresh and fuelled me to get to this point.

I would also like to thank Dr. Kivi for all of the guidance, support, input, and supervision throughout this Master's degree. Without the introduction to research in my fourth year of my undergraduate studies, I'm unsure if I would have even gone into research. Also, I'd like to thank my committee members, Dr. Sanzo and Dr. Zerpa, for their assistance and expertise which greatly contributed to this project.

Lastly, to all my fellow grad students who are completing their theses, congrats for persevering through the pandemic to complete your projects. All of the days spent in coffee shops just to get out of the house were great to catch up and see faces that weren't through screens. Thank you to all of those who participated in my study, as without you I wouldn't have been able to complete this project.

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List of Abbreviations

AMTI – Advanced Mechanical Technologies Incorporated©

ANOVA – Analysis of Variance

ASO – Ankle Stabilizing Orthosis© EVO lace-up brace

ATFL – Anterior talofibular ligament

BI – Bilateral bracing condition

CAI – Chronic ankle instability

CFL – Calcaneofibular ligament

cm – Centimetres

CMJ – Countermovement jump

deg – Degrees

FIVB – International Volleyball Federation

GAQ – Get Active Questionnaire

GRF – Ground reaction force

Hz – Hertz

in – Inches

kp – Kilopond

LAS – Lateral ankle sprain

LED – Light emitting diode

m – Metres

min(s) – Minute(s)

N – Newtons

PTFL – Posterior talofibular ligament

ROM – Range of motion

Sec – Seconds

SJ – Squat jump

T2 – Active Ankle© T2 rigid brace

UB – Unbraced condition

UNI – Unilateral bracing condition

V – Volts

vGRF – Vertical ground reaction forces

VMA – video motion analysis

VO_2 max – Maximal oxygen consumption

Chapter One: Review of the Literature

Overview

The ankle joint is one the most injured joints in the body, with the most common injury being a lateral ankle sprain (LAS; Barelds et al., 2018; Doherty et al., 2014). Lateral ankle sprains are reported as the most common injury across 33 sports, with volleyball having the highest incidence at 45.6% (Fong et al., 2007). In addition to initial injury, LAS have a high recurrence rate with approximately 70% of LAS injuries being a reinjury (Yeung et al., 1994). Due to the high incidence of initial and recurring LASs, volleyball players often employ prophylactic measures to reduce the risk of injury. The most common measures include specific training regimens, ankle taping, and ankle bracing (Verhagen et al., 2000). Ankle bracing has been identified as the most effective measure to prevent and treat ankle sprains (Olmstead et al., 2004). Despite the injury prevention that ankle braces offer, there is some concern that the braces may impact the movements of the athlete and overall performance in a sport. In the sport of volleyball, Bahr and Bahr (1994) identified vertical jumping and agility as the primary movements, which dictated success in volleyball. As a result, if ankle braces were to negatively affect the performance of these skills it would influence the overall success in volleyball.

As a result, the following review will present and discuss the relevant literature surrounding the demands of volleyball, ankle sprains in volleyball players, ankle bracing in volleyball players, and the impact that ankle braces have on the performance of volleyball specific tasks. Furthermore, the measures which quantify performance, the demographics who were assessed, and methodologies administered will also be considered.

Volleyball

Volleyball is a sport which is played worldwide in as many as 130 countries with 50 recognizing it as a major sport (Briner Jr. & Kacmar, 1997). The International Volleyball Federation (FIVB) claims over 800 million players participate in both indoor and beach volleyball (Briner Jr. & Kacmar, 1997). With this mass participation, it makes volleyball one of the most popular sports worldwide. Participants are represented by numerous countries, both males and females, and all skill levels. As is the case with most sports, volleyball has a unique combination of physical demands and technical skills that dictate the overall performance. Volleyball is characterized by repetitive maximal and sub-maximal jumps and rapid changes in direction (Gross & Liu, 2003). Among the demands of the sport, there are specific physical and physiological factors which volleyball athletes must be proficient in to be successful in the sport (Sheppard et al., 2009). When considering the role that the various technical skills and physical demands play, as a researcher it is important to be knowledgeable about these factors and how they influence overall performance.

Physical and Physiological Demands

The physical attributes of an athlete are integral in influencing the success that they have in their sport. In the context of volleyball players, the athletic profile is comprised of aerobic capacity, muscular strength, vertical jump power, speed, and agility (Lidor & Ziv, 2010). Each of these demands are important in their own right and influence the athlete's performance of the sport.

Aerobic capacity is the body's ability to consume oxygen and transport oxygen to the working muscles (Power & Howley, 2012). Measures of aerobic capacity are typically given through the metric known as maximal oxygen consumption (VO_2 max). Although volleyball is a game of high intensity and intermittent bursts, it has been reported that there is an aerobic demand (Lidor & Ziv, 2010). In the context of a multi-set match, the athlete's aerobic capacity is important as it allows the athlete to maintain high levels of performance over an extended period of time (Lidor & Ziv, 2010). Ziv and Lidor (2009) suggested that the VO_2 max values of volleyball players are similar to those of basketball players (approximately 44.0 – 54.0 ml/kg/min). This outcome indicates that volleyball players require a significant VO_2 max since having a substantial aerobic capacity is vital across the span of a match (Ziv & Lidor, 2009). Additionally, aerobic capacity is an important aspect for volleyball players due to the rigor of their competition schedules throughout the year. It has been reported that there are significant increases in VO_2 max over the course of a volleyball season (Fardy et al., 1976). The increases in aerobic capacity were attributed to the constant aerobic stresses put on the body through a series of practices, training sessions, and competitions (Fardy et al., 1976). Having a greater aerobic capacity not only allows the athlete to sustain their high level of intensity over the course of a single match, but also allows the athlete to recover at a quicker rate (Fardy et al., 1976). Over the course of multiple matches on the same or following days, having the ability to recover at a quicker rate will assist the athlete sustain high levels of performance.

Lidor and Ziv (2010) stated that muscular strength is an integral part of success not only in volleyball, but also in all sports. Maximal muscular strength is the amount of force that one can produce in a single effort (Fahey et al., 2016). Although there is specific strength training for volleyball players, there is an importance placed on lower body muscular strength (Lidor & Ziv, 2010). Since a lot of the game of volleyball is dependent on the athlete's ability to perform maximal jumps, lower body strength is of high importance. In addition to the maximal jumps, volleyball athletes perform repetitive and sub-maximal jumps as well which requires a certain degree of muscular endurance (Gross & Liu, 2003). Muscular endurance refers to one's ability to retain muscle contractions or repeatedly contract a muscle for a sustained amount of time (Fahey et al., 2016). Aside from lower body strength, there is also a great importance of upper body strength, specifically in the shoulders and upper back required (Alfredson et al., 1998). The upper body strength to perform at a high level is essential to volleyball players to produce high velocity arm swings in serving and spiking movements (Alfredson et al., 1998). In addition to upper and lower body strength, the athlete also requires significant core and stabilizing strength (Challoumas et al., 2017). Due to the presence of rotational components in volleyball, having a strong core and stabilizing muscles is highly important. It is suggested that by strengthening the core and stabilizing muscles that it will improve performance and play a role in preventing injury from occurring (Challoumas et al., 2017). As a result of this rationale, it is evident that muscular strength is required in the full body for a volleyball athlete.

Muscular power is another relevant physical demand of volleyball and refers to the ability to exert force rapidly and is determined by a combination of strength and speed (Fahey et al., 2016). Specifically, vertical jump power is referred to as the most relevant measure of power for volleyball due to the external applicability of the test to the skills performed by volleyball players (i.e., spiking and blocking; Sheppard et al., 2008). Sheppard and colleagues (2008) established that there was a significant positive relationship between power and vertical jump performance. They suggested that by producing more power, there would be an increase in vertical jump performance (Sheppard et al., 2008). The importance of this in volleyball also applies to performance in other volleyball-related skills such as spiking, serving, and blocking (Lidor & Ziv, 2010). Although vertical jump performance is a vital skill to have in volleyball, it has been suggested that it may not be used as a predictor for outcome of the match (Lidor & Ziv, 2010). This is due to the other variables associated with outcome of a volleyball match such as skill execution, opponent's play, and errors (Lidor & Ziv, 2010). Vertical jump performance, however, is an essential component to success of individual skills and an integral part of the physical demands of a volleyball player.

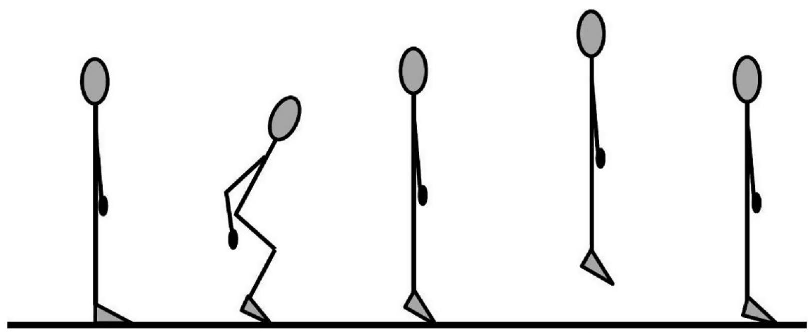
The final physical demand of a volleyball player concerns their ability to perform rapid sprints and changes of direction (Lidor & Ziv, 2010). The majority of offensive and defensive skills in volleyball require some aspect of speed or agility. In volleyball, there are many instances where a sudden change of direction and sprint need to be performed due to the reactionary nature of the game (Gabbett & Georgieff, 2007). It was emphasized that agility and speed training are essential for performance in volleyball as they provide a baseline from which specific skills are built. Gabbett and Georgieff (2007) stated that agility and speed are foundational skills, which factor into every offensive and defensive skill, thereby improving overall performance. This indicates that for success of volleyball-specific skills both speed and agility are key demands, which an athlete must possess.

Technical Skills

Along with the various physical demands volleyball places on the body, there are technical skills, which are vital to performance in the sport. Among these, volleyball is characterized by skills such as serving, blocking, spiking, setting, and defending (Sheppard et al., 2009). These technical skills coincide with the physical demands, which were previously discussed. With the exception of defending, each of these skills includes jumping at some point during the movements (Sheppard et al., 2009). Baker (1996) suggested that there were two types of jumps commonly used in volleyball including the countermovement jump (CMJ) and the squat jump (SJ). The CMJ is characterized by an eccentric contraction without a pause before maximal concentric contraction. In comparison, the SJ involves an eccentric contraction with a pause prior to a maximal concentric contraction and the take-off (Baker, 1996). Each of these jumps contains four distinct phases, which allow the participant to jump; the countermovement (loading phase), take-off, aerial, and landing phases. The loading phase contains the eccentric contractions where the ankles dorsiflex and the knees and hips flex (Eagles et al., 2015). During this phase, the body's center of mass is lowered and force is created by the muscles of the lower extremities (Eagles et al., 2015). Next, the take-off phase is the portion of the jump where the athlete transfers the force from the loading phase and projects their body into the air by means of maximal concentric contractions (Eagles et al., 2015). Once the athlete has taken off, the third phase of the jump is the aerial phase. During this phase, the athlete has projected himself/herself off the ground and he/she is in the air (Eagles et al., 2015). Lastly, the landing phase is where the athlete comes back into contact with the surface and his/her body absorbs the forces, which are placed on it from the ground (Eagles et al., 2015). Each phase of the jump can be illustrated as seen in Figure 1. As a result, researchers examine each of these phases in effort to optimize performance, reduce injury, and quantify fundamental mechanics.

Figure 1

Phases of the vertical jump



Note. The different phases which comprise the vertical jump. From "Height of the Countermovement Vertical Jump Determined Based on the Measurements Coming from the Motion Capture System," by J. Grabski and colleagues, 2019, *Advances in Intelligent Systems and Computing, 925.* Copyright 2019 by Springer Nature Switzerland AG.

Skazalski and colleagues (2018) investigated the jumping demands which, volleyball athletes are exposed to over the course of a season. They found that there was great variability among positions as well as intensity of the jumps, which was quantified by a percentage of the athlete's maximum jump height (Skazalski et al., 2018). On average, outside hitters jumped 68 times per match at an average intensity of 62% of their max jump height (Skazalski et al., 2018). In comparison, opposite side attackers jumped 82 times per match at an average of 76% of their max jump height (Skazalski et al., 2018). The setters had the highest jump count at 100 times per match, but the lowest intensity at 56% of their max jump height (Skazalski et al., 2018). Finally, the middle blockers recorded 85 jumps per match, with an average of 64% of their max jump height (Skazalski et al., 2018). From this, it was concluded that the majority of volleyball skills included a sub-maximal or maximal vertical jump. Although the values vary between positions, it is evident that jumping is a major technical skill that volleyball players must be proficient at

(Sheppard et al., 2009). Of these jumps completed throughout the course of a match, the CMJ is most represented as during the match the athletes do not have time to take a pause during the loading phase. As a result, to assist with external validity and replicating sport specificity, a CMJ should be used when attempting to replicate scenarios which resemble match conditions.

In addition to jumping, Silva and colleagues (2014) reported a high incidence of rapid changes in direction throughout a volleyball match. In both the offensive and defensive aspects of the match, multidirectional movements are highly frequent (Silva et al., 2014). Silva and colleagues (2014) suggested that changes in direction typically occur defensively in reaction to the opponent's attack. With this, it is evident that both explosive jumps and changes in direction are the skills performed most frequently throughout the course of a volleyball match.

Due to the high intensity nature of these skills, there are forces placed on the lower extremities, which may produce adverse effects. Specifically, Bahr and colleagues (1994) identified jump landings and rapid changes in direction as the greatest risk of injury to volleyball athletes. Fong and colleagues (2007) stated that 46% of injuries experienced in volleyball occur at the ankle. Briner Jr. and Kacmar (1997) identified ankle sprains as the type of injury, which most commonly occurs in volleyball. In a study of 28 volleyball teams, Bahr and Bahr (1996) reported over the course of a season that 54% of all injuries were ankle sprains.

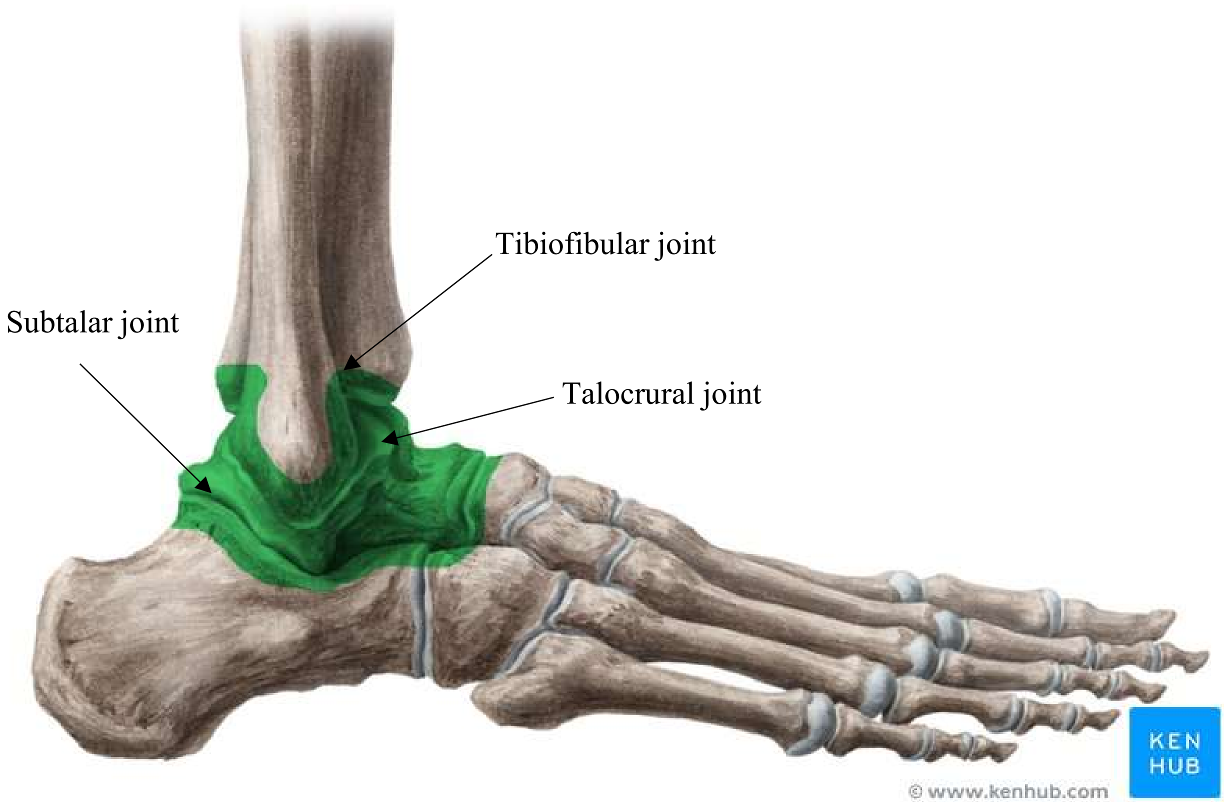
The Ankle Complex

Anatomy of the Ankle

The ankle is one of the most complex structures in the body and is comprised of multiple joints, ligaments, tendons, and neurovascular structures (Anderson, 2017). A common misconception is that the ankle is its own joint, but rather it is comprised of three separate joints. Each component of the ankle plays a vital role, whether it is assisting in locomotion, providing support to the surrounding structures, or providing an attachment site for muscles in the area. The tibiofibular, talocrural, and subtalar joints represent the structures that define the ankle complex. Figure 2 presents the ankle complex as a whole while identifying the individual joints. The tibiofibular joint is unique in the ankle as it is a syndesmosis, which indicates that dense fibrous tissue binds the distal ends of the tibia and fibula (Anderson, 2017). Considering the lack of a joint capsule, this joint allows minimal planar movement, but it ensures the tibia and fibula are supported during movements of the foot and ankle (Anderson, 2017). The talocrural or proper ankle joint is a uniaxial synovial hinge joint, which is comprised of the talus, tibia, and lateral malleolus of the fibula (Anderson, 2017). In addition to the numerous ligaments that support this joint, the articular surfaces of this joint creates a hinge joint, which restricts motion to plantarflexion and dorsiflexion in the sagittal plane (Anderson, 2017). Lastly, the subtalar joint is below the talus where facets articulate with the superior calcaneus (Anderson, 2017). Since this joint includes a series of smaller ligaments, movement in multiple planes is possible. In weight bearing movements, the triplanar movements of this joint contributes to both pronation and supination of the foot and ankle (Jastifer & Gustafson, 2014).

Figure 2

Lateral view of the joints of the ankle

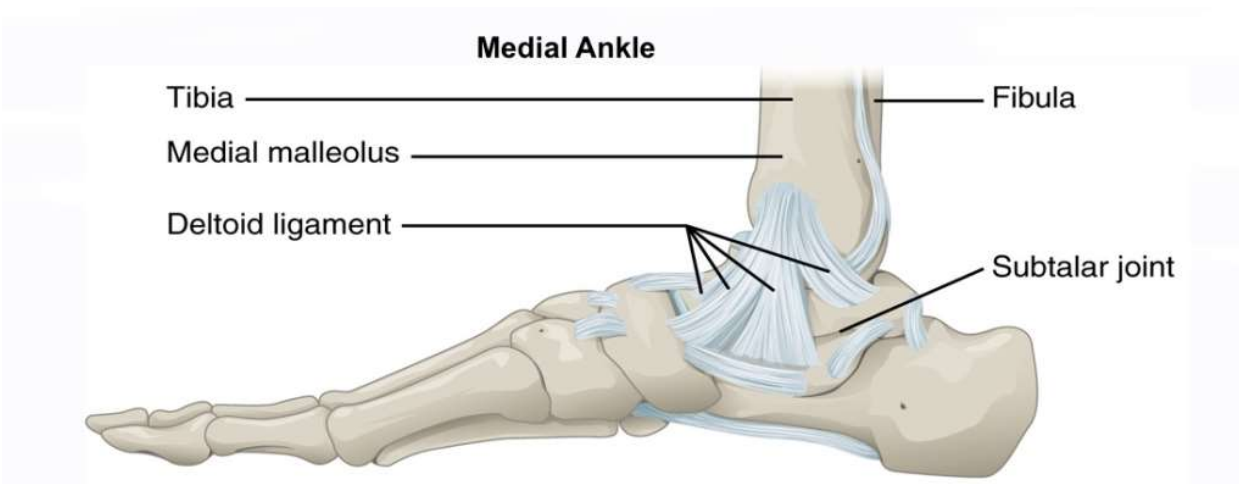


Note. The three joints which comprise the ankle complex. From, "Ankle Joint," by G. Sendic, 2021 (https://www.kenhub.com/en/library/anatomy/the-ankle-joint). Copyright 2022 by Kenhub.

In addition to the joints, there are ligamentous structures, which provide support to the joints and their various movements (Anderson, 2017). On the medial side of the ankle, the deltoid ligament provides support to prevent the ankle from eversion-type injuries (Anderson, 2017). This multi-layered ligament is comprised of four ligaments, which connect the tibia to the navicular, talus, and calcaneus bones (Anderson, 2017). Due to the bony structures and ligament configuration, the strain on the medial compartment is minimal in comparison to its lateral counterparts (Anderson, 2017). As seen in Figure 3, each component of the deltoid ligament attaches to a different site, which provides support in different directions to resist against excessive eversion (Anderson, 2017).

Figure 3

Ligaments of the ankle of the medial compartment

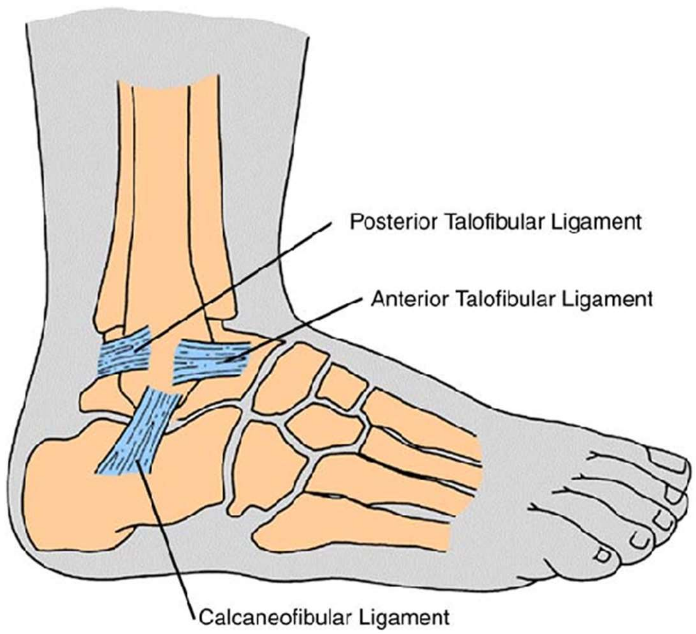


Note. Ligaments of the ankle that are found in the medial compartment. From, "The Ankle Joint," by O. Jones, 2019, TeachMeAnatomy (https://teachmeanatomy.info/lower-limb/joints/ankle-joint/). Copyright 2022 by TeachMe Series.

In the lateral compartment of the ankle, there are three ligaments which provide support to the movements of the lower extremities (Anderson, 2017). These three ligaments include the anterior talofibular ligament (ATFL), calcaneofibular ligament (CFL), and posterior talofibular ligament (PTFL; Anderson, 2017). All of these ligaments extend from an attachment site from the fibula to the foot and ankle region (Anderson, 2017). The ATFL extends from the anterior-inferior border of the fibula to the neck of the talus (Anderson, 2017). The CFL extends from the tip of the fibula to the calcaneus (Anderson, 2017). Lastly, the PTFL runs from the posterior side of the lateral malleolus to the lateral aspect of the talus (Anderson, 2017). These ligaments are responsible for providing support against excessive inversion (Anderson, 2017). In Figure 4, these three ligaments are displayed as they lie within the lateral compartment of the ankle.

Figure 4

Ligaments of the ankle of the lateral compartment

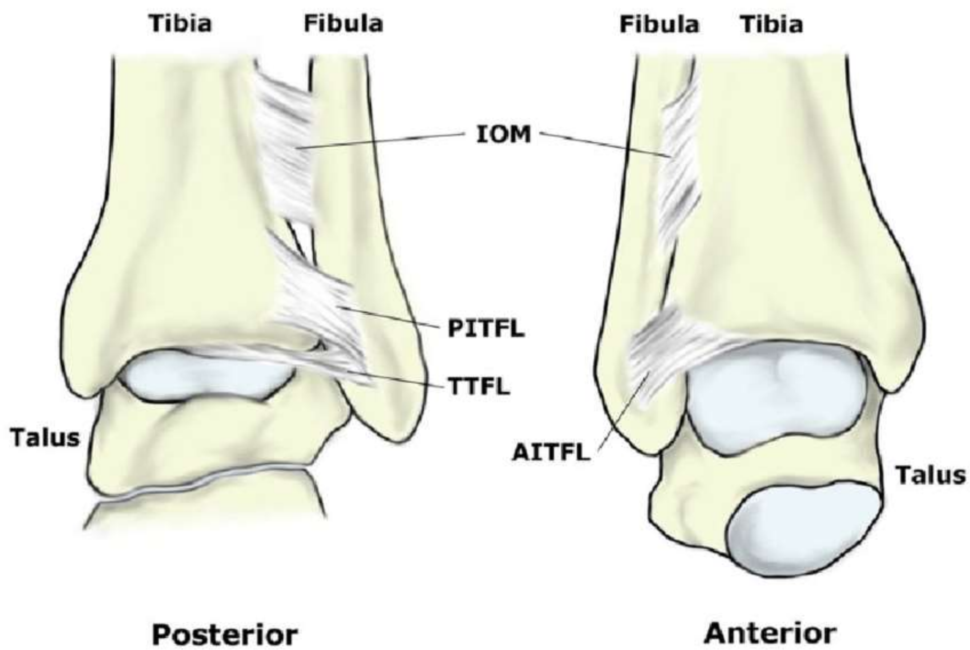


Note. Lateral ligaments of the ankle. From, "What is… a lateral ankle sprain (or rolled ankle)?," by NL Health Hub, n.d. Copyright 2019 by North Lakes Health Hub.

Lastly, the tibiofibular joint comprises the superior compartment of the ankle complex. The articular structures of this joint include the anterior and posterior tibiofibular ligaments and interosseous membrane (Anderson, 2017). The anterior and posterior ligaments traverse laterally from the distal end of the tibia to the distal end of the fibula. In addition, the interosseus membrane is dense connective tissue that spans between the anterior aspect of both the tibia and fibula. This membrane spans from the proximal aspect, close to the knee articulation, of the tibia and fibula to the ankle articulation at the distal end of both bones (Anderson, 2017). Most notably, when the ligaments of this ankle are injured, it is more commonly known as a high ankle sprain. As previously mentioned, this joint lacks a joint capsule which limits the planar motion (Anderson, 2017). An illustration of the structures of this joint can be viewed in Figure 5.

Figure 5

Ligaments of the tibiofibular joint



Note. Ligaments of the tibiofibular joint. From, "Weight-Bearing Radiographic Analysis of the Tibiofibular Syndesmosis," by A. Amin and colleagues, 2018, *Foot & Ankle Specialist, 12*(3), p. 212. Copyright 2018 by The Author(s).

With consideration of these joints and the various ligaments, the ankle is quite complex but crucial for movement to occur. Due to the distal location of the ankle, its two main functions are to propel the body and support the limb through motion (Brockett & Chapman, 2016). Additionally, the ankle is responsible for dispersing the forces, which are applied to the body from the ground (Brockett & Chapman, 2016). Despite the ankle being primarily comprised of bones and ligaments, it has quite a large capability for load bearing and mitigating large amounts of force (Brockett & Chapman, 2016).

Ankle Injuries

As a result of its anatomy, the forces placed on it, and the mass it supports, the ankle has a higher risk of injury. The various types of injuries that may occur in the ankle include ligament sprains, muscle strains, tendinopathies, and fractures (Anderson, 2017). Although all of these injuries are possible outcomes, the most common injury is a ligament sprain (Morrison & Kaminski, 2007). Ankle sprains occur when the ligamentous structures of the ankle are compromised and stretched (Anderson, 2017). Lundberg and colleagues (1989) identified that ankle injuries can occur as a result of any of the ankle's movements (i.e., plantarflexion, dorsiflexion, inversion, and eversion). Although ankle injuries are possible in all planes of movement, sprains most commonly occur due to excessive frontal and sagittal plane movement and are often a combination of both (Lundberg et al., 1989). Anderson (2017) suggested that the ligaments at highest risk of being sprained are the ATFL, PTFL, and CFL. Any sprain to one or more of these ligaments is classified as a LAS (Anderson, 2017). When observing the kinematics of a LAS, Kristianslund and colleagues (2011) noted that LASs occurred within 80 ms from the initial contact with the ground. Additionally, it was noted that LAS commonly occur during loading rather than propulsion (Kristianslund et al., 2011). Kinematic analysis revealed that ankle injuries most commonly occur due to excessive supination of the ankle, which includes both inversion and/or abduction during dorsiflexion upon landing (Kristianslund et al., 2011). Furthermore, there was a positive relationship observed in the inversion velocity between the injury and non-injury trials (Kristianslund et al., 2011). Hence, LAS are more likely to occur when a greater inversion velocity is present.

Incidence of Ankle Sprains

Shah and colleagues (2016) stated that throughout the United States there were 225,114 trips to the emergency room resulting from ankle sprains. Among these injuries, 206,523 of the cases were LAS. Aside from the pain from the injury, ankle sprains have many negative outcomes such as varying degrees of debilitation, decreased athletic performance, absence from academic or occupational responsibilities, and adverse psychological effects (Doherty et al., 2014). The population most commonly associated with LAS is the athlete cohort (Fong et al., 2007). Herzog and colleagues (2019) suggested that over 50% of the reported ankle sprains in the United States occurred due to a non-sporting mechanism. Furthermore, in the general population accidents during activities of daily living resulted in the largest percentage of LAS incidence (Herzog et al., 2019). Shah and colleagues (2016) found the highest incidence of ankle sprains to be within the second to third decade of life (18-34 year old's). Subsequently, the second highest rate of ankle sprain was seen in the 0-17 year old's (Shah et al., 2016). Lastly, Shah and colleagues (2016) reported the higher incidence of sprains in female patients in comparison to males. From this evidence, it is clear that not only do LASs affect athletes, but also occur in many cohorts within the general population.

Ankle Sprains in Sport

As mentioned above, ankle injuries are one of the most common soft tissue injuries. In addition to the general population, the athlete cohort is the most susceptible population to incur an ankle sprain (Doherty et al., 2014). This is due to the added exposure athletes experience from their sport that includes the speed and intensity with which the movements are performed during competition (Gross & Liu, 2003). In a systematic review, Fong and colleagues (2007) reported that ankle injuries were the most common injury across 33 sports. Furthermore, Garrick and

Requa (1989) reported that ankle sprains accounted for 28% of all injuries that resulted from of a sporting incident. Fong and colleagues (2007) stated that of all ankle sprains experienced in sport, 75% were LAS. In addition to being an athlete, the type of sport that is being played is also another factor, which should be considered into the potential risk of ankle sprain. Athletes who compete in sports, which require repetitive jumping, landing, and cutting maneuvers are considered to be at the great risk of ankle sprain (Gross & Liu, 2003). Considering this, Gross and Liu (2003) reported that court sports had high frequencies of jumping, and rapid changes in direction. It was found that these sports resulted in the highest incidence of ankle injury (Doherty et al., 2014). It was reported that volleyball (45.6%), badminton (23.5%), and basketball (15.9%) were the sports where the greatest percentage of injuries occurred in the ankle (Fong et al., 2007). Of these three sports, the incidence of LAS was responsible for the majority of ankle injuries (i.e., 86.5% in badminton, 91% in basketball, and 99.3% in volleyball; Fong et al., 2007). From this, it is evident that volleyball players are the most at-risk athletes of the court sports to experience an ankle sprain.

Recurring Ankle Sprains

In addition to initial acute ankle sprains, another detrimental effect of ankle sprains, are the risk of reinjury. Recurring ankle sprains are present in both the general population, but due to the exposure experienced by athletes they are the cohort who is most likely to re-sprain their ankle (Yeung et al., 1994). As previously established, it has been determined that ankle sprains are one of the most prevalent injuries in all of sport with rates reaching as high as 28% (Garrick & Requa, 1989). Among this percentage, 73% of these injuries are the result of a recurrent sprain (Yeung et al., 1994). Anderson (2017) stated that after experiencing a sprain, it takes the body at least one year to recover. Even after the ligament has structurally recovered, the healing process has not been completed since the ligament still needs to undergo remodelling. As a result of this process, the ligament may take up to one year to fully recover post-injury (Anderson, 2017). Within this healing process, the injured ligaments are susceptible to reinjury due to their compromised strength. Re-sprain has been reported to occur most commonly between two weeks and six months post-injury (van Rijn et al, 2008).

In the event of recurring LAS, the individual may develop a chronic injury where the individual experiences lateral ankle instability (van Rijn et al., 2008). This condition, known as chronic ankle instability (CAI), is characterized by persistent lateral giving way of the ankle, pain, swelling, loss of strength in the lower extremity, and recurrent ankle sprains (Hiller et al., 2011). This condition can develop after an initial sprain as well as repetitive injuries to the same structure and lead to chronic debilitating effects (Herzog et al., 2019). Therefore, due to high incidence and risk of reinjury of ankle sprains it is important that preventative measures are taken to prevent ankle sprains.

Ankle Bracing

Preventing ankle injuries can be accomplished by implementing a number of prophylactic measures such as taping, bracing, and specific-training regimens (Verhagen et al., 2000). Olmsted and colleagues (2004) stated that the most effective measures for preventing ankle sprains from occurring was through the use of taping, bracing, and exercise-based methods. Although these are all feasible methods, ankle bracing was reported as the most effective measure in preventing injury (Dizon & Reyes, 2010). Barelds and colleagues (2018) reported that by wearing ankle braces, the risk of initial ankle sprain is reduced by 47%. It has been stated that through the use of ankle braces, the incidence of ankle sprain was reduced by approximately

66% in athletes who experienced a previous ankle injury (Barelds et al., 2018; Dizon & Reyes, 2010).

In addition to injury prevention, ankle braces are often implemented as a measure, which can be used to treat an acute injury (Kemler et al., 2011). By including ankle braces into the treatment, it allows the individual to continue participating in their activities while protecting the injured ligaments (Kemler et al., 2011). The notion of this treatment is commonly referred to as a functional treatment (Kerkhoffs et al., 2001). Among the multiple treatment methods, it has been concluded that functional treatment is the most effective option for ankle sprains (Kerkhoffs et al., 2001). This conclusion was based on the fact that functional treatment of ankle sprains allowed for many positive outcomes in comparison to cast immobilization, quicker return to sport and work, less persistent swelling, increased stability upon conclusion of treatment, improved range of motion (ROM), and increased patient satisfaction (Kerkhoffs et al., 2001). From this, it was deemed that functional treatment through ankle bracing was more appropriate for the treatment of ankle sprains (Kerkhoffs et al., 2001). Since they are an effective treatment and significantly reduce the risk of injury, it is recommended that athletes such as volleyball players implement the use of ankle braces (Dizon & Reyes, 2010).

Types of Ankle Braces

Although ankle braces are proven to be beneficial, there are several different variations of braces for consideration (Dewar et al., 2019). Specific ankle brace designs are better suited for certain scenarios; therefore, it is important to identify the options available and choose the correct brace. In a survey of sports medicine clinicians, the ability of the brace to treat or prevent injury was identified as the primary concern when selecting a brace (Denton et al., 2015). This survey revealed that the lace-up brace with support straps and the rigid brace were the two most preferred ankle braces (Denton et al., 2015). When considering the lace-up brace, the model which is typically implemented is the Ankle Stabilizing Orthosis brace (ASO; Denton et al., 2015). The rigid brace that is most commonly used is the Active Ankle T2 brace (T2; Denton et al., 2015). Both the ASO and T2 braces are commonly used by athletes due to their ability to reduce risk of injury.

ASO lace up brace. This nylon brace is constructed with multiple components and layers, which provide support yet do not impede the ability to perform multidirectional movements (Dewar et al., 2019). From deepest to superficial, the layers consist of the lace-up boot, two nylon straps, which traverse the dorsal aspect of the foot, and an elastic cuff which fastens with Velcro© around the circumference of the lower shank (Dewar et al., 2019). The two nylon straps secure around the calcaneus, replicating the heel-lock taping design for support in the sagittal plane (DiStefano et al., 2008). Furthermore, the ASO brace also has sleeves along the medial and lateral aspects, which allow for the plastic stays to be inserted (Dewar et al., 2019). These plastic stays are not permanently fixed to this brace, but they provide additional support against inversion and eversion movements (Dewar et al., 2019). This brace can be seen in Figure 6. The ASO lace-up brace is one of the most commonly used braces due to its effectiveness in treating and reducing the risk of injury (Denton et al., 2015). Gudibanda and Wang (2005) reported that the ASO brace was successful in restricting movement in both the frontal and sagittal planes; thereby reducing the incidence of LAS. Furthermore, this brace was recommended for athletes who complete frequent jumps, landings, and change-of-direction movements (Denton et al., 2015; Gudibanda & Wang, 2005).

Figure 6

ASO Lace-up Brace

Note. The Ankle Stabilizing Orthosis lace-up ankle brace. From, “MedSpec ASO Ankle Stabilizing Orthosis,” by OrthoCanada, n.d. (https://www.orthocanada.com/en/medspec-aso-ankle-stabilizing-orthosis-2). Copyright 2022 by OrthoCanada Inc.

T2 brace. This rigid ankle brace is constructed with two molded plastic stirrups, which are connected to a heel piece (West et al., 2014). Through the connection between the stirrups and heel piece, it creates a hinge joint to allow movement in the sagittal plane (West et al., 2014). To secure the brace to the ankle, there are Velcro straps, which the user tightens to ensure the brace is properly fitted (West et al., 2014). An image of this brace and its design can be seen in Figure 7. Due to the rigidity of the two plastic stirrups, this brace is designed to provide support in the frontal plane, which is where the majority of injuries occur (Verhagen et al., 2001). The simple design of this brace is desirable for users due to the support it provides and how simple it is to wear. The T2 brace is commonly used due to its ability to reduce the risk of ankle sprains by significantly reducing inversion ROM (Alfuth et al., 2014). In addition to restricting inversion ROM, Alfuth and colleagues (2014) also concluded that the T2 brace reduced ankle plantarflexion and dorsiflexion. With these results, it is evident that that this rigid ankle brace effectively reduces the ROM in the planes of movement where LASs may occur (Alfuth et al., 2014). Due to the abilities of this brace, the T2 brace is commonly implemented by athletes to reduce their risk of experiencing a LAS.

Figure 7

T2 Brace

Note. The T2 Active Ankle rigid stirrup ankle brace. From "T2 Active Ankle Brace," by Sportfactor, n.d. (https://www.sportfactor.net/ANKLE-BRACE-p/t2%20blk.htm). Copyright 2022 by Sportfactor Inc.

Regardless of which ankle brace is selected, it is important to consider how the brace is worn. In line with Newell's Model of Constraints (see Appendix A), task constraints are considered any factor which are applied and may affect the performance of the individual's movement (Newell, 1986). Equipment which are being used were classified as a task constraint since it often altered the movement being performed, influencing the overall movement (Cummins-Sebree et al., 2007). For ankle braces, they are considered a task constraint and wearing them either unilaterally or bilaterally may affect the resultant movement differently (Cummins-Sebree et al., 2007). As a result, both unilateral and bilateral ankle bracing must be investigated as either method may present a unique task constraint. As previously established, there are three conditions where an ankle brace will be worn; to prevent injury from initially occurring, to treat an initial injury, and to prevent recurrent ankle injury (Barelds et al., 2018; Dizon & Reyes, 2010; Verhagen et al., 2001). The way an individual chooses to wear their brace(s) is(are) dependent on their specific scenario.

Unilateral Ankle Bracing

Unilateral ankle bracing involves the individual only wearing a brace on one ankle (Murphy et al., 2003). Murphy and colleagues (2003) reported that unilateral ankle bracing is typically prescribed when an individual injures a specific ankle and wishes to minimize the risk of re-injury in the future. Notably, unilateral bracing does not often occur prophylactically, rather after an initial acute sprain is experienced (Murphy et al., 2003). Additionally, unilateral bracing can also be implemented to treat an ankle that is unstable (Murphy et al., 2003). As a result, unilateral ankle bracing only accounts for 15% of users (Murphy et al., 2003). Another consideration of unilateral ankle bracing is whether the brace is worn on the dominant or non-dominant ankle. Murphy and colleagues (2003) reported that the dominant leg is placed at a higher risk of injury and attributed this risk to the concept of limb dominance. Limb dominance refers to the notion that the two hemispheres of the brain are functionally dissimilar (Gabbard & Hart, 1996). As a result of this dissimilarity, the body performs movements in a preferential fashion, thereby, creating a dominant limb (Peters, 1988). In sport, a preferential technique usually occurs from repetition of specific skills and results in a dominant limb being established (Gabbard & Hart; Peters, 1988). Yeung and colleagues (1994) also suggested that a large percentage of ankle sprains occur in the dominant limb in comparison to the non-dominant limb. It was considered that in sports that have jumping, landing, and repetitive changing of direction, preference tends towards the dominant leg (Murphy et al., 2003). Due to the rate and risk of injury in the dominant leg, unilateral ankle bracing typically occurs in the dominant ankle (Murphy et al., 2003).

Bilateral Ankle Bracing

When compared to unilateral ankle bracing, it is more common that ankle braces are worn bilaterally (Murphy et al., 2003). To date, the focus of performance-based research has trended towards bilateral bracing. This method is typically found in athletes whose sport presents a high risk of injury in either ankle (Fong et al., 2007). Sports such as volleyball, basketball, and badminton are considered high risk for ankle injuries due to the repetitive jumping, landing, and changing direction (Fong et al., 2007). In the case of these sports, the athletes who bilaterally brace typically do so to prevent initial injury in either ankle (Murphy et al., 2003). An athlete may wish to bilaterally brace due to the perceived demands of their sport, as well as experiences their peers may have had with injuring themselves (Murphy et al., 2003). Another justification for bilateral bracing is the perceived support it provides. Gudibanda and Wang (2005) reported that athletes felt high levels of support with bilateral ankle bracing. Furthermore, DiStefano and colleagues (2008) implemented ankle bracing bilaterally to ensure that their intervention would not create imbalances between the lower extremities. The same assumption can be applied to sport, as an athlete does not want to create imbalances, which may lead to further injury and an alteration in sport performance. This idea aligns with Newell's Model of Constraints as a task constraint since the perceived effect of the equipment may affect the resulting movement (Newell, 1986). For any of these aforementioned reasons, an individual may choose to bilaterally brace, but again it all depends on their specific circumstance (Denton et al., 2015).

Effect of Ankle Braces on Performance

Despite the fact that ankle braces are effective in preventing injury, athletes are also concerned with the impact that ankle braces may have on their performance. Athletes strive to perform at an optimal level while staying physically healthy at the same time. As a result, evaluating the effects that ankle bracing has on performance is imperative. When considering the essential movements of volleyball, the performance determining variables can be broken down into the vertical jump and agility performance (Bahr et al., 1994). Both of these factors play a significant role in determining success within the sport, regardless if it is during offensive or defensive plays (Bahr et al., 1994). It has been noted that ankle braces are effective in decreasing the risk of injury by restricting ROM in the frontal and sagittal planes (Gudibanda & Wang, 2005). There is concern, however, that limiting these motions may create deficits and hinder the overall performance of the volleyball-related skills. In addition to the potential performance deficits while wearing ankle braces, it is important to consider if wearing braces unilaterally or bilaterally impacts the performance of volleyball-related tasks. As a result, investigating the effects that wearing ankle bracing may have on the performance of specific volleyball tasks such as vertical jumping and agility must be evaluated.

Effect of Ankle Bracing on Vertical Jump Performance

Vertical jump performance is vital to volleyball players as a fluctuation in jump height will influence success at different points during the rally (Lidor & Ziv, 2010). As a result, if the braces being worn negatively affect the movements, it may decrease the overall performance.

Paris (1992) completed the first study comparing the effects of different lace-up ankle braces on vertical jump performance. The researcher recruited elite level soccer players from a local high performance center who had no evidence of residual effects from previous injury (Paris, 1992). Although the athletes were not volleyball players, this is still relevant since soccer players rely on vertical jump height throughout the course of a match (Paris, 1992). The braces used in testing were a series of lace-up braces (Paris, 1992). To quantify the vertical jump height, the researcher administered the Sargent Chalk Jump Test (Paris, 1992). At the time of this study, this test was the standard protocol for assessing vertical jump height (Paris, 1992); however, there was no mention of the number of trials the participants performed under each condition. The measurements were collected by measuring the difference between the chalk mark from the participant's standing reaching height and the highest chalk mark from their jump (Paris, 1992). The measurements were taken to the nearest quarter inch to calculate the vertical jump height. This study was the first that revealed that wearing the lace up brace bilaterally significantly reduced vertical jump height, while the remaining braces did not (Paris, 1992). In comparison to the unbraced (UB) condition, vertical jump height was decreased from 23.5 inches (in) in the UB trials, to 22.2 in in the braced trials (Paris, 1992). This study concluded that wearing lace-up ankle braces decreased vertical jump height.

More recently, Smith and colleagues (2016) measured the impact of wearing a softshell ankle brace on vertical jump performance of varsity athletes. The participants were recruited from the institution's eligible varsity athletes who competed in a sport where ankle bracing was prominent, however there was no mention of which sports the athletes competed in (Smith et al., 2016). Additionally, it was identified that the majority of the research has focused on the landing phase of vertical jumping, rather than the loading and propulsion phases. To evaluate the impact that ankle bracing has on the loading and propulsive phases, the researchers examined the lower extremity kinematics to measure the differences (Smith et al., 2016). During the loading phase, the kinematic variables of interest were ankle dorsiflexion and hip and knee flexion angles (Smith et al., 2016). Additionally, ankle plantarflexion was measured during the propulsion phase (Smith et al., 2016). To quantify the vertical jump height, the researchers implemented the protocol for the vertical jump test by using the Vertec™ apparatus (Smith et al., 2016). This method is the most common method used to collect maximum vertical jump height due to its efficiency and cost effectiveness (Peterson et al., 2006). The participants performed five trials of the vertical jump test in both the UB and braced conditions (Smith et al., 2016). The brace which was used during this was a softshell lace-up brace. It was noted that the participants did not wear shoes during either condition as the researchers aimed to eliminate the effect of their shoes on performance. The results of this study revealed that vertical jump height decreased by 2.32 centimetres (cm) while wearing ankle braces bilaterally using a lace-up brace (Smith et al., 2016). Additionally, kinematic analysis revealed significant reductions in the hip flexion angle from 99.6 to 94.9 degrees (deg) and ankle plantarflexion from 37.7 to 32.7 deg in the braced trials, to which the researchers attributed the reduction in vertical jump height (Smith et al., 2016). From this study, the researchers concluded that wearing ankle braces significantly reduced vertical jump performance (Smith et al., 2016). Furthermore, it was suggested that the decrease in performance could be due to the reduced hip flexion during the loading phase and ankle plantarflexion angles in the propulsion phase (Smith et al., 2016). This study was the first to evaluate the kinematics with respect to the impact on vertical jump performance. As a result, the researchers recommended future research evaluating lower extremity kinematics while evaluating vertical jump performance. Additionally, the researchers noted that comparing different styles of ankle braces may also have an impact on both kinematics and vertical jump performance.

Henderson and colleagues (2016) revealed similar results when comparing the impact of ankle bracing on vertical jump performance. The participants included varsity basketball and volleyball players (Henderson et al., 2016). This study compared two of the most commonly used ankle braces including the ASO and T2 braces (Henderson et al., 2016). To measure vertical jump performance, the researchers used the Vertec™ apparatus with identical procedures to Smith and colleagues (2016). The researchers manipulated the type of vertical jump which was being performed. It was stated that the researchers had the participants perform three trials of a SJ with a 2 second (sec) pause in approximately 45 deg of knee flexion (Henderson et al., 2016). This position was subjectively determined by the researchers and the trial was not included if the researcher deemed it insufficient (Henderson et al., 2016). This method was used to isolate the lower extremities, which does not recruit upper extremity movements to contribute to the jump (Henderson et al., 2016). This motion was unlike what would be performed in the real-life context of basketball and volleyball. Additionally, the test was performed on a rubber track rather than a hardwood floor, which would not replicate the athlete's natural performance environment (Henderson et al., 2016). The results of this study revealed that there was a significant reduction in jump height between both braces and the UB trials (Henderson et al., 2016). In comparison to the UB trials, wearing the ASO brace resulted in a decrease of 1.47 cm, while the T2 brace resulted in a 2.35 cm reduction in vertical jump height (Henderson et al., 2016). These results align with those of Smith and colleagues (2016) and suggested that wearing ankle braces negatively affected vertical jump performance. This study suggested that future studies should be conducted with consideration of the biomechanical differences which may be caused by wearing ankle braces.

Henderson and colleagues (2019) later compared vertical jumping performance while wearing the ASO and T2 braces in 40 active university students who had participated in jumping-related sports (Henderson et al., 2019). Although this sample was not made up of elite athletes, the results were still directly generalizable to an athletic population. It was suggested that both recreational and elite athletes had similar exposure to ankle injuries and were both likely to utilize ankle braces (Gross & Liu, 2003). In this study, the researchers used the Vertec™ apparatus to measure vertical jump height to quantify performance (Henderson et al., 2019). The participants performed three trials similar to the methods and SJ used by Henderson and colleagues (2016). Again, it was stated that this was to isolate the lower extremities but this type of jump does not fully represent the movements performed by volleyball athletes. It was found that wearing both the lace-up and semirigid braces again significantly impacted vertical jumping height (Henderson et al., 2019). The lace-up and semirigid braces resulted in a decreased vertical jump height by 2.41 cm and 2.89 cm, respectively.

More recently, You and colleagues (2020) performed a study focused on performance of volleyball-specific skills while wearing ankle braces. The researchers recruited varsity volleyball players from the local university to participate in this study and used the ASO and T2 braces (You et al., 2020). To quantify jumping performance, the Vertec™ was utilized during the vertical jump test and reliable results were reported across all conditions. The researchers noted that video motion analysis (VMA) was established as the gold standard measurement during previous studies (You et al., 2020). The results from the vertical jump test revealed no significant decreases in vertical jump height when wearing both the lace-up brace and semirigid braces when compared to the UB condition (You et al., 2020). Furthermore, the researchers noted that there was no significant difference in jump height when comparing to the two braces to one another (You et al., 2020). From this, it was suggested that future research should continue to evaluate the differences between these two ankle braces. In addition to vertical jump performance, ankle ROM was collected kinematically in all three planes of motion (You et al., 2020). Contrary to the results from Smith and colleagues (2016), the kinematic data revealed no differences in sagittal plane movements when comparing braced and unbraced conditions (You et al., 2020). The disagreement in results suggests a need for further research to be conducted examining the kinematics and how they may vary during vertical jumping under different bracing conditions. In addition, the researchers also investigated the kinetics during the loading and propulsive phases (You et al., 2020). This study is the first to examine kinetic data during these phases as the previous research was concerned primarily with the landing phase. The researchers used a force platform to measure vertical ground reaction forces (vGRF) under all different bracing conditions (You et al., 2020). The results from this analysis revealed a significant difference between the vGRFs in the unbraced and both bracing conditions (You et al., 2020). It was reported that in comparison to the braced conditions, the peak vGRF in the unbraced trials was significantly higher than that when wearing the lace-up and semirigid braces (You et al., 2020). The researchers attributed the significant reduction in vGRF to the decrease seen in vertical jump height (You et al., 2020). Since this was the first study considering take-off vGRF, the researchers recommended that future research be completed examining vGRF measurements along with vertical jump performance.

Additionally, Leonard and colleagues (2014) compared jump performance while participants were in braced and unbraced conditions. In this study, the participants were separated into two groups of interest including those who competed in athletics and those who did not (Leonard et al., 2014). The athletic population in this study was represented by athletes who competed in jumping-related sports such as volleyball and basketball while the non-athletic group was comprised of people who did not actively compete on a sports team and completed less than 60 mins of physical activity daily (Leonard et al., 2014). The aim of this study was to determine if a certain population was more susceptible to performance deficits due to ankle bracing (Leonard et al., 2014). To measure vertical jump performance, the researchers implemented the vertical jump test using the Vertec™ apparatus (Leonard et al., 2014). Participants completed three trials under each bracing condition and the mean vertical jump heights were calculated. The researchers found that while wearing lace-up braces, vertical jump performance was not significantly reduced in both the athletic and non-athletic populations (Leonard et al., 2014). It was reported that while wearing ankle braces, the vertical jump performance of both athletes and non-athletes was not impacted (Leonard et al., 2014). This result directly contradicted those found in previous studies, which found that the lace-up ankle braces decreased vertical jump height (Henderson et al., 2016; Henderson et al., 2019; Paris, 1992; Smith et al., 2016).

Most recently, Morikawa and colleagues (2022) assessed the impact of wearing different ankle braces on the kinetics and vertical jump performance. In this study, regular healthy participants were recruited to perform three jumping tasks; the SJ, CMJ, and a repetitive jump task (Morikawa et al., 2022). Each participant completed five sets of three jumps for each type of jump while wearing semirigid and softshell ankle braces, as well as an unbraced condition. Vertical jump height was automatically calculated using the Optojump™ software and also produced real-time kinetic variables (i.e., vertical jump height and contact time). In addition, measures of ankle dorsiflexion and ankle plantarflexion angles were simultaneously collected using a video camera (Morikawa et al., 2022). It was reported that neither the semirigid nor softshell brace significantly decreased vertical jump height when compared to the UB condition (Morikawa et al., 2022). Similar to Leonard and colleagues (2014), this study suggested that wearing either the softshell or semirigid braces had no impact on vertical jump performance (Morikawa et al., 2022). Furthermore, it was reported that both ankle plantarflexion and ankle dorsiflexion angles were significantly reduced while wearing both the softshell and semirigid braces (Morikawa et al., 2022). In addition, there were no significant differences reported when evaluating the vertical impulse, as well as vGRF for the CMJ (Morikawa et al., 2022). This result suggests that the differences seen in the sagittal plane ankle ROM, does not impact the forces which are produced, as well as the overall vertical jump performance (Morikawa et al., 2022).

From these studies, it is clear that the majority of the literature suggested that ankle bracing decreased vertical jump performance. Although the majority of the research reported a decreased vertical jump performance, there are studies, which reported ankle bracing had no impact on vertical jump performance. Since there is no definite trend, more research should be conducted utilizing similar braces, volleyball-athletes, and similar testing protocols. As a result, using this methodology should be employed to further explore the impact of ankle bracing on jumping performance in volleyball players. From this, performance measures to quantify vertical jump height and the kinematics and kinetics associated with vertical jump performance should be examined.

Effect of Ankle Bracing on Agility Performance

As previously established, agility is the ability to perform rapid changes in direction in reaction to the stimuli of the sport (Lidor & Ziv, 2010). In volleyball, being able to react quickly to the opponents' play or adjust to their strategies, often determines success in the sport (Bahr et al., 1994). Similar to the vertical jump height, if the ankle braces negatively affect the agility performance, it may determine the athlete's ability to successfully complete a play. Paris (1992) first evaluated the impact of the lace-up ankle braces on agility performance. As previously mentioned, the participants in that study included elite soccer players and the agility test conducted was catered towards soccer athletes (Paris, 1992). In this study, performance was measured using the SEMO agility test and revealed no significant differences in time when wearing the lace-up brace compared to the semirigid brace (Paris, 1992). The researcher noted that this agility test was specific to soccer players as it incorporated the movements, which are best represented within the sport of soccer. Although this test was soccer specific, it incorporated the same general movements, which volleyball players commonly perform. The performance was measured using a handheld stopwatch and times were accurate to the nearest tenth of a second (Paris, 1992). When comparing the braced and UB trials, there was no significant differences in the time to complete the agility course (Paris, 1992). From this study, it was concluded that lace-up ankle braces were effective in providing the athlete support without negatively impacting agility time.

Henderson and colleagues (2016) measured the impact that ankle bracing had on agility performance in athletes who competed in jumping sports. The researchers recruited participants who actively participated in a jumping sport including either basketball or volleyball (Henderson et al., 2016). By recruiting experienced jumping athletes, the researchers aimed to generalize the results from this study to all elite athletes who competed in similar sports (Henderson et al., 2016). The ankle braces used for this study included the T2 and ASO braces. These braces were selected as they were the most commonly prescribed braces for athletes who competed in jumping sports (Denton et al., 2015; Henderson et al., 2016). To measure agility, the participants completed a standardized T-test, which was reported to be a reliable tool to assess agility (Pauole et al., 2000). Furthermore, the movements required in the test were similar to those which are typically performed throughout the course of a volleyball match. The reported results of this study were similar findings to those of Paris (1992). The researchers found no statistically significant difference between the braced and UB conditions. They reported that while wearing the T2 brace, the time to complete the agility course increased by 0.06 sec, whereas the time to complete the agility course decreased by 0.15 sec while wearing the ASO lace-up brace (Henderson et al., 2016). In comparison to the UB trials, the times for the agility test while wearing the lace-up brace decreased while agility time increased during the trials when wearing the T2 brace (Henderson et al., 2016). Based on the results from this study, the researchers suggested that further research be conducted assessing the impact of ankle braces on agility performance.

Additionally, Leonard and colleagues (2014) measured the impact that ankle bracing had on agility performance. The researchers recruited athletes and non-athletes to compare the impact that ankle braces had on both populations (Leonard et al., 2014). Among all of the participants, the athletes competed in sports where agility played an integral role in success (Leonard et al., 2014). The brace used in this study included a lace-up brace with a similar design as the ASO brace (Leonard et al., 2014). To measure agility performance, the participants completed the Illinois Agility Test (Leonard et al., 2014). The results from this study revealed that the lace-up brace did not impact agility time (Leonard et al., 2014). Similar to the results of Paris (1992), this study showed a small increase in agility time that was not statistically significant (Leonard et al., 2014). This non-significant result infers that wearing the lace-up brace did not impact the performance of the agility task. This result, however, may have been due to certain methodological considerations. First, the agility test selected did not incorporate sport-specific movements which would be seen in volleyball athletes. Although this test has been reported to be a reliable tool to measure agility performance for athletes, the external validity when applied to volleyball players is low (Pauole et al., 2000). Although this test is reported as a reliable tool to measure agility, the movements used to perform this test did not specifically replicate those seen in a volleyball match (Lidor & Ziv, 2010). As a result, if this study were to be performed with a certain population in mind, a more specific test, which better represented the population of interest should be selected. The researchers suggested that future research should be conducted with athletes from a specific sport in mind as well as administering a test, which better replicated the movements they typically performed.

Henderson and colleagues (2020) examined the impact that ankle braces had on agility performance. In this study, the researchers recruited 42 participants with experience in jumping sports and cutting maneuvers (Henderson et al., 2020). Participants completed a modified agility task while wearing the ASO lace-up and T2 rigid braces (Henderson et al., 2020). The modified agility task was developed specifically from the T-test as it placed a focus on movements in the frontal and sagittal planes (Henderson et al., 2020). The tasks incorporated straight-line sprinting, transitioning to lateral side-stepping, and finishing with backwards running (Henderson et al., 2020). The results of this test are important to consider as the test performed resembles the specific movements required by volleyball players. This study revealed significantly slower agility times when wearing both the ASO and T2 braces when compared to the UB condition (Henderson et al., 2020). The researchers reported that wearing the ASO and T2 braces increased the agility time by 0.16 sec and 0.20 sec, respectively (Henderson et al., 2020). From this study, the researchers suggested that wearing ankle braces negatively impacted on the time to complete a modified agility task. The agility time, however, was not significantly impacted when comparing the results between the two bracing conditions. In an effort to support these results, it was recommended that the complete T-test be conducted rather than the modified task in the future (Henderson et al., 2020).

Similar to how ankle braces effect vertical jump performance, it is evident that there are mixed results on whether wearing certain ankle braces result in performance deficits for agility. Although the majority of the studies reported that wearing ankle braces had no significant impact on agility performance, the results from these studies report some differences in agility times when comparing braced and unbraced trials. Due to methodological considerations such as the sample size, agility test used, and the ankle braces worn, there are conflicting results about the true impact that ankle bracing has on agility performance.

Research Problem

The sport of volleyball is characterized by repetitive maximal and sub-maximal vertical jumps, as well as rapid changes in direction (Gross & Liu, 2003). Due to the intensity with which these movements are performed, there is the potential for adverse forces being placed on the lower extremities (Gross & Liu, 2003). As a result, the incidence of ankle injury is quite common, accounting for approximately 28% of all sport injuries (Garrick & Requa, 1998). More specifically for volleyball players, 45.6% of all injuries occur at the ankle, with 99.3% being a LAS (Fong et al., 2007). Due to the high incidence of LAS in volleyball, ankle braces have been recommended to treat acute sprains and prevent them from occurring (Verhagen et al., 2001). Ankle braces have been shown to reduce the risk of initial LAS by 47% and recurring ankle sprain by 69% (Barelds et al., 2018; Dizon & Reyes, 2010). Researchers have agreed that orthoses such as braces are suitable methods to prevent occurrence and recurrence of LAS, however, there is some dispute of how wearing various ankle braces may affect the movements required for sport-specific performance.

There have been many studies reporting how vertical jump and agility performance may be affected by ankle bracing. In the case of vertical jump performance, there have been multiple studies which have reported reduced vertical jump height while wearing both lace-up and semirigid braces (Henderson et al., 2016; Paris, 1992; Smith et al., 2016). Conversely, there are also multiple researchers who reported that there was no impact on vertical jump height while using the same ankle braces (Ambegaonkar et al., 2011; Henderson et al., 2019; Leonard et al., 2014). In the case of agility performance, conflicting results were also found among multiple studies. There are studies which suggested that wearing either the lace-up or semirigid braces did not affect agility performance (Henderson et al., 2016; Leonard et al., 2014; Paris, 1992). There are also studies which found that the time to complete an agility test increased while wearing ankle braces, which indicated a possible performance deficit (Ambegaonkar et al., 2011; Henderson et al., 2020). One thing to note about the findings related to agility is that each of these studies utilized a different test. For future research, it is important to select a test which applies to the target population as it will strengthen the external validity of the results (Kowalski et al., 2018). As a result, there needs to be further research conducted to strengthen the literature on the effect ankle braces have on vertical jumping and agility.

In addition to the impact that wearing ankle braces has on performance, the type of ankle braces and how they were being worn should be considered. Researchers have suggested that the ASO and T2 braces were the two most prescribed braces used for athletes who suffered a LAS or at risk of experiencing a LAS (Denton et al., 2015). Additionally, Murphy and colleagues (2003) suggested that athletes wear braces either unilaterally or bilaterally, however, the current research has not considered the comparison of unilateral (UNI) and bilateral (BI) bracing. The most relevant research concerning the impact of ankle bracing on vertical jumping and agility has been focused on evaluating individual ankle braces. Furthermore, to date no research has been conducted measuring how UNI and BI bracing may impact performance. Consequently, it is important to evaluate the effects that UNI bracing may have on performance and compare those results to that of BI bracing. This research may provide athletes, coaches, trainers, and clinicians with valuable information regarding the effects that specific ankle braces have on performance. In addition, this study may also provide the athletes insight to how they wear ankle brace(s) and if there is any effect on their vertical jump and agility performance.

Purpose

The aim of this study was to examine the impact of unilateral versus bilateral ankle bracing on the kinetics and kinematics of the vertical jump, vertical jump height, and agility time in volleyball players.

Hypotheses

1. The ASO and T2 braces would produce significantly decreased vertical jump heights for the UNI and BI braced conditions when compared to the UB condition. In addition, no significant differences would be seen in jump height when comparing the ASO brace to the T2 brace.
2. The ASO and T2 braces would produce significantly decreased peak hip and knee flexion and ankle dorsiflexion and plantarflexion angles for the UNI and BI braced conditions when compared to the UB condition. In addition, no significant differences would be seen in these kinematic variables when comparing the ASO brace to the T2 brace.
3. The ASO and T2 braces would produce significantly decreased peak vGRF and impulse for the UNI and BI braced conditions when compared to the UB condition. Furthermore, the BI braced condition would produce significantly decreased peak vGRFs when compared to the UNI condition. In addition, no significant differences would be seen when comparing the ASO brace to the T2 brace.
4. The ASO and T2 braces would produce significantly slower agility times for the UNI and BI braced conditions when compared to the UB condition. In addition, no significant differences would be seen in agility time when comparing the ASO brace to the T2 brace.

Chapter Two: Methodology

A limited number of studies have examined the impact that unilateral versus bilateral ankle bracing has on the kinetics, kinematics, and performance during vertical jump and agility testing. As such, this study was designed to fill this gap in the literature.

Participants Inclusion and Exclusion Criteria

Potential participants were considered for this study if they actively or previously played competitive volleyball on a varsity or club team at Lakehead University. Volleyball athletes were recruited to this study due to the unique demands of their sport, their risk of injury, and their use of ankle braces during sport participation (Gross & Liu, 2003). Being experienced volleyball athletes was a requirement for participation in this research since volleyball is classified as a level 1 sport, which requires repetitive jumping and cutting (Daniel et al., 1994). Experienced volleyball athletes were defined as those who had 3 or more years playing on a competitive volleyball team (Daniel et al., 1994). Both males and females were recruited from their respective teams in an effort to represent both male and female volleyball players. In addition, participants were considered for this study regardless of whether they have previous experience wearing ankle braces or not. Participants who had experience wearing ankle braces were not excluded as Distefano and colleagues (2008) reported that physical adaptations were not made after wearing ankle bracing for an extended period of time. Furthermore, a participant was only selected for this study if they completed a Get Active Questionnaire (GAQ) and no contraindications to exercise were present (see Appendix B).

Potential participants were excluded from this study if they had suffered a lower extremity injury over the past three months, which would have prevented them from participating in their regular training or from playing volleyball in practices or games.

Considering the healing process of soft tissue injuries, three months was deemed as an appropriate amount of time to allow the soft tissue structures to heal and strength to be re-gained (Anderson, 2017). Henderson and colleagues (2020) implemented this recruiting method to exclude those whose performances would be negatively impacted through participation. Furthermore, this was implemented to ensure that the risk of injury was minimized during the experimental trials.

Research Participant Demographics and Recruitment Procedures

A total of 22 participants were recruited for this study, which included fourteen males and eight females. Based on previous literature and a priori analysis, 33 participants was determined as the sample size which would result in a medium to large effect size (0.5–0.8) with 80% power at $\alpha=.05$ (two-tailed; Riggs & Sheppard, 2009; Rosner, 2011; Smith et al., 2016). It is evident that the recruitment for this study did not result in the sample size outlined by the priori analysis. A total of 22 participants were recruited for this study as this number was readily available during the recruitment period. In addition, when comparing this sample size to previous ankle bracing research, the sample size in this study is well within the range of that recruited by previous researchers (20-25 participants; Ambegaonkar et al., 2011; DiStefano et al., 2008; Henderson et al., 2016; Leonard et al., 2014; Morikawa et al., 2022; Smith et al., 2016; West et al., 2014; You et al., 2020). Demographic information for all participants is presented in Table 1.

Table 1

Participant Demographic Information

Category	Sample Statistics
Sex	14 male, 8 female
Height (cm)	179.3 +/- 8.2
Weight (kg)	71.6 +/- 10.2
Age (years)	21.4 +/- 2.5
Playing Experience (years)	7.3 +/-3.4
Previously Worn Braces	13 no, 9 yes
Types of Brace Worn	6 ASO, 3 T2
Conditions of Braces Worn	13 UB, 7 BI, 2 UNI

Upon receiving approval from the Lakehead University Research Ethics Board, participants were recruited by utilizing a combination of convenience and purposive sampling. Through email, contact was be made with the coaches of these teams to gain permission to recruit their athletes for this study. The student researcher provided the coaches with an information letter, which clearly outlined what participation in this study required of their athletes (see Appendix C). Once the coaches approved of their athlete's participation, the information letter was sent to each member of the team to recruit volunteers. Additionally, the student researcher spoke to the athletes to promote the study and simplify the expectations of a potential participant. Athletes were encouraged to contact the student researcher if they were interested in participating or had any questions about the study. In addition, a consent form was emailed to all volunteers to ensure that they met the inclusion criteria (see Appendix D).

The day prior to testing, participants were asked to limit the amount of training they performed to reduce the effect that fatigue may have had on their performance. In addition, for both testing sessions the participants were instructed to wear the shoes which they would normally wear for their regular volleyball training.

Screening Measures

Get Active Questionnaire (GAQ)

The Get Active Questionnaire (GAQ) is a pre-screening tool which was developed by the Canadian Society for Exercise Physiology (CSEP) to easily screen individuals to safely participate in physical activity and exercise (CSEP, 2022). The GAQ was completed by all participants prior to their first testing session before participating in any physical activity of any kind. All participants passed the GAQ with no contraindications to exercise, however, if they did not pass the GAQ, they would not have been able to participate in the study. For a full description of the GAQ, see Appendix B.

Demographics Questionnaire

The demographics questionnaire was developed by the student researcher to collect background information about each participant (Appendix E). This questionnaire included items regarding the participant's background information, experience wearing ankle braces, and history of lower extremity injuries. These items were selected as it provided information to be included in the analysis (i.e., participant's weight), and insights into the participant's familiarity with ankle braces and injury history.

Instrumentation

The participants were asked to wear both the ASO and T2 braces when performing both the vertical jump and agility t-test. The size of the brace that was appropriate for each participant was dependent on their shoe size. To ensure that the braces performed as they were intended to, various sizes of both ankle braces were available to ensure the braces properly fit the participants. Furthermore, to apply the brace the participants were provided with specific instructions to put on the brace as per the manufacturer's instructions. Having the participant apply the brace themselves ensured that the brace was applied to the participant's comfort, all while the student researcher directed them on how to properly apply them.

GoPro Hero 9© Camera

One GoPro Hero 9© camera was placed on a 1 m tall tripod to collect 2D-kinematic data. The camera was positioned perpendicular to the sagittal plane of the dominant limb of the participant in order to record the motion (see Figure 8). With the single GoPro© camera there may have been some perspective error in the image. The GoPro© linear field of view was utilized to reduce the impact of perspective error while not compromising the quality of the images. Compared to the gold standard of three-dimensional (3D) motion analysis, the GoPro© camera reported excellent reliability (ICC=.96-.99) for measures of lower extremity displacement (Paul et al., 2016). The dominant limb was determined by asking the participant which leg they would use to kick a ball (van Melick et al., 2017). The dominant leg was only assessed due to the symmetry of movements between the dominant and non-dominant limbs during the CMJ. Maulder and Cronin (2005) reported that there were no significant differences ($p > .05$) in symmetry when comparing the dominant and non-dominant limbs. As a result, it was suggested that when research is focused on one limb, the dominant limb should be assessed and that symmetry may be assumed (Maulder & Cronin, 2005).

Figure 8

Set-up for the Vertical Jump Test

Note. The GoPro© camera and Vertec™ set-up for the vertical jump test surrounding the AMTI© force platform.

Reflective Markers

To capture the motion of the limbs, the participant had five reflective markers, each measuring 1 cm x 1 cm, placed on their dominant leg attached with adhesive tape. Marks and Karkouti (1996) reported that reflective markers placed on the bony landmarks of the lower extremities resulted in high reliability (ICC=.87). In an effort to increase reliability, the student researcher was the only person to attach the markers to each participant. The markers were placed on the anatomical landmarks presented in Table 2. The participants completed the testing session in their respective volleyball shoes, as well as the various braces. As a result, the marker for the fifth metatarsal was placed on the lateral aspect of the participant's shoe superficial to the fifth metatarsal. The configuration of the markers followed the locations as presented in Figure 9.

Table 2

Anatomical Landmarks for Reflective Markers

Anatomical Landmark	Common Name of Landmark
Greater Trochanter	Hip
Lateral Femoral Condyle	Knee
Lateral Malleolus	Ankle
Calcaneus	Heel
Head of the 5th Metatarsal	Toe

Note. All markers were placed on the participants dominant limb.

Figure 9

Reflective Marker Configuration

Note. The reflective marker set for the vertical jump test will follow this configuration.

Advanced Mechanical Technologies Incorporated© (AMTI) force platform

To collect the kinetic data, an AMTI© force platform was utilized. The AMTI© force platform has reported excellent reliability (ICC=.94) when measuring the GRFs during a vertical jump (Cordova & Armstrong, 1996). The force platform measures three GRFs and three moments of force in three axes of motion (i.e., x, y, and z) with six degrees of freedom (DoF). The designated channels for vertical, anteroposterior, and mediolateral GRFs were connected to a PowerLab (16/30) data acquisition unit, which were displayed in LabChart®. Vertical, anteroposterior, and mediolateral forces were measured in Volts (V), and then converted to Newtons (N) by utilizing the two-point calibration method embedded in the LabChart© software. The first point was zero, where the student researcher recorded the reading of the force platform while no weight was being loaded on it. Next, the second point was the student researcher's mass, which was measured by the scale. The student researcher stood on the platform as their body weight was the known quantity. This allowed the student researcher to convert the Vs recorded by LabChart© to Ns. The GoPro© camera and Vertec© apparatus were positioned around the AMTI© force platform (see Figure 9).

LabChart® 8 software

For this study, GRF data was collected in real time using LabChart® software. Three channels (Fx, Fy, and Fz) collecting GRF data from the AMTI© force platform, and one channel (Trigger) to output a signal to trigger a light-emitting diode (LED) light were plugged into the PowerLab© unit. The trigger signal was utilized to synchronize the GRF from the force platform and kinematic data from the GoPro© camera. Kinematic and kinetic data were synchronized using a LED which was displayed as a channel in the LabChart® software (Bishop, 2001). The LED was activated at the beginning of each trial and it emitted a pulse which was seen in the camera's field of view, which allowed the data to be synchronized. LabChart® software was used to rectify, filter, and extract all force platform data.

Kinovea® Video Analysis Software

Video data collected from the GoPro© camera was extracted and analyzed using Kinovea® video analysis software version 0.9.5. Puig-Divi and colleagues (2017) reported excellent intra- and interrater reliability (ICC=.99-1.0) when measuring 2D kinematics using Kinovea®. Kinovea® software was used to quantify the angular position of the joints of the lower extremities throughout the take-off phase of the vertical jump test.

Brower© Timing Gates

To measure agility time, one set of Brower© infrared timing gates was used to act as the start and finish line for the agility T-test. The timer started when the participant first broke the signal, and the timer was stopped when the participant crossed over the line again. Brower© timing gates have shown great within trial variation with no coefficient of variation (CV) greater than 1.2% (Cronin & Templeton, 2008).

Vertical Jump Test

The vertical jump test is a widely used test used to measure lower body muscular power and is very applicable to jumping-related sports such as volleyball and basketball (CSEP, 2022). There are various methods which have been implemented to administer the vertical jump test, however, the protocol adopted by CSEP was used for this study (see Appendix F). The vertical jump test was utilized to assess vertical jump height. Additionally, the Vertec™ apparatus was used to measure vertical jump height (see Appendix F). The Vertec™ was placed beside the force platform on the participant's non-dominant side to avoid any interference with the video recording. The Vertec™ apparatus was selected for this study as it has been noted as a valid and reliable instrument to measure vertical jump height. More recently, You and colleagues (2020) reported that the Vertec™ provides a reliable measurement of vertical jump height when compared to the gold standard of VMA. For this study, vertical jump height was measured in in and converted to cm.

Agility T-Test

To assess agility performance, the participants completed the agility T-test (see Appendix G). Five pylons were utilized to outline the various points of the course where changes in direction were required. The student researcher placed masking tape on the floor beneath the cones in the event that a cone was disrupted at any point in the testing session. The Brower© timing gates were placed at the start/finish line to begin and end the timing of the test trials. The specific dimensions of the course, space between pylons, and set up of the timing gates can be viewed in Figure 10. The agility T-test has demonstrated excellent intraclass reliability (ICC=.98) when measuring sprint and agility performance (Pauole et al., 2000). For the purpose of this component of the study, time (sec) to complete the agility T-test was recorded.

Figure 10

Set-up for the Agility T-test with Timing Gates

Note. The layout of the agility t-test with the Brower© timing gates set-up at the start/finish line.

Data Collection Procedures

The testing was completed over two sessions, one session included the vertical jump test and the other the agility T-test. During both testing sessions, the participants were asked to wear the shoes which they would typically wear during their regular volleyball training. For both tests, the participants completed the trials with both brace types (ASO and T2) and all bracing conditions (UB, UNI, and BI). For each testing session, the participants were assigned to a random order of conditions, which they would complete through the respective session (Figure

11). To mitigate the effect of extraneous variables, a Latin Square was utilized to determine the order of the experimental conditions (Richardson, 2018). The first participant performed the first line of the matrix, the second performed the second, and so on until the fifth line. For the sixth participant, the student researcher returned to the first line of the matrix. The lab and gym floors were prepared to ensure that the surfaces were clean and dry to reduce the risk of injury during testing. One week after their first testing session, the participants were invited back to perform the test which they did not perform prior. Upon arrival to the second testing session, the student researcher verified that there were no changes based on the consent and GAQ forms which were signed previously.

Figure 11

Latin square for determining order of bracing conditions

1	2	3	4	5
2	3	4	5	1
3	4	5	1	2
4	5	1	2	3
5	1	2	3	4

Vertical Jump Test

The vertical jump testing session was conducted in the multi-purpose laboratory (SB-1028) in the Sanders Building at Lakehead University. This session took approximately 60 min to complete. Prior to the participant's arrival, the student researcher performed a calibration video taken with a meter stick in the field of view. The meter stick was placed on a level tripod with a reflective marker on each end to clearly identify the length of the meter stick. The completion of a calibration video trial ensured that the known coordinates were transformed to real world coordinates during the video digitization processing (Payton & Bartlett, 2008). In addition, the two-point calibration of the force platform was performed by the student researcher. These calibration procedures were performed to increase the validity and reliability of the data collected prior to each data collection session.

Upon their arrival, the participant re-read the information letter, signed the consent form, and filled out the GAQ. Next, the participant completed a 10 min warm-up on a stationary bike. The first 5 min had a resistance load of 1 kilopond (kp) and the last 5 mins had a resistance of 2 kp. During the warmup, the student researcher determined a randomized order which the participants completed the tests based on the brace types and conditions. During both sessions, this process occurred while the participant completed their 10 min warm-up.

After the 10 min of cycling was finished, the participant finished the warm-up by performing two sets of 5 submaximal vertical jumps. Rezende and colleagues (2016) found that vertical jump performance improved after warming up with low-intensity cycling and vertical jumps. The participant was instructed not to jump as high as possible to prevent fatigue and preserve their best efforts for testing. Between each jump and set, the participant was allowed 30 sec and 1 min to rest and recover, respectively. After performing the cycling and jumps, the warm-up was completed and the student researcher prepared the participant for testing.

At the completion of warm-up, the student researcher measured the participant's standing reach height. This occurred with the participant standing beneath the Vertec™ and reaching upwards as high as they could while they maintained flat feet on the ground. This measure was included as a part of the analysis to calculate the participant's vertical jump height. The reflective markers were then applied to the participant in order to collect the kinematic measures. Once the placement of the markers was completed, the order of the bracing conditions was identified. The student researcher then explained the test to the participant and encouraged them to jump as high as possible. It was emphasized that the participant should give maximal effort for each of their trials. After the explanation, the participant stepped onto the force platform to perform the test trials.

Once the participant was in place, the recording of the kinetic and kinematic data was started from the camera's remote and from the force platform by using LabChart© software, respectively. The participant was then informed that they were able to complete their vertical jump trial when they were ready. At this point, the participant performed a maximal vertical jump without a pause between their loading and take-off phases (Baker, 1996; Henderson et al., 2016; Henderson et al., 2020). After each trial, the height of the jump was recorded by counting the veins of the Vertec™ and subtracting that height from the participant's standing reach height. For each bracing condition, the participant completed five vertical jump trials which ensured reliable measures are being collected. James and colleagues (2007) suggested that five trials were sufficient to achieve stability of scores in well-trained, college-aged participants. Once a jump was completed, the participant was given 1 min to recover before performing the remaining trials. This rest interval differed from the warm-up as these jump trials were maximal jumps in comparison to the sub-maximal warm-up trials. Trossman and Li (1989) stated that participants who were allotted 1 min of rest between trials experienced the least amount of decline in their performance in comparison to those who had 15 sec, 30 sec, and 45 sec rest periods.

After the five jump trials of one condition were completed, the participant was given 2-3 min to rest. In this time, the participant changed to the subsequent bracing condition. The bracing conditions used followed the order which was pre-determined by the Latin Square. Once all of the bracing conditions were completed, the participant completed 25 jumps, five per bracing condition. Once all trials were completed, the participant was asked to perform a low-intensity 5 min cool-down to recover from the testing session. This included the participant cycling at a low intensity and performing static stretching of their lower extremities (see Appendix H). At this point, the testing session was completed and the participant was free to leave.

Agility T-Test

Testing for the agility T-test was completed in the main gym at the Sanders Building at Lakehead University in effort to recreate a realistic environment to which the participants would typically compete in volleyball. In this session, the same brace types and bracing conditions were implemented as for the vertical jump test. The expected duration of this session was approximately 60 min.

The participant completed the same cycling warm-up as the vertical jump session, however, rather than asking the participant to complete the vertical jump warm-up jumps, the participant completed lunges, side lunges, high knees, and side shuffling for a dynamic warm-up (see Appendix I). These stretches allowed the participant to replicate the motions of the agility test (Turki et al., 2019). It was found that performing dynamic warm-up stretching improved agility times immediately after the warm-up was completed (Turki et al., 2019). Similar to the vertical jump session, the same Latin square method of randomization was used to determine the order of bracing conditions for the participant (see Figure 9). Once the warm-up was completed, the participant was provided with a demonstration and specific instructions for the test. There was an emphasis placed on the points of the test where the participant had to change directions and touch the cones.

After the demonstration, the participant was allowed two practice trials where they could attempt the course at a sub-maximal intensity. The practice trials allowed the participant to become familiar with the course as well as allowed the student researcher to ensure the timing gates were operating correctly. After the practice trials, the participant was allowed 2 min of rest to ensure they were adequately recovered. In this time, the order in which the bracing conditions would be completed were identified. For each bracing condition, the participant completed three trials of the agility test (James et al., 2007). To mitigate the effects of fatigue, designated rest periods were implemented between trials. Billaut and Basset (2007) suggested during maximal sprints that recovery periods of 30 sec or less did not allow the muscles to adequately recover. As a result, between each trial, the participant was provided with 1 min to recover. Furthermore, Monks and colleagues (2017) reported that in order to restore optimal muscular capacity following a series of sprints, an athlete requires at least 180 sec of recovery time. Therefore, once the participant completed five trials in one condition, they were allowed 3 min rest where they changed to the next bracing condition and recovered from the previous trials. Once the participant completed three trials in each of the remaining bracing conditions, the testing session was completed. The participant was then asked to perform the same low-intensity cycling cool down which they did for the vertical jump testing. After the cool-down the participant was free to leave and their responsibilities were completed.

Data Processing

Vertical Jump Test

Vertical jump height was measured by subtracting the height of the highest Vertec© vein the participant touched during their jump from the standing reach height. From this, the mean and standard deviation for each bracing condition was determined across the five vertical jump trials.

Kinematic Video Data

The GoPro Hero 9© camera recorded video for the vertical jump trials at a frame rate of 120 (Hertz) Hz and shutter speed of 1/960. From this video, peak joint angles were measured for ankle plantarflexion and dorsiflexion, knee flexion, and hip flexion during the take-off phase of the Vertical Jump Test using Kinovea®. For each bracing condition, the mean and standard deviation of the five trials were then calculated for all joint angles. The value which was generated from the average of the five trials was expressed as the joint angles (i.e., Dorsiflex °, Knee °, etc.).

Force Platform Data

Peak vGRF values during the take-off phase of the Vertical Jump Test were measured utilizing the AMTI© force platform and recorded using LabChart®. The raw data was sampled at a frequency of 1000 Hz (Payton & Bartlett, 2008). A low-pass digital filter (10 Hz) was applied to the vGRF data to reduce the impact of high frequency noise on the data set. Kinetic dependent variables for the vertical jump test included peak vGRF and impulse. For each bracing condition, the mean and standard deviation of the peak vGRF and values were determined for the five trials. In addition, net vertical impulse was calculated during the take-off phase of the vertical jump test. Utilizing the data from LabChart®, force values were inputted into Microsoft© Excel and using the equation #1 in Appendix J, vertical impulse was determined for each data point. Furthermore, equation #2 in Appendix J was used to calculate net vertical impulse for each individual trial. Impulse was measured during both the eccentric and concentric phases of the vertical jump until the participants left the force platform which produced a reading of 0 N. From this, mean and standard deviation values were determined across the five jump trials for each bracing condition.

Agility T-Test

The only variable being measured during the agility T-test was time (sec) to complete the test. Cronin and Templeton (2008) suggested that a height less than 80 cm in height would result in the upper legs triggering the signal which resulted in faster agility times. As a result, for this study, the Brower© timing gates were set up at a height of 1 m to ensure that the participant's hip is triggering the infrared signal. In addition, the timing gates were set up 2 m wide to allow for the participant to safely pass through the gates. For each bracing condition, the mean and standard deviation of the agility times was determined across the three trials of the agility T-test.

Table 3

Dependent Variables and Definitions

Variable (Notation)	Definition (Units)
Vertical Ground Reaction Force (vGRF)	In line with Newton's Third Law of Motion, GRF is the amount of force exerted from the ground to the body applying the force. Vertical GRF refers to the force being applied along the vertical axis (y). Measured in Newtons (N).
Impulse (I)	Impulse refers to the amount of force being produced over a period of time. It is calculated by multiplying the total force by the time which this force is being applied for. Measured in Newton second (N·s) or Joules (J).
Vertical Jump Height	Vertical jump height was the height that the participant jumps into the air. This was established by calculating the difference between the participant's standing reach and the height of vein which they touched.
Ankle plantarflexion during take-off phase (Plantarflex °)	The peak angle of ankle plantarflexion during the take-off of the vertical jump (°). The value was determined by the angle between the knee and toe markers. The heel marker was used as the axis of rotation.
Ankle dorsiflexion during preparation phase (Dorsiflex °)	The peak angle of ankle dorsiflexion during the loading phase of the vertical jump (°). The value was determined by the angle between the knee and toe markers. The heel marker was used as the axis of rotation.

Knee flexion during preparation (Knee °)	The peak angle that the knee flexes during jump loading phase (°). Knee flexion was quantified by measuring the angle between the hip and ankle marker. The knee marker was used as the axis of rotation.
Hip flexion during preparation (Hip °)	The peak angle that the hip flexes during jump loading phase (°). Hip flexion was quantified by measuring the angle between the vertical reference and knee marker. The hip marker represented the axis of rotation.
Time	The length of time to complete the agility test course (sec).

Independent Variables

This study altered the conditions of the experimental trials by implementing two independent variables including the condition of ankle bracing (UB, UNI, and BI) and the type of ankle brace (T2 and ASO). In addition to these two braces, the participants completed UB trials which acted as a control condition. This approach allowed the results to be compared from each of the braced trials to the baseline measures collected in the control trials. The second independent variable of bracing condition manipulated whether the participant wore ankle braces unilaterally or bilaterally.

Statistical Analysis

The statistical analyses for this study was completed using version 26 of the SPSS® software. Descriptive statistics were calculated for the data collected from the independent and dependent variables. The following two-way repeated measures analysis of variance (ANOVAs) were conducted to examine possible interactions between the two independent variables on the dependent variables in order to answer the research questions and corresponding hypotheses:

1. A 2 (type of braces) x 3 (bracing conditions) repeated measures ANOVA was conducted to examine the interaction effect between these factors on vertical jump height. More specifically, this analysis evaluated the impact that the ASO and T2 braces had on the UB, UNI, and BI bracing conditions for measures of vertical jump height. Simple main effect were evaluated to help explain significant interaction effects using one-way ANOVAs and paired samples t-tests. If no significant interaction effects were present, main effects for each factor were analyzed. Bonferroni post hoc analysis was implemented for pair mean comparisons.
2. A 2 (type of braces) x 3 (bracing conditions) repeated measures factorial ANOVA was conducted to examine the interaction effect between these factors on lower extremity joint angles during the vertical jump. More specifically, this analysis evaluated the impact that ASO, and T2 ankle braces had on the UB, UNI, and BI bracing conditions for measures of ankle plantarflexion, ankle dorsiflexion, knee flexion, and hip flexion angles. Simple main effects were conducted to help explain a significant interaction effect using one-way ANOVAs and paired samples t-tests. If no significant interactions were present, main effects for each factor were analyzed. Bonferroni post hoc analysis was implemented for pair mean comparisons.
3. A 2 (type of braces) x 3 (brace conditions) repeated measures factorial ANOVA was conducted to examine the interaction effect between these two factors have on vGRFs and impulse. More specifically, this analysis evaluated the impact that ASO and T2 ankle braces had on the UB, UNI, and BI bracing conditions for measures of vGRFs

and impulse. Simple main effects were conducted to help explain the significant interaction effects using one-way ANOVAs and paired samples t-tests. If no significant interactions were present, main effects for each factor were analyzed. Bonferroni post hoc analysis was implemented for pair mean comparisons.

4. A 2 (type of braces) x 3 (brace conditions) repeated measures factorial ANOVA was conducted to examine the interaction effect between these two factors have on agility time. More specifically, this analysis evaluated the impact that ASO, and T2 ankle braces had on the UB, UNI, and BI bracing conditions for measures of agility time. Simple main effects were conducted to help explain the significant interaction effects using one-way ANOVAs and paired samples t-tests. If no significant interactions were present, main effects for each factor were analyzed. Bonferroni post hoc analysis was implemented for pair mean comparisons.

Sphericity of the data was assessed using Mauchly's Test of Sphericity. If a data set violated the assumption of sphericity, the Greenhouse-Geisser correction was utilized.

Missing Data

Due to equipment malfunction (i.e., force platform failure, video file corruption), individual trials were lost from no more than three participants. In the event that a data file was lost or corrupted, the average value for the variables was taken from the four other trials in that bracing condition. No data was lost during the completion and analysis of the agility T-test, however, one participant was unable to complete their agility testing session. As a result, the agility test data was analyzed for 21 participants (n =21), in comparison to the vertical jump test's 22 participants (n = 22).

Chapter Three: Results

Vertical Jump Test

Vertical Jump Height

Descriptive statistics. The mean (+/- standard deviation) vertical jump height from the vertical jump test for each brace type and bracing condition are shown in Table 4.

Table 4

Mean Vertical Jump Heights (+/- SD) from the Vertical Jump Test

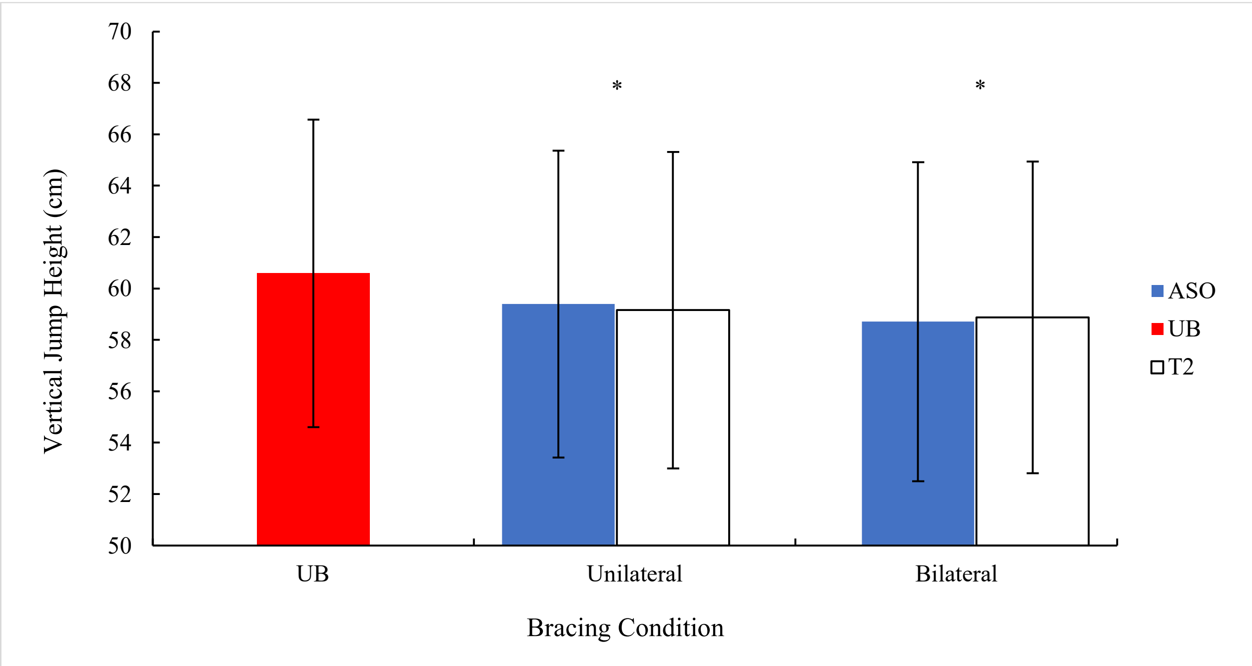
Brace Type	Bracing Condition		
	Unilateral	Bilateral	Unbraced
ASO brace	59.4 (+/- 11.9)	58.7 (+/- 12.4)	---
T2 brace	59.2 (+/- 12.3)	58.9 (+/- 12.1)	---
Unbraced	---	---	60.6 (+/- 11.9)

Note. All values in this table are expressed in cm.

Interaction effect. The repeated measures ANOVA revealed that there was no statistically significant interaction effect between the brace type and the bracing condition for vertical jump height, $F(2,20) = 0.268$, $p > .05$. Figure 12 illustrates this result between brace type and condition, as well as the main effects for brace type and condition.

Figure 12

Means of Vertical Jump Heights During the Vertical Jump Test



Note. Error bars represent the standard deviations around the mean for the respective brace type and bracing conditions. * indicates a significantly lower jump height in the UNI and BI bracing conditions in comparison to the UB condition (p<0.05).

Main effects. The repeated measures ANOVA for vertical jump height revealed a statistically significant main effect with a very large effect size for bracing condition, $F(2,20) = 17.167$, $p < .05$, $\eta^2 = .632$. Post hoc analysis revealed that vertical jump height in both UNI (59.3cm +/- 2.6) and BI (58.8cm +/- 2.6) conditions were significantly decreased compared to the vertical jump heights in the UB condition (60.6cm +/- 2.6). There was no statistically significant difference, however, between the vertical jump heights in the UNI and BI conditions ($p > .05$). No significant difference was found when analyzing the type of brace factor, $F(1,21) = 0.014$, $p > .05$.

Dorsiflexion Angle

Descriptive statistics. The mean (+/- standard deviation) ankle dorsiflexion angle during the loading phase of the from the vertical jump test are shown for each brace type and bracing condition in Table 5.

Table 5

Mean Peak Dorsiflexion Angle (+/- SD) During the Loading Phase of the Vertical Jump

Brace Type	Bracing Condition		
	Unilateral	Bilateral	Unbraced
ASO brace	28.9 (+/- 4.5)	28.8 (+/- 4.5)	---
T2 brace	29.9 (+/- 4.2)	30.2 (+/- 4.6)	---
Unbraced	---	---	29.9 (+/- 4.5)

Note. All values in this table are expressed in degrees (°).

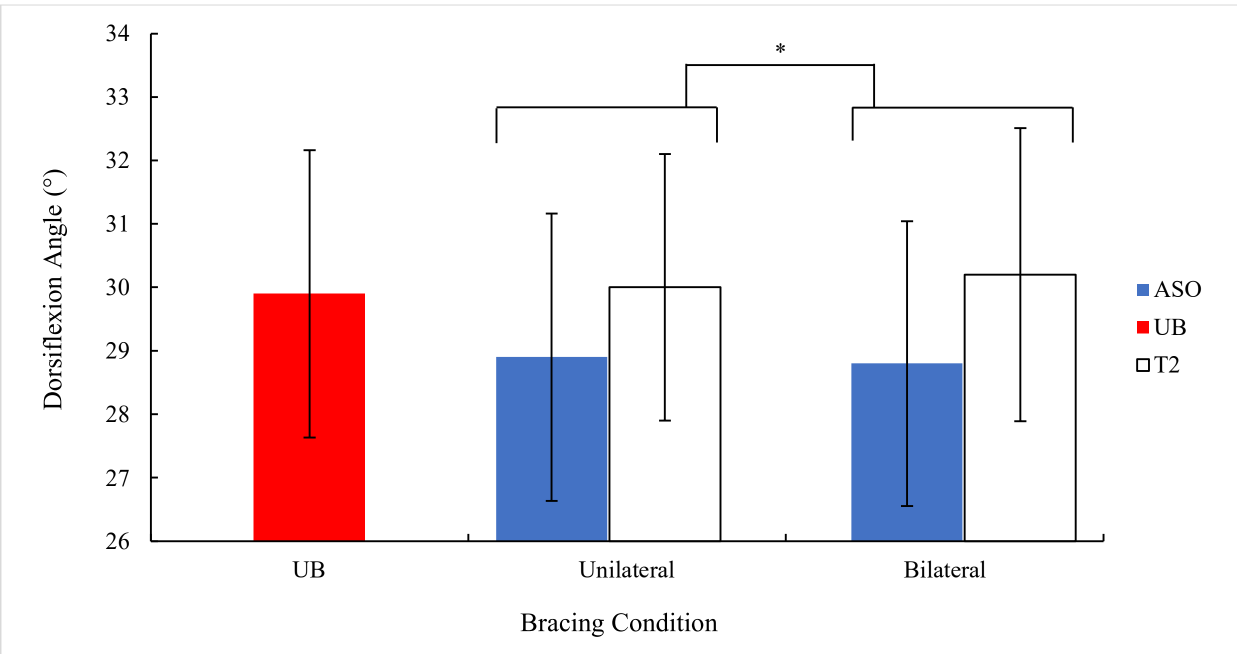
Interaction effect. The repeated measures ANOVA revealed a statistically significant interaction effect between the brace type and the bracing condition for peak dorsiflexion angle with a very large effect size during the loading phase, $F(2,20) = 8.166$, $p < .05$, $\eta^2 = .450$. The interaction effect between brace type and bracing condition can be observed in Figure 13.

As a result of the statistically significant interaction effect, two paired samples t-tests were performed to investigate where the interaction effect was derived from. The first paired samples t-test revealed a statistically significant difference in peak dorsiflexion angle with a very large effect size between the ASO-UNI (28.8° +/- 4.53) and T2-UNI (29.9° +/- 4.20) conditions, $t(21) = -3.442$, $p < .05$, $d = 1.46$, $CI = [-1.719, -0.424]$. Similarly, the second paired samples t-test revealed a statistically significant difference in peak dorsiflexion angle with a very large effect size between the ASO-BI (28.8° +/- 4.49) and T2-BI (30.2° +/- 4.62) conditions, $t(21) = -3.429$, $p < .05$, $d = 1.86$, $CI = [-1.196, -0.252]$.

Furthermore, one-way ANOVAs were performed to examine the peak dorsiflexion angle in each bracing condition for both ankle braces. The first one way ANOVA revealed no statistically significant differences in peak dorsiflexion angle in the UB (29.9° +/- 4.5), UNI (28.9° +/- 4.3), and BI (28.8° +/- 4.9) bracing conditions while wearing the ASO ankle brace, $F(2,63) = 0.386$, $p > .05$. Similarly, there were no statistically significant differences when evaluating peak dorsiflexion angle in the UB (29.9° +/- 4.5), UNI (29.9° +/- 4.2), and BI (30.2 ° +/- 4.6) bracing conditions while wearing the T2 ankle brace, $F(2,63) = 0.028$, $p > .05$.

Figure 13

Means of Peak Dorsiflexion Angles During the Loading Phase of the Vertical Jump



Note. Error bars represent the standard deviations around the mean of the respective brace type and bracing condition. * represents a significant interaction between the brace type and bracing condition for ankle dorsiflexion ($p < .05$).

Plantarflexion Angle

Descriptive statistics. The mean (+/- standard deviation) plantarflexion angle during the take-off phase of the vertical jump for each brace type and bracing condition can be found in Table 6.

Table 6

Mean Peak Plantarflexion Angles (+/-SD) During the Take-Off Phase of the Vertical Jump

Brace Type	Bracing Condition		
	Unilateral	Bilateral	Unbraced
ASO brace	55.7 (+/- 5.6)	54.9 (+/- 5.7)	---
T2 brace	56.7 (+/- 5.8)	57.2 (+/- 5.7)	---
Unbraced	---	---	61.3 (+/- 5.2)

Note. All values in this table are expressed as degrees (°).

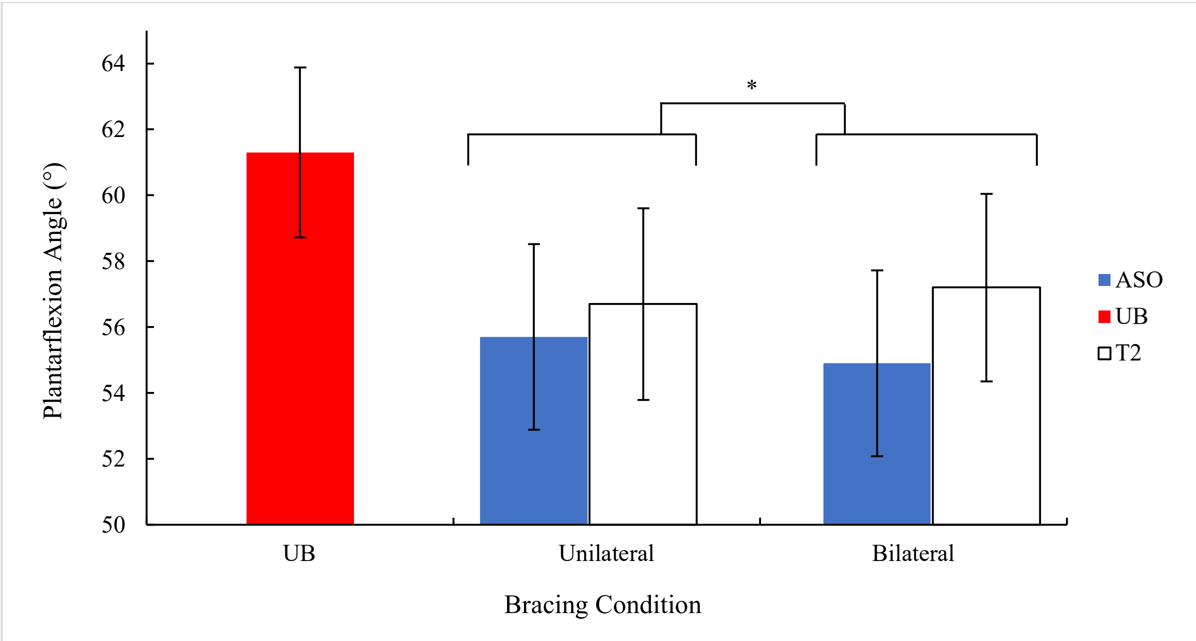
Interaction effect. The repeated measures ANOVA revealed a statistically significant interaction effect with a very large effect size between the brace type and the bracing condition for peak plantarflexion angle during the take-off phase of the vertical jump, $F(2,20) = 7.538$, $p < .05$, $\eta^2 = .430$. This interaction between bracing condition and brace type can be viewed in Figure 14.

As a result of the statistically significant interaction effect, two paired samples t-tests were performed to investigate where the interaction effect was derived from. The first paired samples t-test revealed a statistically significant difference with a very large effect size in peak plantarflexion angle between the ASO-UNI (55.7° +/- 5.63) and T2-UNI (56.7° +/- 4.20) conditions, $t(21) = -2.545$, $p < .05$, $d = 1.78$, $CI = [-1.753, -0.176]$. Similarly, a second paired samples t-test revealed a statistically significant difference with a very large effect size in peak dorsiflexion angle between the ASO-BI (54.9° +/- 5.65) and T2-BI (57.2° +/- 5.69) conditions, $t(21) = -3.954$, $p < .05$, $d = 2.61$, $CI = [-3.361, -1.044]$.

Furthermore, one-way ANOVAs were performed to examine the peak plantarflexion angle in each bracing condition for both ankle braces. The first one-way ANOVA revealed a statistically significant difference with a large effect size in peak plantarflexion angle between the UB (61.3° +/- 5.16), UNI (55.7° +/- 5.63), and BI (54.9° +/- 5.65) bracing conditions while wearing the ASO ankle brace, $F(2,63) = 8.858$, $p < .05$, $\eta^2 = .219$. Bonferroni post hoc analysis revealed the UB condition was statistically significantly different than both the UNI and BI conditions ($p < .05$, $p < .05$), respectively. Furthermore, the UNI bracing condition was not statistically significantly different from the BI condition ($p > .05$). Similarly, the second one-way ANOVA revealed statistically significant differences with a medium effect size between the UB (61.3° +/- 5.16), UNI (56.7° +/- 5.81), and BI (57.2° +/- 5.69) bracing conditions while wearing the T2 ankle brace, $F(2,63) = 4.658$, $p < .05$, $\eta^2 = .129$. Additionally, the UNI bracing condition was also not significantly different from the BI bracing condition ($p > .05$).

Figure 14

Means of Peak Plantarflexion Angles During the Take-Off of the Vertical Jump



Note. Error bars represent the standard deviations around the mean of the respective brace type and bracing condition. * represents a significant interaction between the brace type and bracing condition for ankle plantarflexion ($p<.05$).

Knee Flexion Angle

Descriptive statistics. The mean (+/- standard deviation) knee flexion angle during the loading phase of the vertical jump for each brace type and condition of ankle bracing can be observed in Table 7.

Table 7

Mean Peak Knee Flexion Angles (+/- SD) During the Loading Phase of the Vertical Jump

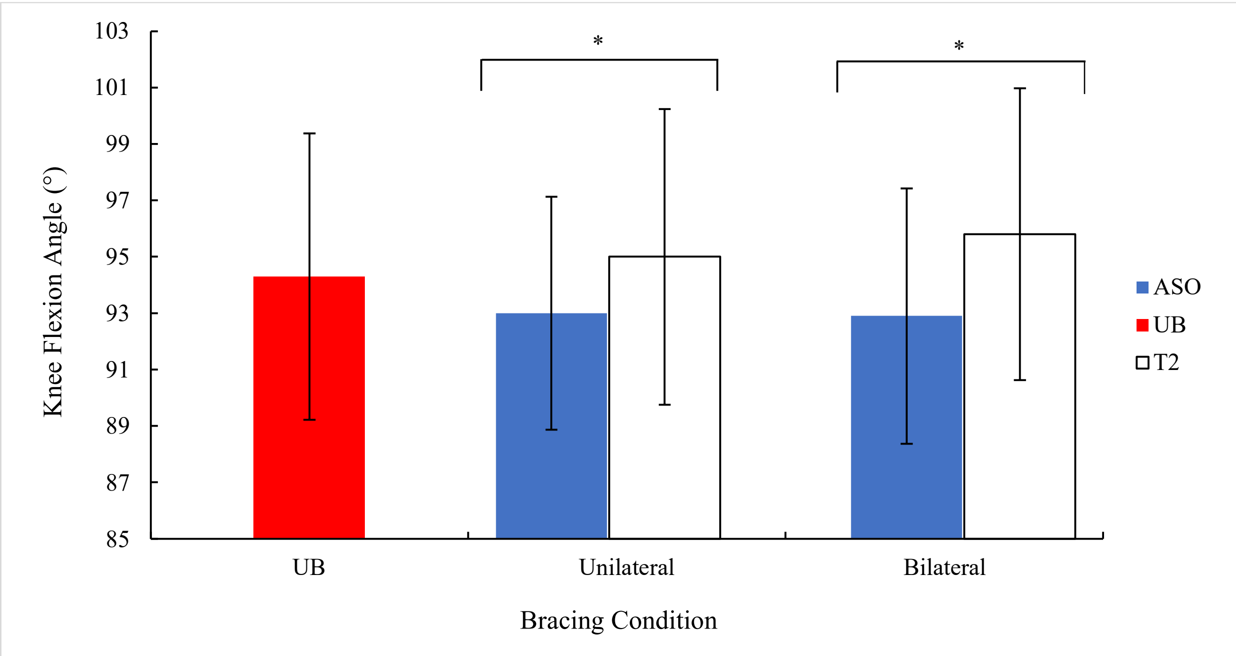
Brace Type	Bracing Condition		
	Unilateral	Bilateral	Unbraced
ASO brace	93.0 (+/- 8.3)	92.9 (+/-9.1)	---
T2 brace	95.0 (+/- 10.5)	95.8 (+/- 10.4)	---
Unbraced	---	---	94.3 (+/-10.2)

Note. All values in this table are expressed as degrees (°).

Interaction effect. The repeated measures ANOVA revealed that there was no statistically significant interaction effect between the brace type and the bracing condition for peak knee flexion angle, $F(2,20) = 3.308$, $p > .05$. Figure 15 illustrates this result between brace type and condition, as well as the main effects for brace type and brace condition.

Figure 15

Means of Peak Knee Flexion Angles During the Loading Phase of the Vertical Jump



Note. Error bars represent the standard deviation around the means for the respective brace type and bracing conditions. * indicates a significant lower knee flexion angle in the ASO compared to the T2 brace ($p<.05$).

Main effects. The repeated measures ANOVA for knee flexion revealed a statistically significant main effect with a large effect size for brace type, $F(1,21) = 6.903$, $p <.05$, $\eta^2 = .247$. This ANOVA revealed that the ASO brace resulted in a statistically significant decrease in peak knee flexion angle in comparison to the T2 brace ($p <.05$). No statistically significant difference was found when analyzing the bracing condition factor, $F(2,20) = 0.163$, $p >.05$.

Hip Flexion Angle

Descriptive statistics. The mean (+/- standard deviation) hip flexion angle during the loading phase of the vertical jump for each brace type and bracing condition can be observed in Table 8.

Table 8

Mean of Peak Hip Flexion Angles (+/- SD) During the Loading Phase of the Vertical Jump

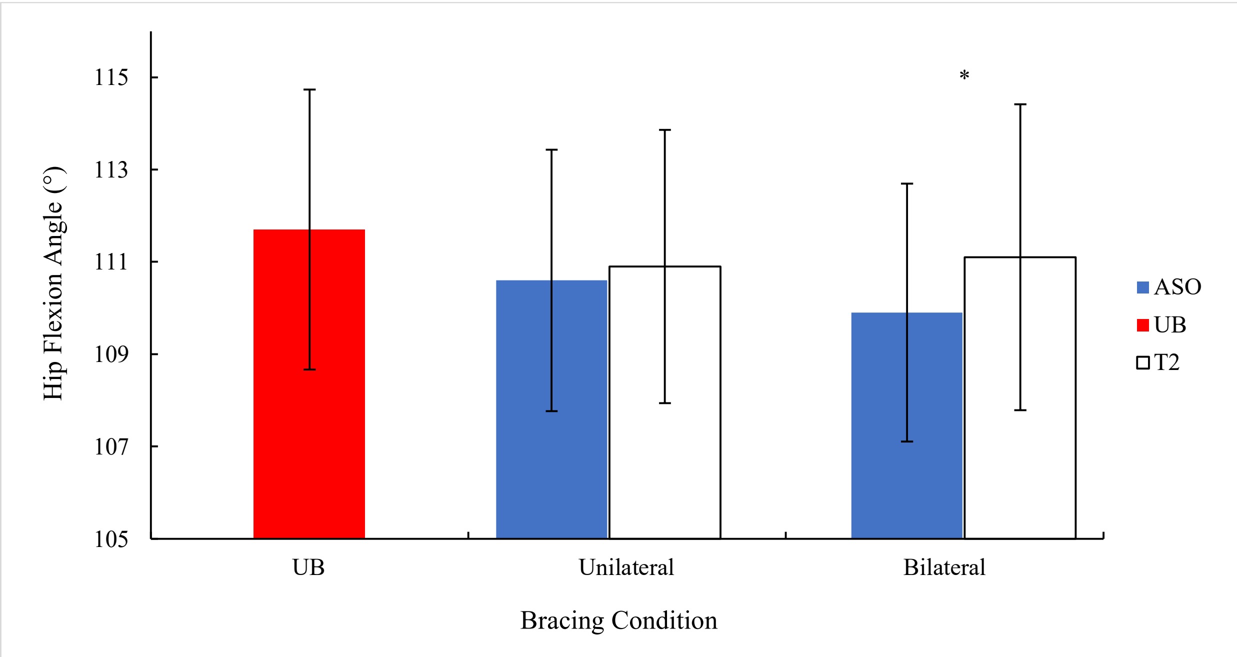
Brace Type	Bracing Condition		
	Unilateral	Bilateral	Unbraced
ASO brace	110.6 (+/- 5.7)	109.9 (+/- 5.6)	---
T2 brace	110.9 (+/- 5.9)	111.1 (+/- 6.6)	---
Unbraced	---	---	111.7 (+/- 6.1)

Note. All values in this table are expressed in degrees (°).

Interaction effect. The repeated measures ANOVA revealed that there was no statistically significant interaction effect between the brace type and the bracing condition for peak hip flexion angle, $F(2,20) = 1.235$, $p > .05$. Figure 16 illustrates this result between brace type and condition, as well as the main effects for brace type and brace condition.

Figure 16

Means of Peak Hip Flexion Angles During the Loading Phase of the Vertical Jump



Note. Error bars represent the standard deviations around the mean for the respective brace type and bracing conditions. * represents a significantly lower hip flexion angle in the BI bracing condition in comparison to the UB condition (p<.05).

Main effects. The repeated measures ANOVA for peak hip flexion angle revealed a statistically significant main effect with a large effect size for the bracing condition, $F(2,20)$ = 4.604, p <.05, η^2 = .315. Post hoc analysis revealed that the peak hip flexion angle in the BI condition (110.5° +/- 1.3) was significantly decreased compared to the peak hip flexion angle in the UB condition (111.7° +/- 1.3). There was no statistically significant difference, however, between the peak hip flexion angle in the UB and UNI conditions (p >.05), as well as the UNI and BI conditions (p >.05). No statistically significant difference was found when analyzing the type of brace factor, $F(1,21)$ = 1.516, p >.05.

Vertical Ground Reaction Force (vGRF)

Descriptive statistics. The mean (+/- standard deviation) vGRF during the take-off phase of the vertical jump for each brace type and bracing condition can be observed in Table 9.

Table 9

Mean of Peak vGRFs (+/- SD) During the Take-Off Phase of the Vertical Jump

Brace Type	Bracing Condition		
	Unilateral	Bilateral	Unbraced
ASO brace	1735.2 (+/- 325.9)	1726.4 (+/- 317.6)	---
T2 brace	1735.1 (+/- 350.5)	1736.1 (+/- 349.3)	---
Unbraced	---	---	1744.2 (+/- 348.6)

Note. All values in this table are expressed as Newtons (N).

Interaction effect. The repeated measures ANOVA revealed that there was no statistically significant interaction effect between the brace type and the bracing condition for peak vGRFs, $F(2,20) = 0.144$, $p > .05$.

Main effects. The repeated measures ANOVA revealed no statistically significant main effect for the type of braces factor, $F(1,21) = 0.098$, $p > .05$. Similarly, the ANOVA revealed no statistically significant main effect for the bracing condition factor, $F(2,20) = 0.774$, $p > .05$.

Net Vertical Impulse

Descriptive statistics. The mean (+/- standard deviation) net vertical impulse measured throughout the take-off phase of the vertical jump for each brace type and bracing condition can be observed in Table 10.

Table 10

Means of Net Vertical Impulse (+/- SD) During the Take-Off Phase of the Vertical Jump.

Brace Type	Bracing Condition		
	Unilateral	Bilateral	Unbraced
ASO brace	218.9 (+/- 48.6)	221.9 (+/- 49.9)	---
T2 brace	215.1 (+/- 53.0)	219.5 (+/- 49.9)	---
Unbraced	---	---	221.2 (+/- 48.5)

Note. All values in this table are expressed as Newton-seconds (N·s).

Interaction effect. The repeated measures ANOVA revealed that there was no statistically significant interaction effect between the brace type and the bracing condition for net vertical impulse, $F(2,20) = 0.255$, $p > .05$.

Main effects. The repeated measures ANOVA revealed no statistically significant main effect for the type of braces factor, $F(1,21) = 0.513$, $p > .05$. Similarly, the ANOVA revealed no statistically significant main effect for the bracing condition factor, $F(2,20) = 2.273$, $p > .05$.

Agility T-Test

Agility Time

Descriptive statistics. The mean (+/- standard deviation) agility time for the agility T-test for each brace type and bracing condition can be observed in Table 11.

Table 11

Means of Agility Time (+/- SD) for the Agility T-Test

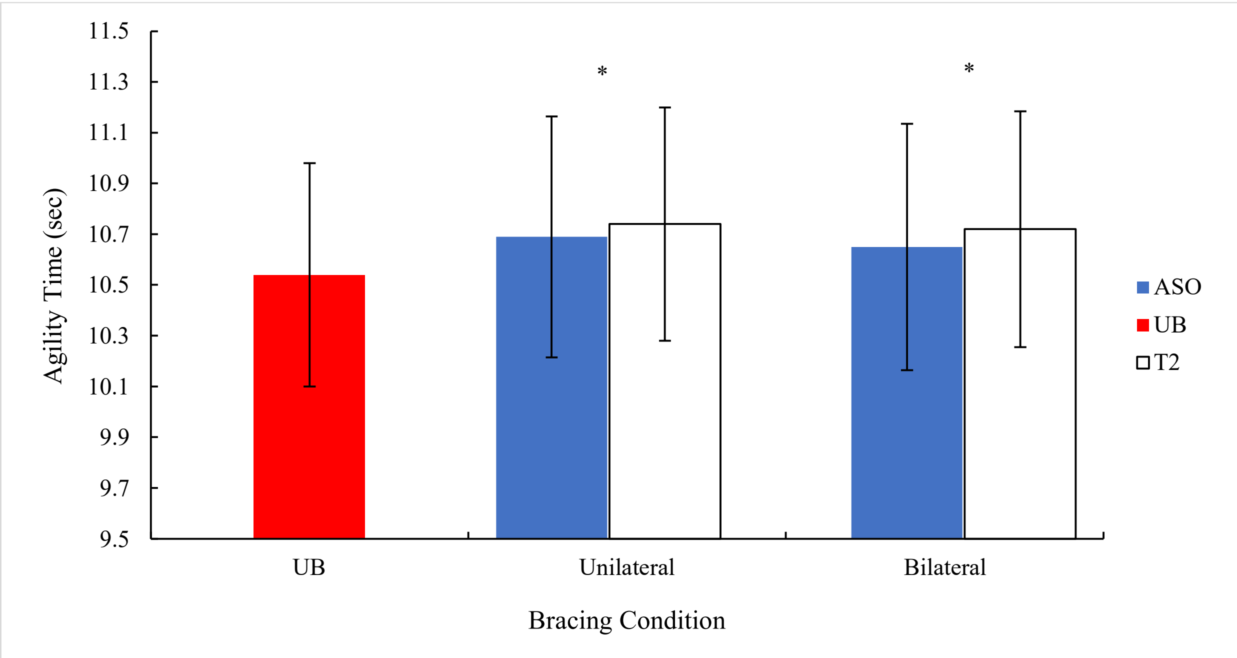
Brace Type	Bracing Condition		
	Unilateral	Bilateral	Unbraced
ASO brace	10.69 (+/- 0.95)	10.65 (+/- 0.97)	---
T2 brace	10.73 (+/- 0.92)	10.72 (+/- 0.93)	---
Unbraced	---	---	10.54 (+/- 0.88)

Note. All values in this table are expressed as time in seconds (sec).

Interaction effect. The repeated measures ANOVA revealed that there was no statistically significant interaction effect between the brace type and the bracing condition for agility time, $F(2,20) = 0.754$, $p > .05$. Figure 17 illustrates this result, as well as the main effects the brace type and bracing condition factors.

Figure 17.

Means of Agility Time for the Agility T-Test.



Note. Error bars represent the standard deviations around the mean for the respective brace type and bracing conditions. * indicates a significantly slower agility time for the UNI and BI bracing conditions in comparison to the UB condition ($p<0.05$).

Main effects. The repeated measures ANOVA for agility test time revealed a statistically significant main effect with a very large effect size for the bracing condition, $F(2,19) = 6.602$, $p <.05$, $\eta^2 = .410$. Post hoc analysis revealed that the agility time in both the UNI (10.72 sec +/- 0.20) and the BI (10.68 sec +/- 0.21) conditions were significantly slower than the agility time in the UB condition (10.54 sec +/- 0.19). There was no statistically significant difference, however, between the agility time in the UNI and BI conditions ($p >.05$). No statistically significant difference was found when analyzing the type of brace factor, $F(1,20) = 1.218$, $p >.05$.

Chapter Four: Discussion

Vertical Jump Performance

Vertical Jump Height

The results of this study indicated that there was no statistically significant interaction between brace type and bracing condition when evaluating vertical jump performance. Nevertheless, there were statistically significant differences found when evaluating the main effects of bracing conditions. More specifically, both the UNI (59.3 cm) and BI (58.8 cm) bracing conditions produced significantly decreased vertical jump heights in comparison to the UB (60.6 cm) condition. As a result, hypothesis #1 which suggested that both UNI and BI vertical jump heights would produce significantly decreased vertical jump heights is confirmed. Furthermore, this hypothesis accepts that no differences were found between the ASO and T2 braces. No statistically significant differences were reported when comparing the jump heights in the ASO brace to the T2 brace. This result suggests that regardless of the brace, either ASO or T2, that wearing an ankle brace both unilaterally and bilaterally significantly impacts vertical jump performance. From this it can be stated that vertical jump height may decrease while wearing the ASO and T2 ankle braces compared to no braces, but when comparing the ASO and T2 braces the impact on vertical jump height is minimal.

Smith and colleagues (2016) reported that lace-up ankle braces significantly decreased vertical jump height. Similarly, Henderson et al. (2016) identified that both ASO and T2 ankle braces significantly decreased vertical jump height in comparison to the UB condition. Furthermore, Henderson et al. (2019) reported a similar result of significantly impacted vertical jump heights while wearing both the ASO and T2 braces. The current study found reductions of 1.3 cm and 1.8 cm from the UNI and BI conditions, respectively. Although the result from this current study is statistically significant, the reductions in vertical jump height were lower than those reported from the aforementioned studies with similar results. This difference may be due to different vertical jump methods used for this test in comparison to other studies (Henderson et al., 2016; Henderson et al., 2019; Smith et al., 2016). In some studies, researchers utilized a squat jump which incorporated a momentary pause in between the loading and take-off phases, and some utilized the countermovement jump which was utilized in the current study. Being so, since all of the aforementioned studies reported similar significant results, the differences in the type of vertical jump may not influence the overall outcomes. In direct contrast of the current findings, You et al. (2020) reported no significant impact on vertical jump height while wearing both the ASO and T2 braces. A potential source for this difference is the type of vertical jump which was selected; the three-step spike approach (You et al., 2020). By including an approach to the jump, there are external factors which are brought into the jump such as momentum and existing muscle activation which may increase vertical jump performance (Samozino et al., 2010). In comparison, the countermovement and squat jumps are simple movements in the sagittal plane and do not allow the participant to utilize momentum. In some instances, this methodological difference may have an effect on the different results seen between these studies. In addition, Morikawa et al. (2022) also reported no significant differences in vertical jump heights while wearing different ankle braces, however, their study included regular healthy participants rather than athletes who competed in jumping-related sports. Furthermore, the differences in the results could be due to the ankle braces which differed in design to those used in the current study. In their study, the ankle braces which were used had a different design than the ones in this current study. Specifically, the semirigid brace did not have the stirrup and hinge design similar to the T2 brace, and their softshell brace did not have the same straps for support as the ASO brace (Morikawa et al., 2022). Moreover, the jumping trials in their study were completed without shoes on (Morikawa et al., 2022). The difference in the significance of these results may be attributed to any combination of these methodological differences. The results of this current study suggest that wearing the ASO and T2 ankle braces, does significantly decrease vertical jump height in comparison to wearing no braces.

Vertical Jump Kinematics

Ankle Dorsiflexion Angle

The results from this study found a statistically significant interaction effect between the brace type and bracing conditions when evaluating the peak ankle dorsiflexion angles during the loading phase of the vertical jump. This interaction effect can be explained by comparing the different brace types for each bracing condition. Specifically, peak ankle dorsiflexion in the ASO-UNI (28.8°) condition was decreased compared to the T2-UNI (29.9°) condition. Furthermore, peak dorsiflexion in the ASO-BI (28.8°) condition was decreased compared to the T2-BI (30.2°) condition. This result confirms hypothesis #2, which suggested that ankle dorsiflexion angles would be impacted while wearing the ASO and T2 braces. Furthermore, this result rejects the hypothesis which assumed that there would be a significant difference between the UB, UNI, and BI bracing conditions for the respective ankle brace.

The reduced peak ankle dorsiflexion seen in the ASO compared to the T2 brace may be due to their construction. The ASO brace encapsulates the entire ankle and lower shank with Velcro© straps which wrap tightly around all sides, whereas the T2 brace has a hinge joint inferior to Velcro straps which promotes movement in the sagittal plane (West et al., 2014). In addition, there were no statistically significant differences reported between the UB, UNI, and BI bracing conditions for the ASO or T2 braces. This suggests that wearing the ASO brace in both the UNI and BI conditions results in significantly decreased peak ankle dorsiflexion angle as compared to wearing the T2 brace. Furthermore, there were no statistically significant differences in peak ankle dorsiflexion when comparing the UNI and BI conditions to the UB conditions in both the ASO and T2 braces, respectively.

Morikawa et al. (2022) reported similar finding while evaluating dorsiflexion angles in multiple ankle braces. In their study, a significant reduction in peak ankle dorsiflexion was reported during the CMJ while wearing a softshell and semirigid ankle brace (Morikawa et al., 2022). Although the ankle braces are not exactly the same design as the braces used in the current study, the differences in dorsiflexion angles are similar. Conversely, these results are in direct conflict to those reported by Smith and colleagues (2016). In their study, no statistically significant reduction in peak dorsiflexion angle was noted. The difference in significant results may be due to the marker sets which were utilized. Morikawa et al. (2022) used the same markers as this current study, whereas, Smith et al. (2016) placed the toe marker on the second metatarsal rather than the fifth. These methodological differences may have had an impact on the significance of the results of the respective studies.

Since the statistically significant difference in peak ankle dorsiflexion angle is between the ASO and T2 braces and not the UB condition, it is not believed that this result directly implies the reduction in vertical jump performance. This result is consistent with those of Smith et al. (2016) where there were no statistically significant differences in peak dorsiflexion between the braced and UB condition. Conversely, it is suggested that while wearing ASO and T2 braces that a greater decrease in peak ankle dorsiflexion may be experienced while wearing the ASO brace. Similarly, Zhang et al. (2012) reported that wearing lace-up ankle braces reduced ankle dorsiflexion angles more than rigid stirrup braces. Zhang et al. (2012) also found that when ankle dorsiflexion is decreased, the ankle plantarflexion which follows is also decreased. As a result, the decreased dorsiflexion angles resulting from wearing ankle braces may have impacted the following plantarflexion angles, therefore, impacting the performance of the vertical jump. Furthermore, the lack of research investigating peak ankle dorsiflexion angle during the loading phase suggests further studies need to consider the loading and take-off phases in addition to the landing phase.

Ankle Plantarflexion Angle

A statistically significant interaction effect was seen between brace type and bracing condition when evaluating peak ankle plantarflexion angle at take-off of the vertical jump. In this interaction effect, both brace type and bracing revealed statistical significance across the different trials. More specifically, peak ankle plantarflexion angles were decreased while wearing the ASO brace in both UNI (55.7°) and BI (54.9°) conditions, in comparison to the UNI (56.7°) and BI (57.2°) conditions while wearing the T2 brace. This result accepts hypothesis #2 which suggested that there would be a significant difference in ankle plantarflexion angles when comparing the ASO and T2 braces at take-off of the vertical jump.

This result aligns with those of You et al. (2020), where a significant difference was reported in peak ankle plantarflexion angles while wearing the ASO (58.3°) and T2 (61.4°) braces. Similar to peak ankle dorsiflexion, this difference between ankle braces may have been due to the construction of the ankle braces. In addition, Morikawa et al. (2022) reported a significant difference in peak plantarflexion angle at take-off while wearing softshell and semirigid braces. Similar to the results of this study, the researchers reported a greater decrease in peak ankle plantarflexion in the softshell brace when compared to the rigid brace (3.6°; Morikawa et al., 2022). As reported by West et al. (2014), sagittal plane movement is reduced further by the ASO brace when compared to the T2 brace. Overall, it has been suggested that while wearing a lace-up or softshell brace, peak ankle plantarflexion is significantly decreased when compared to wearing a rigid ankle brace. This decrease in ankle plantarflexion, and by extension vertical jump height, may be due to the impact that the ankle braces have on the stretch shortening cycle (SSC) of the muscles. In a movement like the vertical jump, the SSC plays a vital part in propelling the participant into the air (Nicol et al., 2006). It has been suggested that by reducing the ROM in any joint, the SSC may be interrupted and maximal output may not be achieved (Kallerud & Gleeson, 2013). From this, it is expected that there would be a decrease in vertical jump height when comparing the ASO and T2 braces as a result of the differences in ankle plantarflexion angles.

In addition, this result also revealed a statistically significant difference in peak ankle plantarflexion angles in the UB, UNI, and BI bracing conditions for both the ASO and T2 braces. Specifically, there was a significant decrease in peak ankle plantarflexion angle in the UNI (56.2°) and BI (56.1°) conditions when compared to the UB (61.3°) condition. This result aligns with hypothesis #2 which suggested that the UNI and BI conditions would be significantly different than the UB condition. When comparing this result to the current literature, Alfuth et al. (2014) reported significant reductions of peak ankle plantarflexion while wearing ankle braces in comparison to an UB condition. Similarly, Smith et al. (2016) reported similar significant differences when comparing peak ankle plantarflexion the UB to braced conditions. In their study, the braced condition (32.7°) was significantly decreased compared to the UB condition (37.7°; Smith et al., 2016). Furthermore, Morikawa et al. (2022) reported a significant decrease in peak ankle plantarflexion angles while wearing softshell (163.9°) and semirigid (167.3°) braces in comparison to the UB condition (170.9°). The values of these studies differed from the current study as a result of a variation of vertical jump methodology. In comparison, the study performed by You et al. (2020) had similar vertical jump test procedures and reported similar plantarflexion values.

Although these studies support the current findings, this study is the first to compare the impact of both UNI and BI bracing. From this result, it is evident that ankle braces significantly impact peak ankle plantarflexion angles, however, there was no significance between the UNI and BI conditions. As a result, wearing ankle braces does impact peak ankle plantarflexion angle, but wearing them either unilaterally or bilaterally has no significant impact. This result of decreased peak plantarflexion angles may contribute to the decreased vertical jump height seen in the braced conditions in comparison to the UB condition. With decreased peak ankle plantarflexion during take-off, the ROM where force is produced against the ground will be limited which may impact the result of the jump.

Knee Flexion Angle

No statistically significant interaction was found between brace type and bracing condition for peak knee flexion during the loading phase of the vertical jump. Furthermore, there was no significant difference when comparing the UB condition (94.3°) to the UNI (94.0°) and BI (94.4°) conditions for both ASO and T2 braces. This result rejects hypothesis #2 which suggested that knee flexion angles would be significantly lower in the UNI and BI conditions in comparison to the UB condition. This result suggests that knee flexion angles are not significantly impacted by wearing ankle braces either UNI or BI in comparison to the UB condition.

Similar results were reported by both DiStefano et al. (2008), Smith et al. (2016), and West et al. (2014). All of these studies reported no significant differences in knee flexion angles during a vertical jump between UB and ASO or UB and T2 ankle braces. In each of these studies, the researchers reported a significant decrease in vertical jump height, but no significant differences in knee flexion angles. Smith et al. (2016) suggested that the knee flexion angle would increase in response to the decreased ankle ROM, but no increases were found. Smith et al. (2016) reported that the difference in knee flexion angle may have been due to the previous research focusing on the landing phase rather than take-off phase. As a result, it was recommended that further research be conducted focusing on the lower extremity joint angles during the take-off phase (Smith et al., 2016). In each of these studies, however, a different vertical jump methodology was utilized. In one study a drop-jump was used (DiStefano et al., 2008) whereas Smith et al. (2016) used a CMJ, and West and colleagues (2014) utilized a specific basketball rebounding task. Although there are methodological differences between these studies, the non-significant result in each of them suggests that these differences are minimal. As a result, the knee flexion angles were not impacted by wearing ankle braces, and the impact that the knee flexion angles have on vertical jump performance may be minimal.

Nonetheless, there was a statistically significant difference when evaluating the main effect for the type of brace. More specifically, the peak knee flexion angles were significantly decreased while wearing the ASO brace (92.9°) in comparison to the T2 brace (95.4°). With that being said, when evaluating vertical jump there was no significant difference found between the ASO and T2 braces. As a result, it is likely that the differences in peak knee flexion while wearing the two different braces is not directly responsible for the decreases experienced in jump height. This result aligns with hypothesis #2 which suggested that there would be a significant difference in knee flexion angles when comparing the ASO and T2 braces. To date, there has been no literature comparing how the ASO and T2 brace impact peak knee flexion angles during the vertical jump. As a result, further research should be conducted to evaluate the differences in the lower extremity kinematics between the ASO and T2 braces.

Hip Flexion Angle

The results from this study revealed no statistically significant interaction between brace type and bracing condition for peak hip flexion during the loading phase of the vertical jump. Furthermore, there was no significant differences in peak hip flexion angle when evaluating the ASO and T2 braces. Nonetheless, there was a significant difference in peak hip flexion angle when evaluating the bracing condition factor. More specifically, the BI condition (110.5°) was significantly decreased compared to the UB condition (111.7°). No significant differences were noted between the UB and UNI, as well as the UNI and BI conditions. The result from current this study aligns with hypothesis #2 which suggested that peak hip flexion angles would be significantly different in the BI condition when compared to the UB condition, however, it rejects the hypothesis which stated that ASO and T2 braces would result in significantly lower peak hip flexion angles. This result suggests that the type of ankle brace has no impact on peak hip flexion, however, it does suggest that wearing ankle braces on both ankles results in decreased peak hip flexion in comparison to no braces.

Similar results were reported by Smith et al. (2016) where peak hip flexion angles were significantly decreased in the BI condition (94.9°) in comparison to the UB condition (99.6°). In their study, the participants completed trials without wearing shoes which may explain the differences in the reported values (Smith et al., 2016). The majority of research has been concerned with the landing phase of the vertical jump, and such peak hip flexion is a relatively unknown variable as it pertains to its impact on vertical jump performance. With that being said, Lee et al. (1989) reported a positive correlation in vertical jump height and hip flexion in male volleyball players, however, it was the opposite negative result for female volleyball players. From this, there is not enough published research which has investigated the impact that hip flexion angles on vertical jump performance.

Vertical Jump Kinetics

Vertical Ground Reaction Force

No statistically significant interaction effect was seen between brace type and brace condition for peak vGRFs during the vertical jump. Moreover, no significant differences were found when individually analyzing the brace type and brace condition factors. This result rejects hypothesis #3 which suggested that there would be a significant difference between the UNI and BI conditions compared to the UB condition, as well as a difference between the ASO and T2 braces. From this, peak vGRF was not impacted by the ASO or T2 braces, as well as UB, UNI, and BI bracing conditions. These results align with those reported previously (DiStefano et al., 2008; Henderson et al., 2019; Morikawa et al., 2022; West et al., 2014). Similar force values were reported by all studies, and no significant differences were noted between UB and braced conditions in any of these studies. In agreement, the current result suggests that the peak vGRFs were not impacted by each of the bracing conditions, and, therefore, do not have a significant impact on vertical jump performance. Conversely, this current result disputes the findings reported by You et al. (2020). In their study, it was reported that peak vGRFs in both ASO and T2 braces were significantly decreased compared to those produced in the UB condition (You et al., 2020). This result may differ from the current study due to the three-step approach vertical jump test which was utilized. By including an approach to the jump, there are external factors incorporated which are brought into the jump, such as momentum and existing muscle activation which may result in greater differences in peak vGRF between the braced and UB conditions. In addition, the sample size of nine (n=9) was described as a sample which was underpowered and with sufficient sample size another result may have been achieved (You et al., 2020). The result from this study suggests that the significant differences noted in ankle dorsiflexion, ankle plantarflexion, knee flexion, and hip flexion angles do not significantly impact the peak vGRF.

Net Vertical Impulse

No statistically significant interaction effect was seen between brace type and bracing condition for net vertical impulse during the take-off phase of the vertical jump. Furthermore, no significant differences were found when evaluating the main effects for both the brace type and bracing condition factors. This current result rejects hypothesis #3 which suggested that the UNI and BI bracing condition would differ in comparison to the UB condition. Furthermore, this result also rejects hypothesis #3 where net vertical impulse would be significantly different while wearing the ASO and T2 braces. This result suggests that wearing ASO versus T2 braces has no impact on net vertical impulse, in addition to no impact on net vertical impulse while wearing ankle brace either UNI or BI in comparison to UB.

Morikawa et al. (2022) reported no significant difference in net vertical impulse in the UB and braced conditions. The values of impulse which were reported in the current study were greater than those reported by Morikawa et al. (2022). In their study, recreationally active individuals acted as participants rather than the competitive athletes which participated in the current study. Nonetheless, it was reported that net vertical impulse was not significantly different from UB to multiple bracing conditions. Similar to the results of vGRFs, it is not believed that wearing ASO and T2 ankle braces in UNI and BI conditions significantly impacts net vertical impulse. From this, it can be inferred that the changes seen in the lower extremity joint angles do not influence the net vertical impulse produced throughout the take-off phase of the vertical jump. One potential reason for this may be that compensations were made from other joints to produce similar net vertical impulses. As seen in peak plantarflexion angles, there were significant differences between the UNI and BI conditions and the UB condition whereas for the peak knee flexion angles there were no significant differences between the bracing conditions. This suggests that a compensation may have been made in peak knee flexion in an effort to produce similar net vertical impulses across all bracing conditions. Similarly, when evaluating the type of brace peak plantarflexion angles were significantly smaller in both the ASO and T2 brace, whereas peak hip flexion was not significantly different. This suggests that while wearing the ASO and T2 braces could have been a compensation made in peak hip flexion angles which allowed the net vertical impulse to remain relatively constant. The results of this current study suggest that the decrease in vertical jump height cannot be attributed to the vertical impulse which is produced during the take-off phase of the vertical jump.

Agility T-Test Performance

Agility Time

No statistically significant interaction effect was seen between brace type and bracing condition when evaluating agility time. In addition, no significant differences were noted when comparing agility times between the ASO and T2 braces. The difference in agility times while wearing the ASO brace (10.67 sec) are minimal when compared to the agility times while wearing the T2 brace (10.73 sec). This finding aligns which hypothesis #4 which suggested that there would be no significant differences between the agility times while wearing the ASO and T2 braces. This result is similar to those reported by Parsley et al. (2013) where it was suggested that agility performance was not significantly impacted while wearing three different ankle braces. In contrast, the results from Parsley et al. (2013) were derived using the ASO, Seattle

Ankle Orthosis (SAO), and Aircast semirigid braces. Although the ASO brace was utilized and the Aircast is comparable to the T2 brace, the SAO was incorporated on a trial basis (Parsley et al., 2013). With that being said, the non-significant result between the ASO and Aircast braces is comparable to the result from this current study, which reported no significant differences between the agility times while wearing the ASO and T2 braces. Notably, the current study utilized a different procedure of agility test which may have impacted the results, however, since both studies found no differences between agility and type of ankle braces, the discrepancy between agility tests is likely irrelevant. In addition, Henderson et al. (2016) reported similar results of no significant differences in agility time while wearing the ASO and T2 braces. The findings from this study are most relatable to the results reported by Henderson et al. (2016) due to the methodological similarities of the two studies. Specifically, in both studies the researchers sampled athletes who participated in jumping sports, utilizing the same two ankle brace (ASO and T2), and incorporated the same agility T-test. Furthermore, the similar non-significant result reported by both studies suggest that agility performance is not impacted more by one brace in comparison to the other. Lastly, Ambegaonkar et al. (2011) reported no difference between a softshell brace and rigid stirrup brace. Similar to the study completed by Parsley et al. (2013), although the braces worn and agility test utilized were different there was no impact on agility performance (Ambegaonkar et al., 2011). As a result, the findings from this study support the previous research which found that the type of ankle brace does not impact agility performance.

There was, however, a statistically significant result found when evaluating the main effect of bracing condition. More specifically, agility time was significantly different while wearing braces in both the UNI (10.72 sec) and BI (10.69 sec) conditions when compared the UB condition (10.54 sec). Moreover, there was no significant differences reported when comparing the agility times between the UNI and BI conditions. This result directly aligns with hypothesis #4 which suggest that the UNI and BI braced conditions would produce significantly slower times to complete the agility task than the UB condition. This result suggests that wearing an ankle brace significantly impacts the agility times, but how the brace is worn (i.e., UNI or BI) does not influence agility performance. Similarly, Ambegaonkar et al. (2011) reported a significant difference in agility time between their softshell (14.14 sec) and rigid brace (14.14 sec) and the UB condition (13.55 sec). Although the difference in values from their study was larger than the current study, the significant differences in both studies suggests that agility time is impacted while wearing an ankle brace in comparison to no braces. In addition, Henderson et al. (2020) reported a significant difference in agility time while wearing the ASO (6.33 sec) and T2 (6.37 sec) braces in comparison to the UB (6.17 sec) condition. This result aligns with the findings from the current study in that wearing ankle braces significantly impacts agility time in comparison to the UB condition. With that being said, the agility test procedure from Henderson et al. (2020) was drastically different than that from the current study. The differences in values, however, are quite similar between the braced and UB conditions from both studies, and the procedure utilized by Henderson et al. (2020) was a modified version of the procedure used in the current study.

Furthermore, as previously discussed there has been research which reported no significant impact on agility time while wearing ankle braces (Henderson et al., 2016; Leonard et al., 2014; Paris, 1992). In each of these studies, the researchers found differences in agility time, but the magnitude of these differences were not deemed to be significantly different. In addition, different samples were utilized which may have influenced the type of test which the researchers implemented (Henderson et al., 2016; Leonard et al., 2014; Paris, 1992). As a result of the different samples, the researchers utilized different tests which were attempting to replicate the movements which their participants typically performed. Furthermore, some studies utilized different ankle braces than the braces utilized in this current study (Leonard et al., 2014; Paris, 1992). By utilizing different ankle braces, the impact that those braces have compared to the current braces cannot be generalized. From any of these methodological differences, the difference in significance may be found.

As a result, the differences in procedure are unlikely to influence the significant results from the respective studies. From this, it is evident that wearing an ankle brace; either UNI or BI, and ASO or T2, does in fact significantly impact agility performance.

Practical Application

The results from this study indicate there are both significant and non-significant findings from specific variables which inform a greater meaning in the practical sense. There was a significant decrease in vertical jump height and increase in agility time while wearing both the ASO and T2 braces. Moreover, there were no differences seen when comparing the UNI condition to the BI condition. From this, it is suggested that wearing ankle braces either unilaterally or bilaterally decreases vertical jump and agility performance, however, wearing ankle braces UNI versus BI has no statistically significant impact on performance. As discussed, this result suggests that regardless of UNI or BI that wearing an ankle brace significantly reduces vertical jump height and increase agility time.

When considering these results in the context of volleyball, there are much greater implications concerning performance. For vertical jump height, having the ability to jump as high as possible greatly increases the odds of success during both an attack and block of the ball (Lidor & Ziv, 2010). Being able to jump higher than the blocker would give the attacker an advantage of more court available into which the ball can be hit. On the contrary, if the defender is able to jump higher than the attacker, they can take away more court and not allow the attacker much area to navigate. Thereby, increasing the odds that the team behind the block can make a defensive play (Lidor & Ziv, 2010). In the event that the ankle braces which the player is wearing decrease their vertical jump height, they may not be jumping their highest and even the 2 cm decrease in vertical jump height may stop the player from scoring on an attack or getting the block touch. Furthermore, it is evident that being able to perform rapid changes in direction will allow the player to be in a better position to make a defensive play (Lidor & Ziv, 2010). If the ankle braces which they are wearing slow them down, even a tenth of a second, that brief period may determine whether they make the play or the ball will hit the floor. As a result, the deficits seen in vertical jump height and agility time while wearing the ankle braces may have an effect on the outcome of the individual points throughout the game, as well as, the outcome of the entire game.

When evaluating the kinematics which influence vertical jump performance, there were significantly smaller peak ankle plantarflexion and peak hip flexion angles found in the UNI and BI conditions. Upon analysis of the peak vGRF and net vertical impulse, no statistical significance was found for either variable which suggests that the smaller peak ankle plantarflexion and peak hip flexion angles did not impact the kinetics of the vertical jump. This implies that there may have been compensations made between the UNI and BI bracing conditions which resulted in relatively similar peak vGRF and net vertical impulse values. Although there are differences in the UB, UNI, and BI bracing conditions, there are no clear statistical significances which indicate that a compensation was made in the joint angles of the lower extremities. Due to these differences seen in lower extremity kinematics and performance, it is apparent that the both the ASO and T2 braces in reduced vertical jump height and agility performance in compared to the UB condition, however, there are no differences between the unilateral and bilateral bracing conditions.

No differences in vertical jump or agility time were found when comparing the ASO and T2 braces. The kinematics suggest that there were compensations made in peak knee and hip flexion angles to produce relatively constant vertical jump heights and agility times while in the ASO and T2 braces. Although there were a significantly smaller peak plantarflexion and peak knee flexion angles in the ASO and T2 braces, there were no decreases in vertical jump height or increases in agility time, however, peak ankle dorsiflexion and hip flexion angles revealed no significant differences. This suggests that there were compensations made to result in no significant differences. As seen in peak knee and hip flexion angles, there are increases in peak hip and knee angle in the bracing conditions where there were significantly lower peak ankle plantarflexion and dorsiflexion angles. Furthermore, no kinetic differences were found between the ASO and T2 braces. Although there are kinematic differences in peak ankle dorsiflexion and plantarflexion, the compensations which were in peak knee and hip flexion angles may be responsible for the similar peak vGRFs and net vertical impulses. Conclusively, although there were kinematic differences found, there was no impact on vertical jump and agility performance while wearing the ASO brace compared to the T2 brace.

In summary, the results of this study suggest that wearing ankle braces significantly decreases vertical jump height and increases agility time in comparison to the UB condition, however, wearing ankle braces unilaterally or bilaterally has no impact on performance. Furthermore, the type of brace which was worn did not reveal any impact on vertical jump height or agility time. Considering all of this, the reduced the risk of injury when wearing ankle braces may outweigh the decrease in vertical jump height and agility performance. It has been reported that wearing ankle braces reduces the initial risk of injury by 47% and recurring injury by 66% (Barelds et al., 2019). However, when comparing the performance while wearing braces to the UB condition there was a 3% decrease in vertical jump height a 1.8% increase in agility time. This suggests that the magnitude of the performance decrease while wearing braces may not be practically significant enough to justify not wearing braces when considering the benefits which the ankle braces provide in terms of injury prevention. From this, it is up to the athletes, coaches, trainers, and/or clinicians to determine which braces the athletes should wear and how they should be worn (UNI vs BI).

Limitations

There are various potential limitations to this study which need to be acknowledged. First, the sample size for this study was relatively small (n = 22), with an unequal distribution of males (n = 14) and females (n = 8). When generalizing the results of this study, some caution should be taken. This sample represented members from a combination of current and previous members of the men's and women's competitive volleyball teams, however, a more equal representation of both sexes may make the findings of this study more generalizable. From this, recruiting a larger sample with more equal representation from both sexes is recommended.

Another potential limitation is in the use of reflective markers during the vertical jump test. The markers were to be placed on the specific bony landmarks on each participant, however, for some of these markers (i.e., hip, ankle, heel, and toe), the markers were placed on the clothing, ankle brace, and/or shoes, superficial to the skin. As a result, the clothing, shoes, or ankle braces may have moved during the loading phase of the vertical jump, and, therefore, the position of the hip, ankle, heel, and toe markers may have varied. This may have caused the angles to vary slightly upon kinematic analysis. The recommended method of marker placement is to place them directly on the skin, however, when this is not possible, placing the markers superficial to the deeper bony landmarks on the clothes, ankle brace, and shoes was performed.

Finally, another potential limitation of this study was that each participant utilized their own shoes which they typically used during volleyball competition. Although the same shoes were used for each of the respective participant's testing sessions, each participant wore a different type of shoe for their test. Different shoes may have influenced the ankle braces movement inside their shoes, comfort of the brace, and the overall effectiveness of the brace. Although the shoes were all different, the goal of the study was to assess the performance within each participant, so having the participants wear the shoes which they typically wear during volleyball training and competition increases the generalizability of the results.

Assumptions

There were various assumptions made throughout this study. It was assumed that all participants applied the ankle brace the same way under all brace conditions. The student researcher instructed the participants how to properly put on the brace, but the tightness of the brace was subjective to the comfort level of each participant. Another assumption from this study is that the participants were not fatigued as the trials of both the vertical jump and agility tests progressed. To reduce the risk of fatigue, there were specific rest intervals between each jump and sprint, as well as between each bracing condition. In addition, it was assumed that the participants gave maximal effort during all trials of the vertical jump and agility tests. Prior to each testing session, the participants were instructed to give maximal effort for each trial.

Future Considerations

This study was the first to examine the impact of unilateral versus bilateral bracing and although there were no significant differences, there were in fact differences among the different variables in this study which future studies may want to investigate. In addition, there were significant decreases in vertical jump and agility performance which aligns with the existing literature (Ambegaonkar et al., 2013; Henderson et al., 2016; Henderson et al., 2019; Henderson et al., 2020; Smith et al., 2016). Being so, there is previous literature which suggests that there are no differences in vertical jump and agility performance (Morikawa et al., 2022; Parsley et al., 2013; You et al., 2020). As a result, future research should be conducted to contribute to a more definite conclusion of the impact that ankle bracing has on vertical jump height and agility time. Furthermore, conducting future research while evaluating the kinematics of the take-off phase would be beneficial as including this current study, there are only four studies which do so (Smith et al., 2016; West et al., 2014; You et al., 2020). From this study, it is evident that ankle dorsiflexion, ankle plantarflexion, and hip flexion are all significantly impacted during the vertical jump, which may explain the decreases seen in vertical jump height. As a result, future research should consider these joint angles and how they relate to vertical jump performance. Moreover, future studies should consider the kinetics during the take-off of the vertical jump. Although this study reported no significant result, You and colleagues (2020) reported a significant decreases in peak vGRF while wearing ankle braces. Peak vGRF is a relatively new variable to be evaluated in the take-off phase, therefore, further research should be conducted to contribute to a conclusion. Lastly, electromyography (EMG) should be considered while evaluating the kinetics as the muscle activity relates closely to the forces which are generated by the said muscles. Specifically, utilizing EMG electrodes on the muscles which are responsible for the take-off phase of the vertical jump, would be valuable to combine with the peak vGRF and impulse data from the force platform. Through the results of this study, it is clear that further research needs to be conducted concerning the impact that unilateral versus bilateral ankle bracing has on the lower extremity kinetics and kinematics during a vertical jump, vertical jump height, and agility time.

Chapter Five: Conclusion

The purpose of this study was to investigate the impact of unilateral versus bilateral ankle bracing on the kinetics and kinematics during the vertical jump for measures of vertical jump height, joint angles in the lower extremity, vGRF, impulse, and agility time in volleyball players. Vertical jump height was found to be significantly lower in the UNI and BI conditions in comparison to the UB condition, but no differences were noted when comparing the UNI and BI conditions. This result infers that regardless of the brace type or bracing condition that while wearing ankle braces, there are decreases in vertical jump height. In addition, there were significant decreases in agility performance in both the UNI and BI bracing conditions, regardless of the type of ankle brace. This result infers that regardless of brace type or bracing condition, that wearing ankle braces significantly impacts agility performance. There were significant differences noted when evaluating the interaction effect of brace type and bracing conditions for peak dorsiflexion. Specifically, during the loading phase of the vertical jump, peak ankle dorsiflexion was significantly lower in the ASO brace than the T2 brace. A significant interaction effect was also seen when evaluating the type of ankle brace and bracing condition, with the ASO brace producing significantly less plantarflexion angles in comparison to the T2 brace. In addition, significant effects were also noted when comparing the UNI and BI conditions of both the ASO and T2 braces to the UB condition. Furthermore, significant decreases in knee flexion angles were noted in the ASO brace in comparison to the T2 brace. Lastly, there were significant decreases in hip flexion angles when comparing the BI condition in both ASO and T2 braces, to the UB condition. While considering the significant effects in the lower extremity joint angles, it is believed that these differences can be attributed to the decreases seen in vertical jump height.

In the context of the athlete, the results of this study suggest that there are vertical jump and agility performance deficits introduced by wearing the ASO and T2 ankle braces. Although it may not seem practically significant, 2 cm difference in vertical jump height and 0.2 sec difference in agility time may impact the performance on the volleyball court. Jumping as high as possible for an attack or a block, or being quick enough to make a defensive play are two of the most important aspects of volleyball and by decreasing the performance of these skills, it may have an impact on the outcome of the point, and even the match. Inversely, it is clear that ankle braces offer substantial protection to ankle injuries. In this scenario, it is dependent on the individual scenario to determine if the injury prevention benefits that the ankle brace provides outweigh the performance decreases. With that said, if an athlete opts to wear ankle braces, the results of this study suggest that wearing ankle braces UNI versus BI will have little impact on performance. As a result, the athletes, coaches, trainers, and/or clinicians may decide between only wearing a brace on previously injured ankles or wearing braces prophylactically on both ankles without being concerned about potential performance deficits.

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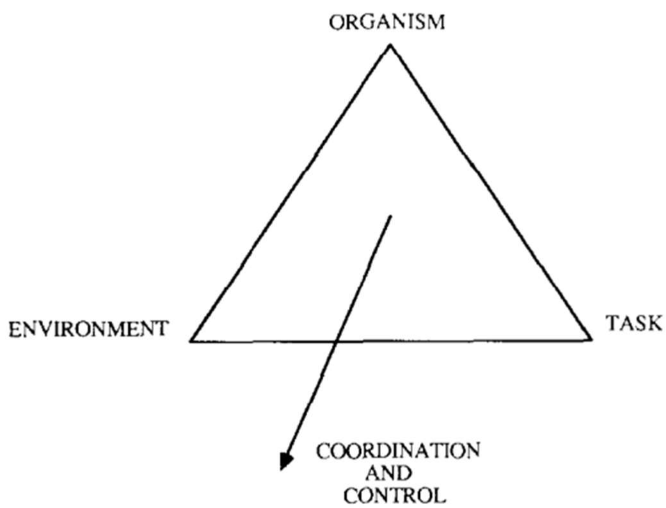
Appendices

Appendix A

Newell's Model of Constraints

Figure A1

Newell's Model of Constraints



Note. Newell's Model of Constraints regarding coordination and control. From "Constraints on the Development of Children," by K. Newell, 1986, Martinus Nljhoff Publishers. Copyright

Appendix B

Get Active Questionnaire

CSEP | SCPE
THE GOLD STANDARD IN EXERCISE SCIENCE AND PERSONAL TRAINING

Get Active Questionnaire

CANADIAN SOCIETY FOR EXERCISE PHYSIOLOGY –
PHYSICAL ACTIVITY TRAINING FOR HEALTH (CSEP-PATH®)

Physical activity improves your physical and mental health. Even small amounts of physical activity are good, and more is better.

For almost everyone, the benefits of physical activity far outweigh any risks. For some individuals, specific advice from a Qualified Exercise Professional (QEP – has post-secondary education in exercise sciences and an advanced certification in the area – see csep.ca/certifications) or health care provider is advisable. **This questionnaire is intended for all ages – to help move you along the path to becoming more physically active.**

☐ I am completing this questionnaire for myself.

☐ I am completing this questionnaire for my child/dependent as parent/guardian.

PREPARE TO BECOME MORE ACTIVE

The following questions will help to ensure that you have a safe physical activity experience. Please answer **YES** or **NO** to each question before you become more physically active. If you are unsure about any question, answer **YES**.

YES	NO	
		1 Have you experienced **ANY** of the following (A to F) **within the past six months**?
○	○	**A** A diagnosis of/treatment for heart disease or stroke, or pain/discomfort/pressure in your chest during activities of daily living or during physical activity?
○	○	**B** A diagnosis of/treatment for high blood pressure (BP), or a resting BP of 160/90 mmHg or higher?
○	○	**C** Dizziness or lightheadedness during physical activity?
○	○	**D** Shortness of breath at rest?
○	○	**E** Loss of consciousness/fainting for any reason?
○	○	**F** Concussion?
○	○	**2** Do you currently have pain or swelling in any part of your body (such as from an injury, acute flare-up of arthritis, or back pain) that affects your ability to be physically active?
○	○	**3** Has a health care provider told you that you should avoid or modify certain types of physical activity?
○	○	**4** Do you have any other medical or physical condition (such as diabetes, cancer, osteoporosis, asthma, spinal cord injury) that may affect your ability to be physically active?

NO to all questions: go to Page 2 – ASSESS YOUR CURRENT PHYSICAL ACTIVITY

YES to any question: go to Reference Document – ADVICE ON WHAT TO DO IF YOU HAVE A YES RESPONSE

CSEP | SCPE Get Active Questionnaire

THE GOLD STANDARD IN EXERCISE SCIENCE AND PERSONAL TRAINING

ASSESS YOUR CURRENT PHYSICAL ACTIVITY

Answer the following questions to assess how active you are now.

1 During a typical week, on how many days do you do moderate- to vigorous-intensity aerobic physical activity (such as brisk walking, cycling or jogging)? ☐ DAYS/WEEK

2 On days that you do at least moderate-intensity aerobic physical activity (e.g., brisk walking), for how many minutes do you do this activity? ☐ MINUTES/DAY

For adults, please multiply your average number of days/week by the average number of minutes/day: ☐ MINUTES/WEEK

Canadian 24-Hour Movement Guidelines recommend that adults accumulate at least 150 minutes of moderate- to vigorous-intensity physical activity per week. For children and youth, at least 60 minutes daily is recommended. Strengthening muscles and bones at least two times per week for adults, and three times per week for children and youth, is also recommended (see csep.ca/guidelines).

GENERAL ADVICE FOR BECOMING MORE ACTIVE

Increase your physical activity gradually so that you have a positive experience. Build physical activities that you enjoy into your day (e.g., take a walk with a friend, ride your bike to school or work) and reduce your sedentary behaviour (e.g., prolonged sitting).

If you want to do **vigorous-intensity physical activity** (i.e., physical activity at an intensity that makes it hard to carry on a conversation), and you do not meet minimum physical activity recommendations noted above, consult a Qualified Exercise Professional (QEP) beforehand. This can help ensure that your physical activity is safe and suitable for your circumstances.

Physical activity is also an important part of a healthy pregnancy.

Delay becoming more active if you are not feeling well because of a temporary illness.

DECLARATION

To the best of my knowledge, all of the information I have supplied on this questionnaire is correct.
If my health changes, I will complete this questionnaire again.

I answered NO to all questions on Page 1

Sign and date the Declaration below

I answered YES to any question on Page 1

Check the box below that applies to you:

☐ I have consulted a health care provider or Qualified Exercise Professional (QEP) who has recommended that I become more physically active.

☐ I am comfortable with becoming more physically active on my own without consulting a health care provider or QEP.

Name (+ Name of Parent/Guardian if applicable) [Please print] ______ Signature (or Signature of Parent/Guardian if applicable) ______ Date of Birth ______

Date ______ Email (optional) ______ Telephone (optional) ______

With planning and support you can enjoy the benefits of becoming more physically active. A QEP can help.

☐ Check this box if you would like to consult a QEP about becoming more physically active.
(This completed questionnaire will help the QEP get to know you and understand your needs.)

Appendix C

Information Letter

Dear Potential Participant,

Thank you for expressing an interest in the research study titled "The Impact of Unilateral Versus Bilateral Ankle Bracing on the Lower Extremity Kinetics, Kinematics, and Performance in Volleyball Players". The study is being conducted by Stephen Boulanger, a graduate student of the Masters of Science in Kinesiology program ay Lakehead University. The study will be completed under the supervision of Dr. Derek Kivi, as well as committee members Dr. Paolo Sanzo and Dr. Carlos Zerpa. The purpose of this study is to examine the impact that unilateral versus bilateral ankle bracing on the kinetics and kinematics during the vertical jump, vertical jump height, and agility time in volleyball players.

You have been selected to voluntarily participate in this study because you are between the ages of 18 and 24 and a member of the Lakehead University varsity women's volleyball team or men's club volleyball team. To be an eligible participant, you must have had no previous injuries to your lower extremities (e.g. hips, knees, or ankles) which prevented you from participating in your sport in the past six months. If you have incurred a lower extremity injury in this time, you must have received medical clearance to resume participating in your sport. If you agree to participate in this study, you will be asked to come to Sander's Fieldhouse at Lakehead University for two sessions which will last 45-60 minutes in duration. The first you will be asked to complete the vertical jump test and the second session you will be asked to complete the agility T-test. The two sessions will be scheduled at least one week apart from each other. You will be asked to wear clothing which you would typically wear while playing volleyball, most notably the shoes which you wear when playing.

If you agree to participate and fully understand what the study involves, you will be asked to sign a consent form. This form is written documentation that you have read this information letter and understand your rights as a volunteer participant. Prior to data collection, you will also complete a Get Active Questionnaire (GAQ) and a COVID-19 Data Collection Pre-Screening. The GAQ form will ensure that you are healthy and free from any medical conditions which may prevent your safe participation in this study. The pre-screening form will ensure that you are not currently experiencing, or have not experienced symptoms of COVID-19 in the past 14 days. Once all of the forms are complete, the first session will begin with a moderate warm-up of stationary cycling for ten-minutes, followed by a series of sub-maximal vertical jumps. The student researcher will then present the order of bracing conditions and apply reflective markers to the hip, knee, ankle, foot, and toe on your dominant leg. During the second data collection session, you will complete the same ten minute cycling warm-up, but you will perform a series of lower extremity dynamic stretches.

Please note that our research team is required logs for the purposes of contact tracing beyond our social circle. Well will request your name and telephone number for this purpose. If a research team member or research participant(s) contracts COVID-19, the log would be shared with health authorities if requested. Only your name and telephone number, and not the reason for contact would be shared with health authorities. Your information will be combined with all other contacts and you will not be identified as a participant in this research study. Contact logs are kept for 30 days, then all identifying information is destroyed. In addition, numerous measures will be implemented to reduce the risk of COVID-19. To reduce the risk of exposure, only the student researcher and participant will be permitted in the laboratory. In the event that the student researcher requires assistance from the research supervisor, that will take place prior to the participant's arrival. In line with the Ontario COVID-19 Safety Plan, social distancing of 6-feet or more will be maintained between patrons in the laboratory. Each person will be expected to wear a mask in the laboratory, with exception to the participant only when they are completing physical activity. In addition, sanitation measures such as hand sanitizing, bacterial spray, and wipes will be used to clean all equipment and ankle braces after each participant. Participants scheduled consecutively will be done so with a 15-minute gap to ensure that the student researcher has adequate time to clean and to reduce the risk of exposure to the previous participant.

The vertical jump testing session will involve performing maximal effort vertical jumps while wearing the Ankle Stabilizing Orthosis (ASO) and T2 Active Ankle (T2) braces in unilateral and bilateral conditions. You will be performing five vertical jumps in each of these conditions in addition to an unbraced condition, for a total of 25 jumps. You will be asked to perform these vertical jumps while taking off and landing on the force platform. In addition, a GoPro camera will be set-up on a tripod to record video data, which will be used to determine joint kinematics during the take-off phase of the jump. When instructed by the student researcher, you will be asked to perform a maximal vertical jump and to reach to the highest point possible on the Vertec™ apparatus. Once you have completed one jump trial, you will be given 30 seconds before your next jump to avoid the onset of fatigue. After you have completed five jumps in all conditions, the student researcher will give you cool down stretches to perform.

One week later, you will be invited back to perform the agility T-test while under the same conditions as the vertical jump test. However, instead of performing five trials under each condition, you will be asked to perform three trials. The student researcher will describe the test and provide a specific instructions upon request. You will be given the opportunity to perform two practice trials in the condition that they are performed with sub-maximal effort. You will then be provided with 2 minutes to recover before the data collection trials. You will start the test lined up behind a designated mark on the floor and your time will automatically begin once you break the plane of the timing gate and will be stopped when you pass through the same gate at the end of the test. Upon completion of the trial, you will be provided with 1-minute to recover in effort to mitigate the impact of fatigue. Once you have completed three trials in each condition, you will perform the same cool-down stretches which were completed after the vertical jump testing session.

Please be advised that, as a volunteer participant, you can withdraw from the study at any time, or refuse to complete any part of the study if you are not comfortable with what is being asked of you. There will be no penalty for withdrawing. You are also encouraged to ask the student researcher any questions regarding the nature of the study.

As a participant in this study, you will remain anonymous and your information will remain confidential throughout the study. The data that is gathered during the testing will be safely stored on a password-protected computer. Only the student researcher will know the passwords and only the student researcher and research supervisors will see the raw data. Your name will not be attached to any of the data (a numerical identification will be used instead) and your name will not be published with any of the results. At the end of the study, the data will be stored with Dr. Derek Kivi on a password-protected computer for a period of five years. A presentation of the findings will be made in the Summer of 2022 to fellow graduate students and the Faculty of Kinesiology. The study's findings will also be submitted for publication in a peer-reviewed journal and/or presented at a scientific conference. A summary of the results will be available to you upon your request, via email.

If you wish to participate in the study or would like more information about the nature of the study, please contact the student researcher, Stephen Boulanger, as soon as possible at the contact information listed below. You may also contact the research supervisors, Dr. Derek Kivi. If you have any questions related to the ethics of the research and would like to talk to someone other than the researchers, you can also contact Sue Wright at the Research Ethics Board at (807) 343-8283 or research@lakeheadu.ca.

Your participation would be greatly appreciated! Thank you for your consideration.

Sincerely,

Stephen Boulanger
Student Researcher
smboulan@lakeheadu.ca

Dr. Derek Kivi
Research Supervisor
dkivi@lakeheadu.ca

Appendix D

Consent Form

I ________________________________ agree to participate in the study titled "The Impact of Unilateral Versus Bilateral Ankle Bracing on the Lower Extremity Kinetics, Kinematics, and Performance in Volleyball Players", which will measure the kinetics, kinematics, vertical jump height while performing the vertical jump test, and agility time while performing the agility T-test.

I have read and understand the terms and conditions of this research study as outlined in the information letter. I willingly agree to participate in this study.

I understand the potential risks and benefits of the study. I also understand that I have certain rights as a participant in this study. I understand that as a volunteer, I may withdraw at any time and may refuse to answer any questions or perform any activities.

I understand that personal information used in the study will remain anonymous and confidential, as it will only be used by the researchers conducting the study. I understand that I will be protected and remain anonymous in any presentation of the research findings. I am also aware that the data recorded in this study will be securely stored at Lakehead University for five years with Dr. Derek Kivi. I have been informed that the results from this study will be made available to me via email once the study has been completed. I also understand that the data may be published on journals or presented publicly; although no individual results will be made available.

Please indicate if you would like a copy of the results via email at the completion of the study.

☐ Yes Email: ______________________________________
☐ No

____________________________________ ____________________
Signature of Participant Date

____________________________________ ____________________
Signature of Student Researcher Date

____________________________________ ____________________
Signature of Research Supervisor Date

Appendix E

Demographic Questionnaire

Participant ID # (to be filled in by student researcher): ____________________________

Age: __________

What best describes your current gender identity (circle one):

A. Male
B. Female
C. An identity not listed above (e.g. gender fluid, non-binary)

Height: ________

Mass: ________

Years of Playing Experience: ___________

Position: ____________

History of Ankle Brace Use

Question	Explain
Do you currently use ankle braces? If yes, answer the following questions.	
Which ankle brace do you wear?	
Do you wear your ankle brace on your dominant, non-dominant, or both ankles?	
Do you wear an ankle brace due to previous injury or to prevent injury? If neither explain your reasoning for wearing ankle braces.	

History of Lower Extremity Injuries

Question	Explain
Have you sustained an injury to your hips, knees, ankles, or feet? If yes, what injury?	
If yes, how recent was your latest injury?	
How long did it take you to recover from your most recent injury?	

Was a brace prescribed to facilitate the recovery from this injury?	
Do you wear this brace during competition?	

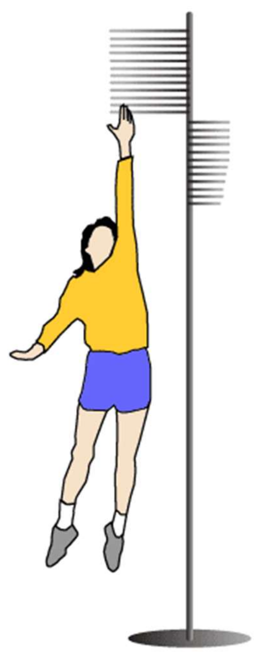
Appendix F

Vertical Jump Test Procedures

The athlete begins by standing beneath the Vertec^{TM} apparatus with both feet flat on the force platform. Once settled, the participant vertically leaps as high as possible using both their arms and legs to assist in projecting their body upwards. The transition between the squat and upward projection should not include a pause before the participant jumps upward. Once in the air, the participant should reach up to touch the highest Vertec^{TM} vein possible. The difference between the participant's standing reach height and the highest vein on the Vertec^{TM} will be recorded as their vertical jump height.

Figure F1

Demonstration of the Vertical Jump Test



Note. Demonstration of the vertical jump test with the Vertec^{TM} apparatus. From "Vertical Jump Test," by R. Wood, 2008, (https://www.topendsports.com/testing/tests/vertjump.htm)

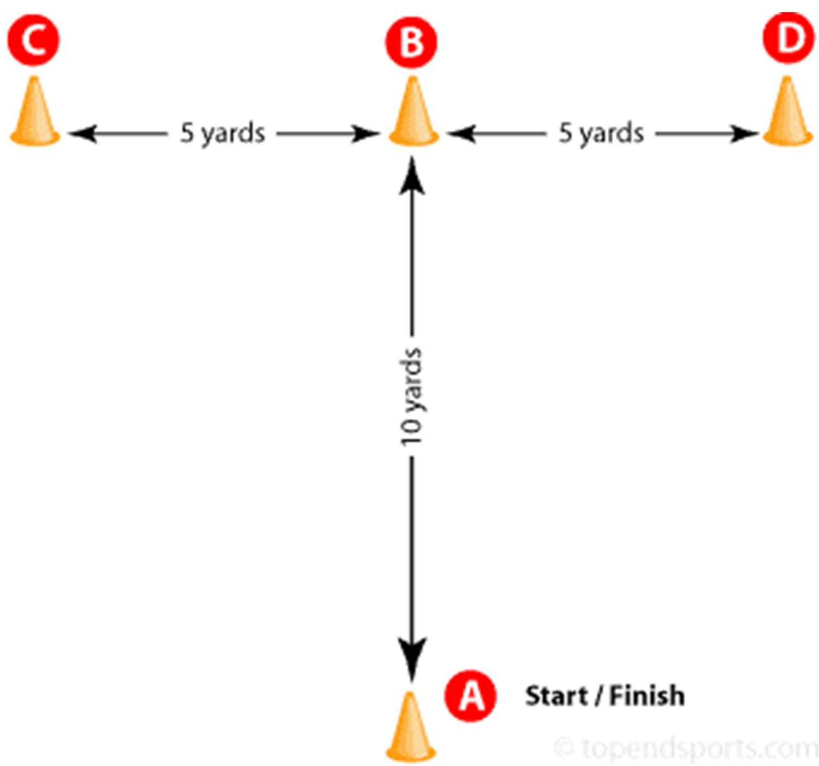
Appendix G

T-Test Agility Course and Instructions

The participant starts at cone A. On the command of the timer, the participant sprints to cone B and touches the base of the cone with their right hand. They then turn left and shuffle sideways to cone C, and also touches its base, this time with their left hand. Then shuffling sideways to the right to cone D and touching the base with the right hand. They then shuffle back to cone B touching with the left hand, and run backwards to cone A. The time is stopped as they pass cone A.

Figure E1

Layout of the Agility T-Test



Note. The layout of the agility t-test with the Brower timing gates set-up at the start/finish line. From "T-Test of Agility," by R. Wood, 2008, (https://www.topendsports.com/testing/tests/t-test.htm). Copyright 2022 by Topend Sports Network.

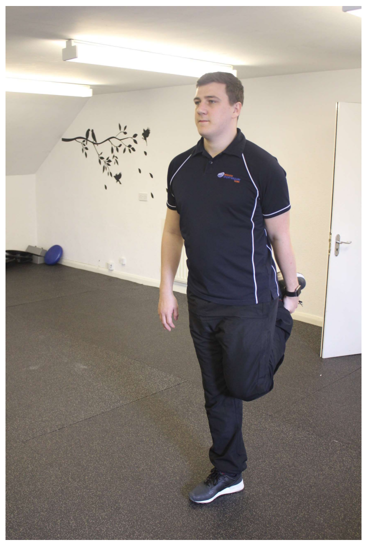
Appendix H

Static Stretches for Vertical Jump Test Cool-Down

Stand tall or leaning to an object to keep your balance. Grasp the top of your ankle or forefoot behind you and pull ankle toward the buttocks. Repeat with opposite leg.

Figure F1

Demonstration of the quadriceps stretch



Note. Demonstration of the quadriceps stretch. From "Ten Static Stretching Exercises," by K. Deardon, 2017, (https://www.newcastlesportsinjury.co.uk/ten-static-stretching-exercises/). Copyright 2022 by Newcastle Sports Injury Clinic.

Stand tall with feet approximately two shoulder widths apart. Turn the feet and face to the right. Bend the right leg so that the right thigh is parallel with the ground and the right lower leg is vertical. Gradually lower the body keeping your back straight and use the arms to balance. You will feel the stretch along the front of the left thigh and along the hamstrings of the right leg. Hold a comfortable stretch and repeat by turning and facing to the left.

Figure F2

Demonstration of the hip and thigh stretch

Note. Demonstration of the hip and thigh stretch. From "Ten Static Stretching Exercises," by K. Deardon, 2017, (https://www.newcastlesportsinjury.co.uk/ten-static-stretching-exercises/). Copyright 2022 by Newcastle Sports Injury Clinic.

Stand tall with one leg in front of the other, hands flat and at shoulder height against a wall. Ease the back legs further away from the wall, keeping it straight and press the heel firmly into the floor. Keep your hips facing the wall and the rear leg and spine in a straight line. You will feel the stretch in the calf of the rear leg. Hold the stretch and then repeat with the other leg.

Figure F3

Demonstration of the calf stretch

Note. Demonstration of the calf stretch. From "Ten Static Stretching Exercises," by K. Deardon, 2017, (https://www.newcastlesportsinjury.co.uk/ten-static-stretching-exercises/). Copyright 2022 by Newcastle Sports Injury Clinic.

Sit on the ground with both legs straight out in front of you, bend the left leg and place the sole of the left foot alongside the knee of the right leg. Allow the left leg to lie relaxed on the ground, bend forward keeping the back straight. You will feel the stretch in the hamstring of the right leg. Repeat with the other leg.

Figure F4

Demonstration of the hamstring stretch

Note. Demonstration of the hamstring stretch. From "Ten Static Stretching Exercises," by K. Deardon, 2017, (https://www.newcastlesportsinjury.co.uk/ten-static-stretching-exercises/). Copyright 2022 by Newcastle Sports Injury Clinic.

Appendix I

Dynamic Stretches for Agility Test Warm-Up

Walking Lunges

Stand tall with feet hip-width apart. Take a big step forward with right legs. Start to shift weight forward so the heel hits the floor first. Lower the body until the right thigh is parallel to the floor and right shin is vertical. Be sure that the right knee does not pass over the right foot. If mobility allow, lightly tap the left knee to the ground while keeping the weight on the right heel. Press into the right heel to drive body back into standing position. Repeat on opposite side.

High Knees

Stand up straight and slowly bring one knee up toward chest. Return to the stating position and repeat with the knee on the opposite side. Continue to alternate knees, increasing speed as the body warms up. Continue this for 30-seconds with increasing speed.

Side Lunges

Start with the feet shoulder-width apart, toes pointed straight forward. Step out as wide as possible with your right foot. Engage through the right heel as you drop your hips down and back while keeping the left leg straight, stretching the groin on the left leg and keeping both soles of the feet on the ground and toes pointing straight forward. Make sure the right knee is tracking over the right foot throughout the motion. Powerfully push the right heel into the floor to push the body back to the standing position. Repeat on opposite side.

Side Shuffle

Stand with feet hip-distance apart and hinge forward at the hips with the knees slightly flexed. Ensure the chest is listed and spine remains in a neutral position. Hold hands out to the side to assist with balance. Start by moving to the right using small, quick side steps. Repeat these side-steps to initiate “shuffling”. Perform this side shuffle for the desired distance and return to starting position by shuffling the opposite direction. This will ensure that both sides of the body are being engaged in this process.

Appendix J

Equations for Calculating Net Vertical Impulse

There were two equations which were utilized to calculate vertical impulse at each data point (0.001 sec) and to determine net vertical impulse for the entire take-off phase.

Equation #1 was used to calculate vertical impulse at each time interval is:

$$I = (F - w) * 0.001$$

Equation #2 was used to calculate net vertical impulse from all data is:

$$I_{NET} = (I_1 + I_2 + I_3 + I_4 \ldots..)$$

Appendix K

Data Used in Analyses

Table K1

Vertical Jump Heights (cm)

Participant #	Trial	ASO-UNI	ASO-BI	T2-UNI	T2-BI	UB
1	1	56.35	55.125	57.575	52.675	61.25
	2	56.35	56.35	51.45	55.125	60.025
	3	56.35	56.35	53.9	57.575	57.575
	4	61.25	57.575	55.125	56.35	60.025
	5	58.8	60.025	58.8	55.125	60.025
2	1	58.8	66.15	68.6	68.6	68.6
	2	62.475	69.825	68.6	67.375	69.825
	3	63.7	67.375	69.825	67.375	68.6
	4	67.375	68.6	69.825	63.7	67.375
	5	69.825	69.825	69.825	66.15	69.825
3	1	69.825	66.15	67.375	69.825	69.825
	2	67.375	66.15	67.375	69.825	63.7
	3	67.375	72.275	69.825	69.825	69.825
	4	74.725	69.825	72.275	67.375	71.05
	5	68.6	72.275	69.825	67.375	71.05
4	1	61.25	56.35	61.25	61.25	58.8
	2	58.8	58.8	57.575	61.25	56.35
	3	62.475	61.25	60.025	61.25	60.025
	4	60.025	58.8	61.25	62.475	58.8
	5	57.575	56.35	60.025	61.25	60.025
5	1	49	45.325	46.55	49	49
	2	47.775	47.775	47.775	50.225	49
	3	46.55	47.775	46.55	49	47.775
	4	45.325	47.775	46.55	47.775	49
	5	46.55	47.775	47.775	47.775	47.775
6	1	71.05	72.39	71.05	71.05	71.05
	2	69.825	72.39	69.825	69.825	69.825
	3	73.5	69.85	69.825	69.825	72.275
	4	69.825	73.66	72.275	67.375	72.275

	5	71.05	72.39	69.825	68.6	72.275
7	1	83.3	83.3	84.525	86.975	88.2
	2	86.975	86.975	84.525	86.975	88.2
	3	88.2	85.75	88.2	85.75	89.425
	4	86.975	85.75	85.75	85.75	86.975
	5	90.65	88.2	86.975	86.975	89.425
8	1	66.15	63.7	63.7	66.15	66.15
	2	64.925	68.6	61.25	66.15	66.15
	3	61.25	68.6	64.925	62.475	62.475
	4	66.15	67.375	64.925	64.925	67.375
	5	68.6	66.15	67.375	67.375	68.6
9	1	67.375	61.25	64.925	68.6	69.825
	2	63.7	67.375	67.375	68.6	68.6
	3	66.15	67.375	66.15	67.375	68.6
	4	67.375	68.6	68.6	69.825	69.825
	5	68.6	69.825	67.375	68.6	66.15
10	1	52.675	52.675	51.45	41.65	51.45
	2	51.45	51.45	51.45	47.775	49
	3	51.45	52.675	52.675	50.225	49
	4	51.45	50.225	50.225	50.225	53.9
	5	52.675	42.875	51.45	49	53.9
11	1	52.675	47.775	45.325	49	51.45
	2	51.45	47.775	47.775	46.55	53.9
	3	51.45	49	49	47.775	55.125
	4	51.45	51.45	47.775	47.775	56.35
	5	51.45	50.225	49	47.775	53.9
12	1	34.3	34.3	35.525	37.975	35.525
	2	34.3	37.975	34.3	34.3	36.75
	3	35.525	37.975	36.75	36.75	36.75
	4	35.525	37.975	36.75	33.075	36.75
	5	34.3	37.975	36.75	35.525	36.75
13	1	56.35	50.225	55.125	53.9	51.45
	2	53.9	52.675	52.675	53.9	57.575
	3	53.9	53.9	53.9	52.675	57.575
	4	53.9	56.35	52.675	53.9	56.35
	5	55.125	57.575	55.125	53.9	57.575
14	1	52.675	51.45	50.225	51.45	53.9
	2	53.9	52.675	52.675	52.675	52.675

	3	52.675	56.35	52.675	53.9	57.575
	4	53.9	55.125	52.675	52.675	53.9
	5	52.675	53.9	52.675	52.675	57.575
15	1	66.15	61.25	63.7	62.475	63.7
	2	64.925	62.475	64.925	62.475	64.925
	3	66.15	62.475	61.25	64.925	64.925
	4	64.925	64.925	68.6	66.15	66.15
	5	64.925	64.925	64.925	62.475	63.7
16	1	71.05	71.05	66.15	73.5	72.275
	2	69.825	67.375	71.05	71.05	69.825
	3	69.825	68.6	67.375	64.925	72.275
	4	69.825	71.05	72.275	67.375	71.05
	5	72.275	67.375	73.5	72.275	68.6
17	1	47.775	39.2	45.325	42.875	46.55
	2	46.55	46.55	46.55	45.325	47.775
	3	46.55	45.325	47.775	46.55	46.55
	4	47.775	45.325	47.775	46.55	47.775
	5	46.55	45.325	45.325	45.325	49
18	1	40.425	39.2	37.975	39.2	42.875
	2	40.425	40.425	37.975	39.2	44.1
	3	40.425	39.2	40.425	41.65	39.2
	4	41.65	20.425	41.65	41.65	41.65
	5	40.425	39.2	39.2	40.425	40.425
19	1	64.77	64.77	64.77	66.04	67.31
	2	63.5	60.96	63.5	60.96	66.04
	3	62.23	63.5	63.5	63.5	63.5
	4	62.23	64.77	62.23	64.77	64.77
	5	64.77	64.77	64.77	62.23	64.77
20	1	73.66	72.39	76.2	74.93	77.47
	2	73.66	73.66	76.2	73.66	77.47
	3	73.66	72.39	77.47	74.93	76.2
	4	73.66	72.39	78.74	74.93	77.47
	5	74.93	74.93	77.47	76.2	76.2
21	1	54.61	40.64	52.07	54.61	55.88
	2	55.88	53.34	53.34	52.07	57.15
	3	55.88	53.34	52.07	54.61	55.88
	4	55.88	52.07	55.88	52.07	55.88
	5	55.88	55.88	55.88	53.34	57.15

22	1	54.61	53.34	53.34	59.69	57.15
	2	55.88	55.88	55.88	54.61	53.34
	3	55.88	49.53	57.15	57.15	58.42
	4	52.07	57.15	55.88	54.61	57.15
	5	54.61	57.15	55.88	57.15	57.15

Table K2

Ankle Dorsiflexion Angles (°)

Participant #	Trial	ASO-UNI	ASO-BI	T2-UNI	T2-BI	UB
1	1	32.6	28.9	31.9	31.9	33.1
	2	32.5	28.1	32.4	35.9	32.9
	3	32.6	33.9	34.5	33.8	32.1
	4	33.7	34	34.8	33.4	27.8
	5	27.3	34.3	35.2	30.4	31.6
2	1	31	34.7	35	38.3	33.3
	2	36.3	34	35.3	37	39.4
	3	35.9	32.1	35.1	40.4	34.8
	4	32.7	34.7	39.5	37.5	36.8
	5	31	36.6	35.9	33.5	34.4
3	1	39.2	35.6	38.4	38.3	39.6
	2	38.2	39.1	40.1	37.6	41.2
	3	36.5	39.2	38.1	41.7	38.2
	4	37.9	40.6	39.2	37.1	38.5
	5	39.5	35.6	38.9	40.8	36.8
4	1	32.7	33.7	35	35	30.2
	2	33.7	32	33.5	34.5	33.6
	3	34.6	34.6	34.9	34.2	33.8
	4	29.7	34.3	31.1	34.2	36
	5	31.5	30.8	34.5	34.4	34.1
5	1	22	25.6	32	27.4	25.1
	2	21.6	28.6	25.8	26.6	24.5
	3	21.2	23	26.8	25.1	23.3
	4	23.4	23.4	21.8	26.7	21.8
	5	22.5	23.7	23.5	23.3	27.1

6	1	23.4	27.5	28.9	28.4	27.3
	2	28.4	28.5	27.1	29.5	27.3
	3	29.2	26.7	26.2	26.2	28.9
	4	28.8	28.8	27.4	28.9	27.9
	5	28.8	27.3	28.5	29.3	30.2
7	1	26.3	31.4	25.5	33.9	30.4
	2	31.2	29.1	27.5	34.1	31.4
	3	31.2	31	30.8	32.6	34.1
	4	28.8	27.3	34.6	29	31.8
	5	30.4	26.2	31.1	31.8	33.5
8	1	31.5	29.1	35.5	34.4	32
	2	34.7	30.9	34	33.9	29.8
	3	32.8	34.4	32.9	34.7	33.3
	4	33	32.6	30.1	34.7	32.4
	5	33.7	32.4	30.5	33.2	32.1
9	1	36.1	35	35.3	38.4	38.3
	2	36.2	34.6	37.2	35.5	37.9
	3	36.2	32.8	35.7	34	37.6
	4	33.7	35.6	34	35.7	34.3
	5	36.8	36.8	35.9	36.9	32.7
10	1	27.4	22.9	23	23.1	23.2
	2	26.6	20.7	26	23.9	24.2
	3	21.1	21.3	26.5	23	23
	4	23.2	24.3	27.3	24.8	28.3
	5	23.8	24.2	29.8	28.2	24.7
11	1	25.1	25.2	26.6	25.6	27.4
	2	26.6	25.8	26.9	25.5	26
	3	27.2	/	28	27.4	28.1
	4	24.5	23.3	25.8	25.1	27.8
	5	25.2	26.2	26.2	27	24.4
12	1	26.2	26.3	29.8	26	29.4
	2	26	25.1	27.6	25.4	26.1
	3	23	26	26.7	28.6	22.6
	4	28.2	26.8	26.1	29.1	26.9
	5	27.2	26.5	26.4	27.5	29.5
13	1	33.1	34.7	32.9	32.7	34
	2	33.4	34.3	33.1	32.8	34.1
	3	33.1	34.8	32.7	32.9	31.3

	4	34.5	32.8	29.7	31.8	35.4
	5	33.5	33.4	30.9	32.3	36.8
14	1	27.3	32.1	28.4	29.7	28.3
	2	27.7	26.4	31.3	34.5	25.9
	3	26.4	26.1	29.8	30.4	30.3
	4	31.9	29.2	32.9	31.5	30.5
	5	29.2	32.8	31.1	29.5	30.5
15	1	27.9	25.7	22.3	30.6	22.6
	2	28.6	25.1	23.1	29.4	27.7
	3	23.4	24.5	25.3	28.7	31.9
	4	22.2	21.8	24.3	31.3	23.5
	5	15.9	19	31.3	30.5	24.7
16	1	23	25.7	35.2	32.3	31.6
	2	33.2	26.1	27.4	29	33.2
	3	31.6	29.4	33.4	29	30.9
	4	32.6	30.7	32.1	31.6	31.2
	5	34.4	27.7	31.8	29.5	28.8
17	1	27.4	29.6	30.1	29.3	32.7
	2	30.1	26.2	30.1	30.8	32
	3	27.7	26.8	30.2	31.5	30.6
	4	30.5	27.6	29.1	30.7	30.7
	5	30.2	28.1	31.2	30.6	30.4
18	1	28.9	32.8	31	31.4	30.2
	2	28.6	33.2	30.6	33.9	34.4
	3	32.6	33.5	32	30.7	33.6
	4	34.6	28.5	35.2	30.2	35.5
	5	26.3	29.9	33.7	34	38.8
19	1	30.8	28	26.3	28.4	27.3
	2	25.1	31.7	29.8	29.3	30.6
	3	24.8	29.6	28	31.3	28.7
	4	30.2	28.5	26.3	28.2	28.8
	5	33.2	33.2	31.3	29.1	28.2
20	1	26.6	24.3	23.9	24	26.3
	2	25.8	27.7	22.8	21.5	23.8
	3	25.3	27.7	22.9	20.6	24.7
	4	26.6	23.3	24.4	24.8	21.4
	5	22.2	23.2	23.1	24	25.5
21	1	20.8	22	19.7	23.9	25

	2	25.9	20.4	27.7	22.2	21.5
	3	25	20.5	25.6	21.8	25.4
	4	19.4	23.5	25.1	24.8	27
	5	24.7	22.3	26.7	22.2	25.4
22	1	19.7	23.1	23.3	27.8	19.9
	2	23.7	19.9	24.4	19.6	22.7
	3	23	28.3	24.1	23.4	21.8
	4	22.9	24.3	27.2	21.6	23.6
	5	19.7	23.9	25.3	26	24.5

Table K3

Ankle Plantarflexion Angles (°)

Participant #	Trial	ASO-UNI	ASO-BI	T2-UNI	T2-BI	UB
1	1	52.2	48.5	45.4	45.5	55.5
	2	47.1	50	50.4	46.8	52.2
	3	51.1	49.9	51.5	47.8	60.3
	4	49.1	47.4	52.1	48.4	54.9
	5	50.9	51.1	51.7	52.8	54.8
2	1	35.5	39.2	34.7	42.6	52.3
	2	44.2	42.3	42.9	38.5	50.9
	3	37.9	40.1	39.8	45.9	56.5
	4	43.6	42.7	44.4	46	50.5
	5	42	40.5	41.5	47.5	48.9
3	1	51.3	49.7	54.5	58.1	57.5
	2	52.6	47.5	53.9	52.7	58
	3	51.7	50.2	54.2	55	55.2
	4	54.9	51.6	57	54.1	55.4
	5	53.4	51.2	52.8	57.1	55.6
4	1	55.5	56	55.8	54.7	67.2
	2	58.8	56.4	58.2	54.8	56.8
	3	56.8	59.2	56.5	56.1	64.4
	4	54.8	55.4	57	57.8	63.4
	5	59.3	55.7	58.3	58.5	59.2
5	1	56.7	57.2	60.9	66.9	67.5

	2	63.3	59.3	59.6	64.6	67.7
	3	57.7	58.4	60.7	57.3	63
	4	64.8	63.7	58.5	64.2	67.3
	5	62.8	56.5	58.8	65.2	63.2
6	1	57.3	56.9	62.6	60.3	60.2
	2	60.2	57.2	59.1	61.8	58.1
	3	58.4	55.1	58.4	58.2	65.4
	4	59.9	57.4	61.3	58.4	65.8
	5	55.7	57.7	63.4	59.6	68.5
7	1	54.3	57.9	62.1	58.7	61.4
	2	56.6	58	59.9	60.8	61.5
	3	57.9	57.3	58.1	58.9	56.2
	4	55.8	56.8	58.7	61.3	54.7
	5	55.2	56.1	57.9	58.6	58.1
8	1	44.6	46.4	45	46.8	50.6
	2	46.8	46	45.9	47.1	51.5
	3	44.4	45.1	46.9	47.3	49.3
	4	44.2	46.1	45.2	43.5	50.3
	5	44.4	44.7	45.1	46.9	52.2
9	1	57.1	52.5	60	61.7	64.4
	2	56.6	56.4	59.7	61	60.8
	3	57.8	54.9	61.4	63	63.6
	4	63.3	53.1	60.6	62.1	66.5
	5	57.5	64.6	60.1	60.5	67.2
10	1	57.7	60.2	61.7	62.8	66.7
	2	55.7	53.7	59.9	58.3	63.1
	3	61.9	58.9	63.3	63.6	66.9
	4	60.8	51.1	58.6	62	66.2
	5	51.9	56.2	56.2	58.3	68.2
11	1	58.6	57.7	54.6	58.6	64.7
	2	56	56.5	58	55.9	62.9
	3	55.9	/	54.3	58.5	62.8
	4	59.7	56.6	57.6	55.1	64.7
	5	59.1	58.4	56.1	59.4	61.8
12	1	56.2	52	53.5	54.4	59.4
	2	57.2	51.9	57.1	57.4	62.7
	3	57.9	51.8	57.8	56.1	61.8
	4	55.3	48.3	57.6	59.2	61.3

	5	57.1	50.7	59.1	56.5	60.8
13	1	55.2	52.5	52.9	52.7	64.7
	2	54.4	60.4	58.2	59.1	68.2
	3	57.1	58.4	58	58.1	67.4
	4	55.6	55.1	57.5	59.9	68.2
	5	62.7	60.4	61.8	56.1	66.6
14	1	65.6	68.5	64.2	65.5	58.2
	2	63.5	71.2	63	59.8	65.8
	3	63.8	71.8	59.3	67.4	67.2
	4	67.1	63.6	64.4	62.5	65.7
	5	61.7	63.9	58.9	62.7	67.3
15	1	59.2	51.1	53.4	51.4	57.7
	2	52.7	54	55.1	55.2	62
	3	55.2	53.8	55.7	57.6	62.2
	4	60.8	51.1	54.4	55.6	59.4
	5	57.6	59.4	59.1	55.4	60.6
16	1	56.9	60.6	55.4	54.8	61.9
	2	58.8	54.5	61.3	55.4	66.6
	3	56.2	54.2	54.5	55.7	58.9
	4	56.2	59.8	59.1	58.2	61.3
	5	63.8	58.2	58.6	61.1	64.2
17	1	59.5	55.3	59.9	60.3	63.4
	2	61.8	54.6	67.4	61.4	64.2
	3	58	56.8	66.5	62.5	63.1
	4	60.4	56.7	62.5	65	66.9
	5	57.1	57.9	61.1	59.6	64.4
18	1	53.9	51.4	55.7	56.5	63.3
	2	55.7	58.9	63.5	58.5	61.5
	3	57.7	55	60.2	62.8	64.1
	4	56.5	62.5	57.7	57.8	59.4
	5	57.7	54.7	57	54.7	62.7
19	1	55.9	61.6	59.4	65.9	67.9
	2	60.2	60.7	59	64.5	67.3
	3	62.2	62.6	65.7	67.1	65.1
	4	61.5	61.6	63.3	63.8	69.4
	5	62	60.3	68.8	64.1	71.9
20	1	58.9	55.4	61.8	60.2	68.2
	2	61.5	55.8	62.1	64.9	69.6

	3	62.4	61.9	59.8	61.3	66.7
	4	60.2	55.6	63.1	60.5	67.6
	5	56.5	63.9	63.5	63.9	63.7
21	1	56.4	55.7	57.9	57.8	59.3
	2	52.6	56.8	58.3	58.4	64.2
	3	55.9	55.5	54	58.5	59.4
	4	57.7	55.5	58.4	59.5	62.8
	5	53.9	56.1	53.6	59.4	58.7
22	1	47.2	51.5	47.4	47.1	51.7
	2	45.3	48.3	50	46.1	53.5
	3	46.6	45.4	51.3	51.2	56.4
	4	49.4	44.4	50.3	47.6	48
	5	42.7	52.2	42.6	54	50.8

Table K4

Knee Flexion Angles (°)

Participant #	Trial	ASO-UNI	ASO-BI	T2-UNI	T2-BI	UB
1	1	103.6	99.5	101.7	98.8	97.5
	2	93.2	98.4	100.9	103.7	93.5
	3	101.9	97.4	101.1	103.6	96.7
	4	96.6	95.3	97.3	96.5	90.9
	5	102.1	109.9	105.6	98.6	94.1
2	1	103.3	112.7	105.7	105.7	103.5
	2	98.9	108.7	103.8	115	104.3
	3	105.1	103.7	100.3	115.5	103.6
	4	104.9	109.2	106.6	108.7	102.5
	5	99.5	103.6	108.9	108.9	108.2
3	1	102.1	110.1	104.6	98.2	98.5
	2	99.7	106.7	99.3	105.8	108.6
	3	95.5	98.5	105.6	107.8	101.9
	4	96.1	102.4	106.5	101.5	103.5
	5	94.3	98.4	101.9	108.7	99.8

4	1	89.5	98.1	89	97	91.6
	2	97.6	97.6	94.9	92.5	96.5
	3	99.3	99.8	97.7	94.4	91
	4	97	97.3	91.2	98	97.8
	5	102.1	103.9	101.9	98.8	106.2
5	1	82	83.3	86.8	85.5	82.9
	2	83.2	83	83.2	85	84.4
	3	82.4	75.6	80.8	85.8	87.7
	4	86.7	80.7	83.4	90	86.5
	5	85.9	86.3	83.1	86.8	91
6	1	102.9	104.2	90.1	92.7	96.6
	2	101.2	97.4	86.2	100.5	95.6
	3	95.2	93.6	95	94.8	100.5
	4	101.1	98.8	98.4	97.1	104.9
	5	97.3	87.7	91.9	96.1	98.8
7	1	91.5	90.4	96.7	108.8	111.2
	2	94.6	91.6	102.7	113	113.2
	3	101	94.2	110.5	116.2	114
	4	93.7	94.6	108.8	111.1	115.5
	5	99.2	93.2	110.3	111.9	110
8	1	100.6	100.8	107.7	106.6	111.4
	2	106.1	101.2	93.8	110.5	114.1
	3	104.2	108.3	107.5	99.6	109.5
	4	97.8	115.2	107.4	112.3	103.3
	5	103.1	115.4	101.8	116	99.9
9	1	88.2	91.4	88.1	90.3	89.9
	2	89.3	89.4	85	88.2	93.1
	3	86.3	88.7	93.3	88.7	95.7
	4	87.3	87.1	88	88.3	88.3
	5	93.1	92.9	90	90	85.7
10	1	72.7	78.6	78.2	71.4	72.4
	2	77.3	76.6	82.7	76.9	74.7
	3	78.3	75.7	81.7	71.5	76.7
	4	79.1	81.3	86.7	78.7	76.8
	5	83.3	79.2	84.9	84.7	77.1
11	1	94	92.6	90.9	93.7	83.4
	2	92	84.1	91.8	88.3	86.5
	3	94.1	/	94.1	93.8	84

	4	90.9	90.4	91.7	95.6	86.6
	5	91	92.6	93.5	91.6	85.6
12	1	86.6	84.5	91.6	94.7	90
	2	83.5	92.5	88.2	86.4	89.9
	3	90.4	90.7	97.1	94.3	90.3
	4	89.3	89.4	96.3	93.1	93.1
	5	92.6	90.6	93.3	90.4	91.8
13	1	103	97.3	108.6	105.1	99
	2	104.6	102.3	106.7	107.2	103.6
	3	101.6	101.6	110.5	108	100.3
	4	101.4	101.3	98.7	110	104.9
	5	100.1	98.5	108.4	104.9	108.4
14	1	87.8	91.5	90.7	99.3	87
	2	86.2	84.2	95.5	95	85.3
	3	82.9	84.9	87.6	91.8	89
	4	90.9	90	100.4	98.6	88.3
	5	83	88.4	97.7	99.6	92.3
15	1	117.8	105.9	113.1	121.3	107.7
	2	119.4	98.3	109.4	104.7	107.9
	3	104.9	103.2	113.6	112.4	106.9
	4	101.4	96.8	114.1	114	109.6
	5	96.4	96.8	128.8	113.7	107.6
16	1	76.9	84.7	83.3	88.8	87.7
	2	89.5	84.6	88.6	84	84.6
	3	83.4	86.1	84.8	85.8	91.9
	4	87.6	77.4	83.9	86.6	90.9
	5	90.6	92.4	87.3	87.2	82
17	1	83.6	90.6	87	90.1	88.1
	2	83.7	84.3	84.4	87.5	91.6
	3	80.6	87	83	88.9	91
	4	85.5	90.2	84.3	92.9	89
	5	85.4	85.6	87.2	87.7	88.5
18	1	89.5	97.9	112.8	94.3	96
	2	96.7	104.6	109.8	97.3	102.7
	3	95.5	92.9	104.6	94.6	98.3
	4	99.4	100.3	107.3	95.2	105.8
	5	100.7	100.8	99.2	88.6	105.9
19	1	102.3	95.2	105.6	101.5	100.2

	2	100.5	101.7	101	102.2	99.9
	3	98.9	100.2	100	102.2	104.1
	4	106.6	99.6	113.4	97.4	101.1
	5	101.6	99.6	102.1	101.1	106.3
20	1	85.2	80.4	76.3	86.4	83.3
	2	85.6	81.8	79.7	78.6	84.8
	3	94.1	81.8	80.9	81	79
	4	96.9	82.2	85.7	82.8	79.7
	5	83.5	83.8	86.6	87.6	85.1
21	1	84.1	80.7	75.9	82.2	79.3
	2	81.9	73.6	79.9	85.9	75.4
	3	85.9	74.7	72.5	87.2	76.8
	4	80.3	76.3	77	84.6	81
	5	79.3	78.8	81.6	89.7	81.2
22	1	81.9	83.2	84.2	82.2	82.9
	2	78.9	90	82.9	86	94.9
	3	86.4	93.1	83.1	81.3	82.4
	4	86.1	92.4	85.7	84	91.3
	5	89.6	88.2	87	90.9	84.5

Table K5

Hip Flexion Angles (°)

Participant #	Trial	ASO-UNI	ASO-BI	T2-UNI	T2-BI	UB
1	1	106.2	100.5	105.1	101.4	102.5
	2	102.7	101.6	104.4	101.5	102.7
	3	105.1	103.8	104.7	101.9	105.2
	4	104.1	103	103.7	102.2	102
	5	103.7	107.9	105.6	103.8	104.3
2	1	113	115.2	108.8	110.2	111.6
	2	112.6	110.3	111.2	112.8	110.3
	3	112.7	109.7	110.5	114.2	111.7
	4	109.5	112.8	110.4	113.6	112.6
	5	107.8	109.7	109.9	110.2	112.9

3	1	114.3	112.2	112.9	110.5	114.9
	2	115.2	113.7	109.9	114.8	114.5
	3	108.5	108.7	115.9	116.2	119
	4	109	111.2	115.5	116.4	115.1
	5	109.9	111.6	114.5	113.5	112.6
4	1	106.7	107.2	109.9	108.9	105.5
	2	108.1	102.6	107.2	108.3	103.6
	3	107.4	102	107.3	106.6	107.2
	4	108.3	107.9	106.1	109.9	106.5
	5	111.2	112.4	108	108.1	111.2
5	1	104.5	104.3	105.6	101.9	104.6
	2	106.9	103.5	104.3	101.8	109.2
	3	105.2	103.3	104.6	108.6	111.3
	4	109.6	103.6	108.5	106.4	108
	5	109.2	105.4	111.7	109	110.7
6	1	119.1	113.3	109.6	111.7	114.9
	2	114.7	113.1	107.1	113.2	117.4
	3	112.2	114.9	110.7	118.2	117.1
	4	116.4	113.6	115.8	113.4	116.5
	5	114.2	111.8	113.9	109.2	115.1
7	1	111	107.7	117.9	126.9	120.6
	2	111.7	110.9	125.5	129.2	127.4
	3	114.8	116	120.4	123.2	124.5
	4	114.5	117.3	119.8	128.4	127
	5	117.5	118.8	124.7	124.9	121.7
8	1	121.9	119.2	117.7	119.6	124.2
	2	119.5	115	112	122.5	125.6
	3	118.6	118	121.1	113.1	124.2
	4	114.7	122.7	122.9	119.8	118
	5	118.4	123.5	119.7	126.4	117.3
9	1	110.4	111	111.4	107.8	110.8
	2	111	111.3	108.1	109.2	109.9
	3	106.4	113	106.9	106.6	111.4
	4	108.4	111.7	109	109.3	112.2
	5	109	109.8	108.7	107.8	110.9
10	1	112.4	117.2	116	114.4	117.1
	2	114.1	117.8	115.7	115.8	115
	3	119.8	113.1	121.7	114.4	120.7

	4	112.5	116.9	115.8	116.6	112.7
	5	118.3	115.3	115.1	118.8	116.9
11	1	118.7	119.5	119	116.9	117.4
	2	119.2	114.8	118.5	120.5	116.7
	3	119.3	/	121.1	120.6	117.4
	4	117.1	117.4	116.5	122.5	117.7
	5	117.4	116.8	117.1	118.7	120.5
12	1	103.1	103	102.8	103.6	101.9
	2	99.3	105.1	98.3	98.9	99.5
	3	100.2	103.9	107.1	105.2	101
	4	103.5	103.7	109.8	101.1	100.5
	5	102.3	102.5	104.8	98.1	100.5
13	1	117.4	106.3	107.1	109.3	110.2
	2	111.4	108.9	110.3	107.2	107.2
	3	111.2	109.3	110.4	109.2	114
	4	110.5	109.8	108.3	106.8	112.3
	5	108.8	102.9	106.3	110.3	112.2
14	1	101.1	105.3	112	110.4	110.1
	2	106.9	99.5	107.4	101.6	104.4
	3	101.1	104.5	102.4	104.4	104.3
	4	103.4	100.3	112.3	112.8	113.5
	5	92.6	97.3	108.6	113.4	115.1
15	1	118.8	111.8	119.4	113.6	111.7
	2	119.5	107	113.4	107.9	107.3
	3	116.2	111.8	109.9	111.9	104.9
	4	109.3	104	113.2	106.9	112.2
	5	111.5	111.9	119	111.3	115.9
16	1	112	108.7	105	107.9	104.8
	2	108.9	113.1	112.5	111.4	102.6
	3	111.8	110.3	105.7	113.7	108.1
	4	109.9	108.9	111.9	107.2	114.6
	5	109.7	115.9	111	112.2	112.8
17	1	102.1	109.6	105.6	105	108
	2	100.8	109.2	108.4	106	108.7
	3	100.1	106.1	103.3	106.4	109.5
	4	103.1	107.6	106	108.5	107.4
	5	102.4	107.6	106.9	104.2	103.4

18	1	102.6	101.8	98.7	100.3	106.2
	2	105.2	104.6	99.4	103.2	104.1
	3	102.2	98.6	106	106.1	103.9
	4	100.5	102.6	100.2	105.8	106.4
	5	109.8	100.1	102.4	94.9	104.7
19	1	118.2	117.9	123	120.7	123.2
	2	120.7	119.4	121.5	123.4	119.1
	3	121.7	120.5	119.8	122.1	115.9
	4	119.8	118.6	130.9	123.8	121.1
	5	120.8	120.8	125	120.2	123.4
20	1	108.3	110.3	107.5	111.9	110.8
	2	109.8	108	107	108.5	111.3
	3	113.2	106	105.1	106.8	108.5
	4	116.6	103.8	109.2	110.3	105.2
	5	107.3	104.9	108	108	106.9
21	1	107	106.8	106.8	108	107.5
	2	110.2	106.6	108.8	103.7	108
	3	108	106.9	105.3	108.8	107.2
	4	104.3	102.8	105.1	107.1	106.5
	5	108.1	106.9	106.6	107	108.8
22	1	115.3	113.7	107.8	106.3	114.8
	2	112.4	115.3	111.1	116.5	115.6
	3	112.2	113.9	111.4	111.5	114.8
	4	115.7	118.1	111.5	114	114
	5	118.7	117.3	115.5	113	116.2

Table K6

Peak vGRFs (N)

Participant #	Trial	ASO-UNI	ASO-BI	T2-UNI	T2-BI	UB
1	1	1844.8	1673.44	1650.47	1612.71	1668.36
	2	1691.99	1674.48	1593.88	1621.09	1615.25
	3	1749.7	1703.47	1723.43	1724.75	1773.05
	4	1781.43	1646.61	1578.25	1653.95	1764.39
	5	1743.02	1705.07	1732.76	1763.73	1782.08

2	1	1698.48	1579.48	1627.68	1750.93	1739.82
	2	1691.99	1697.73	1668.64	1606.69	1700.08
	3	1695.38	1652.92	1700.93	1571.1	1653.01
	4	1719.48	1689.63	1673.16	1681.44	1651.5
	5	1716.28	1661.48	1643.88	1638.23	1740.29
3	1	1903.94	1856.74	1874.03	1921.52	1913.02
	2	1918.18	1791.37	1938.53	1863.33	1800.83
	3	1928.41	1924.77	1830.07	1879.96	1882.44
	4	1957.26	1920.09	1963.95	1888.84	1898.88
	5	1881.77	1975.42	1914.07	1867.34	1910.34
4	1	2028.37	1861.68	2131.81	2125.91	2097.9
	2	1994.65	1931.21	2025.13	1943.6	2011.03
	3	1975.98	1901.11	1959.69	2049.32	1840.63
	4	1909.21	1771.38	2104.76	1962.65	1940.64
	5	1901.88	1618.12	2004.46	1952.17	1959.98
5	1	1979.41	1916.64	1914.26	1961.69	2013.13
	2	1952.84	1959.6	2021.23	1987.6	1928.45
	3	1854.35	2036.66	2068.66	1994.36	1851.68
	4	1966.74	2045.7	1980.93	1914.64	1944.26
	5	1936.64	1968.55	2000.08	1898.92	1886.35
6	1	1915.69	1897.78	2011.99	2041.61	2026.37
	2	1849.3	1924.07	1993.79	1984.08	1904.73
	3	2005.51	1950.26	1998.94	1855.58	1902.73
	4	1931.78	1949.88	1986.55	1912.83	1924.64
	5	1933.5	1997.22	1954.07	1978.27	1817.58
7	1	2164.8	2135.24	1975.95	2000.41	2216.92
	2	2196.71	2174.62	1873.41	2193.5	2168.67
	3	2132.79	2052.81	2059.8	2180.75	2239.01
	4	2136.19	2043.18	1970.38	2098.42	2223.15
	5	2116.93	2069.62	2053.95	2010.61	2109.84
8	1	1845.94	1758.6	1751.89	1803.16	1773.99
	2	1778.8	1825.16	1828.05	1692.79	1689.2
	3	1720.07	1811.38	1782.86	1835.27	1739.43
	4	1939.7	1733.58	1744.62	1749.06	1781.54
	5	1783.15	1749.72	1841.88	1740.28	1817.7
9	1	1991.51	1835.52	1837.61	2001.92	2045.81
	2	1956.04	1949.51	1811.96	1990.19	1985.17
	3	2050.45	2035.5	1898.71	2049.6	1926.71

	4	1975.9	2036.73	1976.77	2018.19	1988.39
	5	1971.46	2033.99	2003.34	2100.49	2034.18
10	1	1559.01	1521.45	1464.4	1552.48	1522.11
	2	1518.42	1533.84	1487.86	1550.3	1518.89
	3	1517.66	1558.81	1546.89	1550.11	1471.97
	4	1531.29	1538.57	1466.11	1553.61	1532.99
	5	1499.78	1558.81	1517.38	1514.35	1556.26
11	1	2033.14	1941.09	2038.43	2019.7	2007.12
	2	1989.15	2000.78	1922.83	1956.79	2031.81
	3	1953.58	1946.01	1942.6	1958.88	1989.43
	4	1968.52	1941.94	1956.04	1992.84	2095.38
	5	2001.73	1977.13	1980.73	1978.74	2076.56
12	1	1601.8	1636.54	1591.89	1650.14	1599.54
	2	1690.35	1644.57	1640.51	1660.52	1631.82
	3	1656.74	1653.16	1622.11	1584.43	1584.62
	4	1634.94	1673.64	1585.1	1606.15	1617.66
	5	1698.01	1660.8	1628.52	1677.98	1611.53
13	1	1395.86	1420.08	1336.63	1369.93	1354.13
	2	1395.96	1408.35	1323.57	1312.31	1333.79
	3	1372.77	1316.38	1337.48	1311.55	1397.56
	4	1379.87	1392.45	1384.71	1333.03	1422.45
	5	1355.17	1433.99	1372.3	1342.21	1421.13
14	1	1898.07	1841.53	1750.66	1814.86	1864.98
	2	1873.49	1908.28	1743.47	1800.02	1956.22
	3	1953.67	1948.84	1896.08	1769.29	1836.23
	4	1854.67	1888.99	1707.26	1739.41	1817.98
	5	1912.35	1795.57	1810.99	1765.41	1921.99
15	1	1069.12	1013.05	978.35	1068.93	1128.88
	2	1011.16	1049.55	1019.38	996.12	1066.28
	3	1018.15	971.82	952.06	1015.03	1130.77
	4	979.1	1012.86	1090.87	1025.15	1006.9
	5	999.05	976.46	1022.88	990.54	1102.12
16	1	2121.61	2084.14	2032.67	2109.4	2022.73
	2	2008.25	2008.25	2030.96	1981.1	2017.72
	3	2011.38	2064.27	2055.94	1998.03	2051.4
	4	2056.04	2138.83	2044.68	1993.49	1995.29
	5	2000.02	1932.46	1972.01	1989.8	1971.73

17	1	1397.47	1404.38	1413.18	1377.13	1356.03
	2	1412.33	1424.44	1403.24	1417.72	1402.86
	3	1485.09	1439.67	1436.17	1419.52	1381.49
	4	1441.66	1396.43	1443.74	1397.38	1396.24
	5	1398.32	1410.81	1417.81	1369.37	1433.62
18	1	1363.12	1384.51	1310.13	1381.29	1400.31
	2	1325.18	1322.25	1294.52	1446.11	1293.67
	3	1291.4	1342.4	1232.26	1421.79	1344.77
	4	1294.43	1314.49	1309	1445.73	1311.36
	5	1344.67	1268.41	1323.76	1431.44	1346.09
19	1	1238.68	1289.48	1329.04	1219.7	1227.54
	2	1185.14	1287.49	1242.08	1180.99	1316.86
	3	1272.39	1268.89	1279.09	1326.77	1219.32
	4	1296.09	1288.06	1243.78	1231.03	1215.64
	5	1226.69	1252.56	1190.05	1239.81	1238.96
20	1	2461.69	2437.89	2589.15	2501.06	2555.92
	2	2398.9	2351.59	2642.03	2474.9	2518.43
	3	2186.17	2384.73	2713.5	2642.5	2660.63
	4	2216.29	2374.25	2577.73	2580.46	2704.53
	5	2468.01	2377.09	2588.96	2463.2	2594.06
21	1	1409.23	1597.06	1612.16	1481.21	1547.68
	2	1553.57	1672.27	1535.43	1452.53	1517.49
	3	1389.01	1631.72	1612.54	1436.1	1439.71
	4	1519.86	1544.17	1530.97	1349.97	1461.27
	5	1455.67	1638.75	1506.85	1303.06	1480.74
22	1	1748.24	1710.26	1975.49	1889.64	1786.13
	2	1793.73	1661.73	1857.83	1742.26	1668.85
	3	1721.84	1611.69	1819.46	1759.73	1734.01
	4	1648.15	1622.23	1756.31	1758.21	1702.66
	5	1636.28	1668.66	1665.44	1754.41	1652.81

Table K7

Net Vertical Impulse (N·s)

Participant #	Trial	ASO-UNI	ASO-BI	T2-UNI	T2-BI	UB
1	1	262.72	256.26	251.97	247.71	251.08
	2	255.12	250.44	242.82	245.83	252.82
	3	260.13	256.41	252.55	250.47	258.07
	4	260.58	256.16	248.79	244.41	257.25
	5	255.35	259.19	254.67	252.99	256.74
2	1	224.24	225.68	218.38	230.56	228.77
	2	227.96	231.01	220.15	227.1	232.26
	3	230.53	229.66	222.26	226.07	228.28
	4	232.39	232.56	223.83	228.96	228.81
	5	232.29	227.14	227.7	227.8	229.31
3	1	243.81	258.96	252.93	250.72	239.95
	2	254.93	245.1	251.82	254.65	240.91
	3	243.5	272.34	256.72	264.01	250.3
	4	261.93	255.3	252.16	247.72	255.6
	5	264.3	256.62	256.12	242.89	252.61
4	1	242.57	235.99	121.2	204.15	236.6
	2	223.65	246.89	121.43	203.27	243.44
	3	223.33	239.35	243.72	205.96	195.01
	4	177.32	182.11	202.02	120.48	228.09
	5	215.97	210.63	119.72	121.51	228.18
5	1	283.61	272.81	273.15	297.45	290.91
	2	283.93	288.21	260.61	285.26	294.25
	3	283.16	283.55	258.15	291.09	287.95
	4	268.89	283.5	280.96	286.55	288.64
	5	291.14	280.92	265.29	296.31	282.91
6	1	202.87	200.25	200.07	202.25	199.49
	2	192.39	192.17	200.65	204.88	176.89
	3	198.65	203.58	189.92	195.61	191.39
	4	199.95	201.98	195.52	194.22	206.47
	5	235.08	198.63	198.14	203.7	188.84

7	1	235.32	280.08	273.34	277.99	286.66
	2	288.03	293.82	284.18	291.01	259.42
	3	299.19	295.21	293.55	284.59	285.59
	4	239.44	293.84	289.16	287.89	277.04
	5	289.43	286.89	292.22	279.48	290.88
8	1	281.31	284.16	276.94	282.97	279.62
	2	279.79	288.02	266.88	279.19	277.44
	3	269.01	284.06	281.76	269.54	274.46
	4	275.5	285.21	278.86	281.44	275.64
	5	280.32	288.98	280.59	285.73	286.59
9	1	208.11	210.06	148.58	218.25	212.72
	2	203.44	183.12	40.3	215.33	211.86
	3	202.53	184.39	123.78	221.38	209.93
	4	204.34	214.23	214.94	216.58	209.01
	5	205.84	207.75	209.83	217.82	209.15
10	1	182.95	183.78	179.82	187.38	185.64
	2	182.99	191.22	180.99	190.37	186.25
	3	185.01	179.37	184.69	189.46	180.44
	4	186.4	193.73	179.18	192.79	187.21
	5	184.64	181.84	174.72	186.26	185.82
11	1	274.07	263.43	251.4	259.6	271.32
	2	263.25	257.02	272.83	265.11	273.72
	3	263.02	265.9	266.85	257.52	273.17
	4	261.86	267.77	255.28	258.94	272.76
	5	278.02	272.3	263.24	259.43	270.05
12	1	284.82	312.8	286.52	297.56	290.39
	2	282.49	303.67	287.88	288.26	287.85
	3	284.12	297.56	286.81	287.8	281.88
	4	288.28	310.92	292.76	287.51	291.49
	5	294.59	293.47	293.4	297.16	292.27
13	1	171.61	165.69	167.95	171	173.05
	2	165.01	167.8	165.92	166.39	170.63
	3	167.69	170.37	165.21	160.34	166.47
	4	171.74	173.3	144.1	166.84	175.55
	5	165.46	175.06	165.64	157.77	173.82
14	1	42.26	79.86	206.77	176.38	231.33
	2	228.65	223.22	211.76	217.98	231.92
	3	221.28	226.45	220.55	201.41	231.87

	4	141.62	225.79	211.66	211.39	113.94
	5	177.69	222.41	220.88	212.21	145.15
15	1	163.32	152.01	152.51	153.49	151.99
	2	157.47	156.28	151.87	152.04	149.03
	3	158.52	154.93	162.87	163.51	163.99
	4	160	166.58	154.35	153.4	150.02
	5	153.77	157.59	150.88	150.82	151.52
16	1	267.76	276.54	255.3	277.14	257.2
	2	253.84	264.52	282.47	275.2	247.51
	3	252.03	256.89	259.31	263.74	254.06
	4	251.45	275.2	266.8	266.66	255.18
	5	276.74	253.51	282.06	283.56	259.29
17	1	195.87	200.32	197.73	186.3	190.97
	2	203.73	203.31	195.13	197.11	189.44
	3	198.46	205.49	205.02	191.61	193.5
	4	194	194.52	199.24	195.5	195.84
	5	191.19	194.61	198.11	201.05	209.89
18	1	192.02	200.34	193.34	211.77	203.64
	2	202.52	197.65	191.66	208.93	196.57
	3	202.18	201.14	202.52	208.9	208.48
	4	203.59	201.09	203.31	205.71	215.48
	5	204.19	204.8	196.15	192.77	203.75
19	1	166.65	169.64	166.32	167.46	168.07
	2	159.65	169.03	168.03	163.07	165.25
	3	165.04	170.25	167.51	169.98	164.46
	4	162.6	172.3	165.81	170.5	162.27
	5	163.38	168.64	166.22	166.47	161.33
20	1	260.38	251.48	268.83	272.75	266.75
	2	256.58	248.31	272.85	261.94	266.45
	3	253.8	255.33	278.2	274.11	259.7
	4	255.03	252.45	274.22	258.25	254.38
	5	251.54	257.65	266.52	264.45	255.19
21	1	113.65	132.23	120.4	122.79	116.18
	2	118.13	113.5	119.01	119.82	115.55
	3	108.94	126.36	124.51	124.42	114.24
	4	117.09	126.93	125.54	119.01	112.22
	5	114.91	123.17	121.01	116.2	111.49

22	1	200.18	197.36	202.24	207.61	199.24
	2	196.01	203.64	200.09	201.88	198.47
	3	195.92	192.16	201.77	205.24	200.72
	4	192.37	201.27	201.42	203.43	198.16
	5	198.83	199.42	201.11	202.49	199.08

Table K8

Agility Time

Participant #	Trial	ASO-UNI	ASO-BI	T2-UNI	T2-BI	UB
1	1					
	2					
	3					
2	1	10.02	9.8	10.04	10.31	9.82
	2	9.9	9.81	9.67	10.2	9.64
	3	9.96	10.09	9.77	9.85	9.92
3	1	9.15	9.31	9.05	9.4	8.96
	2	9.03	8.91	9.06	9.07	8.91
	3	9.19	8.75	9.06	9.02	8.9
4	1	11.17	10.82	11.27	10.81	10.68
	2	10.85	11.06	10.94	10.99	10.58
	3	10.68	11.07	11.1	10.68	10.63
5	1	11.81	11.63	11.47	11.86	11.84
	2	11.76	11.61	11.75	11.83	11.7
	3	11.79	11.67	11.46	11.68	12.04
6	1	9.55	9.69	10.19	9.74	9.46
	2	9.61	9.35	10.12	9.39	9.47
	3	9.33	9.16	9.55	9.6	9.3
7	1	10.15	10.77	10.9	10.8	10.39
	2	10.44	10.25	10.52	10.66	10.47
	3	10.26	9.91	10.48	10.63	10.23
8	1	9.51	9.57	9.8	9.37	9.81
	2	9.35	9.3	9.33	9.01	10.25
	3	9.3	9.5	9.11	9.11	9.35

9	1	10.4	10.19	10.44	10.61	9.66
	2	10.18	9.98	10.33	10.35	10.02
	3	10.06	10.26	10.14	9.68	9.94
10	1	11.88	11.4	11.47	11.77	11.6
	2	11.35	11.12	11.79	11.81	11.41
	3	11.88	11.01	11.55	11.6	11.36
11	1	11.11	10.62	10.66	10.46	10.65
	2	11.02	10.49	10.34	10.68	10.65
	3	10.61	10.27	10.26	10.5	10.19
12	1	11.77	12.32	11.79	12.07	11.66
	2	12.01	12.1	11.97	11.79	11.68
	3	11.76	12.44	12.1	11.81	11.74
13	1	11.59	11.69	11.56	11.64	11.51
	2	11.18	11.71	11.3	11.64	11.44
	3	11.05	11.35	11.71	11.53	11.34
14	1	10.81	10.73	10.53	10.95	10.36
	2	10.58	10.39	10.44	11.16	10.69
	3	10.48	10.52	10.65	11	10.3
15	1	10.8	11.08	11.76	10.62	10.56
	2	10.48	10.53	11.23	10.66	10.51
	3	10.59	10.63	10.81	10.91	10.43
16	1	9.87	9.94	9.78	10.06	9.91
	2	9.94	9.98	9.96	10.03	9.72
	3	10.1	9.81	9.95	10.05	9.74
17	1	11.44	11.46	11.99	11.59	11.01
	2	11.29	11.35	11.66	11.76	11.06
	3	11.31	11.51	11.72	11.76	11.1
18	1	11.29	11.27	11.1	10.85	10.89
	2	11.23	11.03	10.82	10.79	11.28
	3	11.13	11.04	10.71	10.77	10.9
19	1	12.21	11.79	11.56	11.4	11.24
	2	12.16	11.72	11.24	11.54	11.34
	3	12.13	11.74	11.35	11.62	11.27
20	1	9.01	9.22	9.3	9.12	8.84
	2	9.27	8.95	9.24	8.95	9.35
	3	9.24	8.95	9.04	9.11	8.82
21	1	11.94	12.28	12.18	12.06	11.78
	2	11.88	11.79	12.15	11.82	11.82

	3	12.1	11.99	12.08	11.72	11.49
22	1	10.49	10.96	11.02	11.52	10.51
	2	10.76	10.91	10.93	10.96	10.75
	3	10.48	10.66	11.22	10.73	11.03