Effect of Selected Ankle Supports on Resistance to Inversion Force and Range of Motion

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Abstract

Ankle injuries account for 15-60% of all volleyball injuries (Briner & Benjamin, 1999). The majority of injuries are sprains caused by excessive inversion which stretch and tear the lateral ligaments of the ankle. The incidence of reoccurrence and chronic instability is very high. Ankle braces have been designed to protect ankles from injuries by limiting inversion range of motion and supporting weakened ligaments. High-top volleyball shoes were also created to provide additional support to the ankle and prevent injury during play. The mechanism by which these supports prevent injury had not been quantitatively measured. The purpose of this study was to determine if the ankle supports chosen were able to provide increased resistance to inversion, as measured by moment of force, without limiting plantar flexion or dorsiflexion. Resistance to inversion moment of force was measured on an isokinetic dynamometer (KinCom) in passive mode, for six support conditions (low-top (LT) and midcut (MC) shoes with semi-rigid and flexible orthoses). The braces used were the Active Ankle T1 Trainer (AA) and the Ankle Stabilizing Orthosis (ASO). The shoes were ASICS Gel Airier volleyball shoes in low-top and midcut models. It was found that there was a significant difference in resistance to inversion moment of force mean, between the MC alone and the LT with AA. The MC and brace combinations provided less resistance to inversion. The construction of the midcut shoe may have interfered with the brace, inhibiting its performance. Plantar flexion ($F(5,145) = 8.264$) and dorsiflexion ($F(5,145) = 8.264$) range of motion were decreased in the MC conditions. These did not impede normal parameters for walking. It was concluded that the best support condition was the combination of LT and AA. It decreased sagittal range of motion the least and provided increased force to resist inversion as compared to the control condition (LT).

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Acknowledgements

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Chapter 1: Introduction

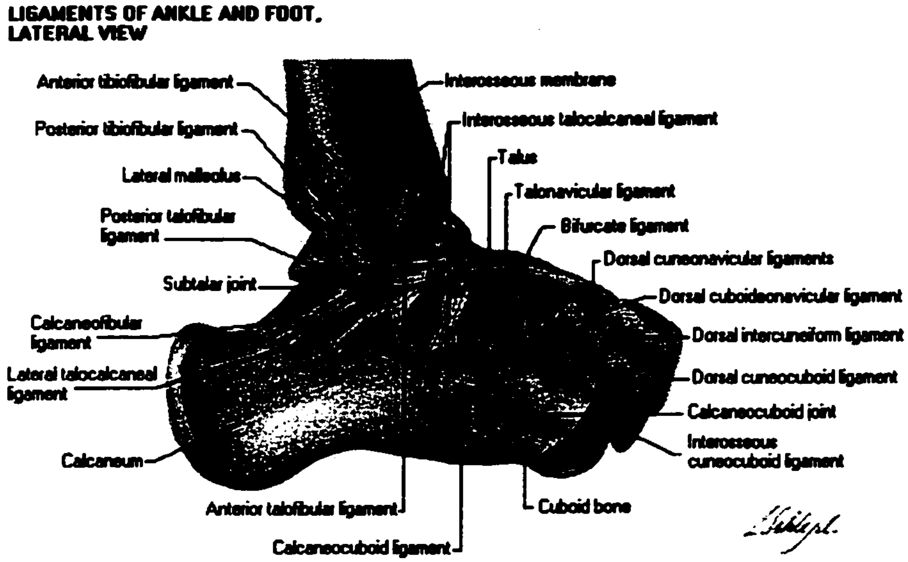
Ankle sprains account for almost 85% of all ankle injuries and can account for 15% of all injuries requiring time away from activity (Garrick, 1977). As Garrick (1997) indicated, ankle sprains are "a major threat to participants in all sports" (p. 242). Sprains occur most frequently in sports which involve running, jumping and quick lateral movements, such as basketball, football and volleyball (Barrett & Bilisko, 1998). In volleyball, ankle sprains account for 15-60% of all injuries (Briner & Benjamin, 1999). As the most common acute injury, sprains are caused by landing improperly, either on the floor or another player's foot, or by repetitive jumping (Bahr, Karlsen, Lian, & Øvrebø, 1994). The incidence of reoccurrence of ankle injuries is very high. Chronic pain or instability occurs in 20-50% of all people who have suffered ankle sprains (Robbins & Waked, 1998).

Ankle sprains can occur in everyday life, not just on the playing field. Many sprains are caused by stepping on uneven ground and falling (Moore & Dalley, 1999). Robbins & Waked (1998) determined that the most common cause of ankle injuries was an unanticipated foot placement on a sloped surface or inappropriate positioning of the foot in space before contact with a surface. For example, slipping on gravel or ice can result in forced inversion, causing injury. This is of serious concern to the elderly population where long periods of immobilization and the lengthy recovery time can lead to future problems. Chronic ankle instability can cause falls which may result in more serious injuries as well.

Description of Ankle Anatomy and Injuries

The ankle joint is a hinge type synovial joint, located between the superior part of the talus and the distal aspects of the tibia and the fibula (Figure 1.1). The distal ends of the tibia and fibula form a deep socket into which the trochlea of the talus fits. The lateral malleolus of the fibula articulates with the lateral surface of the talus; the medial malleolus and the inferior surface of the tibia both articulate with the talus. The ankle joint is less stable during plantar flexion because the narrow posterior end of the trochlea is not tight within the mortise. It is the subtalar and transverse tarsal joints of the foot that allow for inversion and eversion. The subtalar joint is between the talus and the calcaneus, and the transverse tarsal joint is formed by two separate joints which are transversely aligned, the talonavicular and the calcaneocuboid articulations. (Moore & Dalley, 1999)

Ankle sprains usually result from an inversion and plantar flexion movement. Eversion sprains are rare in the general population and are only a common sport injury in wrestling (Garrick, 1977). Inversion is the movement of the foot so that the sole faces toward the medial aspect and downwards (Figure 1.2). Forced inversion, is uncontrolled inversion due to external forces. Plantar flexion points the toes downward, such as standing on your toes (Figure 1.3). Dorsiflexion occurs when lifting the toes off the ground and decrease the angle between the dorsum of the foot and the anterior aspect of the lower leg (Figure 1.3) (Moore & Dalley, 1993). When the inversion is great enough, lateral ankle sprains usually occur on contact with the ground with the lateral ligaments being the most commonly injured (Kreighbaum & Barthels, 1996). These ligaments include the anterior talofibular ligament (ATFL), the posterior talofibular ligament (PTFL) and the



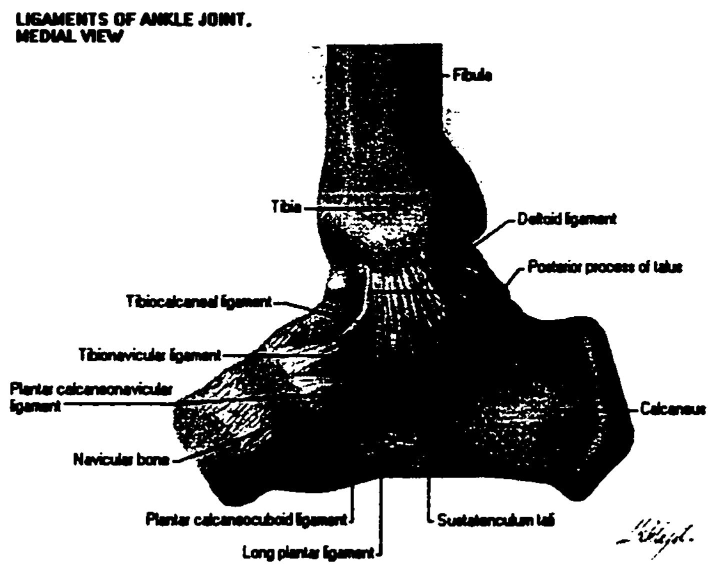


Figure 1.1. Lateral and medial views of the ankle joint. (Oberson, 1998)

calcaneofibular ligament (CFL). The tendon of the peroneal muscles adds lateral support to the ankle and can also be damaged. The lateral side of the ankle is weaker than the medial side, because the deltoid ligament (medial) is much stronger than the combined lateral ligaments (Safran, Benedetti, Bartolozzi & Mandelbaum, 1999a). There is greater susceptibility to inversion injuries because the lateral malleolus projects more distally than the medial malleolus resulting in less bony obstruction to inversion than eversion (Figure 1.1).

The anterior talofibular ligament allows for "stabilization against rotation of the ankle" (Barrett, Tanji, Drake, Fuller, Kawasaki & Fenton, 1993: 583). It is the primary restraint against plantar flexion and internal rotation. However, the ATFL is a generally weak ligament in that it is only a thickening of the anterior joint capsule. This ligament is most commonly ruptured in severe sprains (Figure 1.4). The calcaneofibular ligament is an extra-articular ligament closely associated with the peroneal tendon sheath, and its rupture can lead to damage of the sheath. The posterior talofibular ligament is the strongest lateral ligament and is rarely injured except for severe trauma. (Renström & Kondradsen, 1997)

Each of the ligaments play a different stabilizing role during movement of the ankle. There is coordinated effort so that at least one of the lateral ligaments is tight throughout the entire range of motion (Walgenbach, 1996). During dorsiflexion, the PTFL is maximally stressed, the CFL prevents talar tilt and the ATFL is relaxed. The opposite occurs during plantar flexion, where the ATFL is taut and the others are relaxed (Hintermann, 1999). This explains why the ATFL is most commonly injured. Since most injuries occur during a combination of plantar flexion and inversion, the ATFL is torn as it

Figure 1.2. Inversion and Eversion movements. (Moore & Dalley, 1999:8)

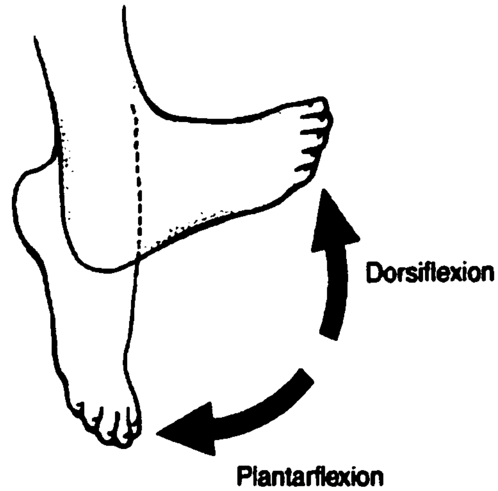


Figure 1.3. Sagittal plane motion of the ankle. (Moore & Dalley, 1999:9)

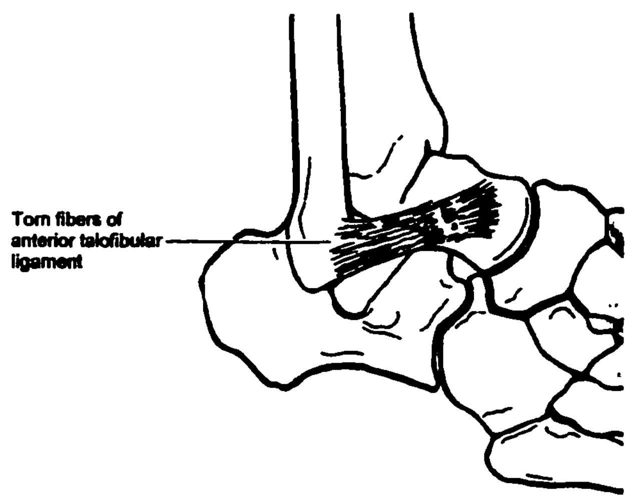


Figure 1.4. Severe ankle sprain, as seen by torn ligaments. (Moore & Dalley, 1999:636)

is stretched beyond its limits. Loss of the ATFL or CFL can lead to an increase in inversion, increasing the chance of further injury to the ankle ligament complex.

There are three levels of ankle sprains. Grade 1 sprains involve a stretch of the ligaments and no macroscopic tearing. There is very little swelling or tenderness, and no mechanical instability or minimal functional loss. If there is a partial macroscopic tear the sprain is considered to be Grade 2 (Figure 1.4). Moderate pain or swelling are associated with this degree, as well as mild to moderate instability and loss of motion. The most severe sprain is a Grade 3 sprain, where complete rupture of the ligament occurs. There is severe swelling and tenderness and weight-bearing is impossible, as there is limited function. The joint may have abnormal function and instability, even after a recovery period (Renström & Kondradsen, 1997).

Functional instability can become chronic in those who have had multiple sprains or who do not fully rehabilitate their injury. Ankle injuries can take up to a year to completely heal. Ankle braces and shoes that can prevent injury and provide support to the ankle are very important during rehabilitation and in reducing the occurrence of injuries. Protected weight-bearing and return to activity are important in ensuring full recovery and aiding those with chronic instability.

Ankle Supports

Ankle braces were created to support ankles as an alternative to taping. Athletic therapists and coaches have often taped athletes' ankles to help prevent the occurrence of ankle injuries and provide extra support to unstable ankles. Braces have many advantages over athletic tape. They are re-usable and more cost-effective over the long term, can be applied by the individual and re-tightened during use (Siegler, Liu, Sennett, Nobilini, & Dunbar, 1997). They can also be used in a non-athletic environment.

There are two main types of ankle braces, non-rigid stabilizers and semi-rigid orthosis. The non-rigid stabilizers are often referred to as 'lace-up' ankle braces. These supports have bilateral supports sewn together to allow for opening at the heel. The Achilles tendon is protected by elasticized heel counters, and there is a padded tongue beneath the laces. Some of these braces have additional supports that are permanent or removable. These non-rigid stabilizers are preferred above tape because they can be easily re-tightened (Kaminski, 1998). The Ankle Stabilizing Orthosis (Medical Specialities Inc., Charlotte, NC) is a non-rigid stabilizer. It is a lace-up brace with additional straps in a figure-eight pattern, similar to a classic ankle tape job.

Originally designed for the early immobilization of acute injuries, semi-rigid orthoses are in the shape of moulded plastic stirrups. The prefabricated plastic sides fit around the arch of the foot and cover both malleoli. The sides are secured using Velcro or elastic straps. Plantar flexion and dorsiflexion are not inhibited but inversion and eversion are limited (Kaminski, 1998). The Active Ankle Trainer T1 (Active Ankle Systems Inc., Louisville, KY) is an example of a semi-rigid orthosis. It is slightly smaller than those designed for injury rehabilitation, as it is designed for wear during sport. It is secured by two large velcro straps that wrap around the lower leg, and a small strap that covers the Achilles tendon.

There has been some debate as to the role of ankle braces and how they are able to reduce ankle sprains. Ankle braces are designed to limit the ankle range of motion to prevent injury. By restricting the inversion available, braces reduce the possibility of an inversion sprain occurring (Hume & Gerrard, 1998). The application of the brace forces the foot into a dorsiflexed and everted position. This would maintain the ankle in a more correct anatomical position at impact (Thonnard, Bragard, Willems & Plaghki, 1996). The foot is not able to plantar flex and invert because of its starting position. The mechanical restrictions may alter a person's landing pattern and prevent inversion from occurring during the fall before the actual landing (Kinzey, Ingersoll & Knight, 1997).

Another important function of ankle braces is to absorb the force at the ankle and protect the ankle ligaments (Hume & Gerrard, 1998). They provide an external support to compensate for the lack of internal support from damaged ligaments. The increased stability should help to prevent further injury from occurring. The use of a brace can provide support when the evertor muscles are relaxed and by increasing the maximal resistance to inversion when these muscles are activated (Renström & Kondradsen, 1997).

High-top athletic shoes are also designed to provide more ankle support than other athletic shoes. The main role is to stop the ankle from 'going over' by forced inversion of the ankle. High-top shoes provide support to the level of the malleoli. They are recommended for sports, such as volleyball, where ankle injuries frequently occur due to jumping and lateral movements (Barrett & Bilisko, 1998).

There are many types of shoes and braces available on the market which vary in cost and effectiveness. Many of the braces have been studied by researchers, but no one has identified the "best" brace consistently. The classic high-top shoe made popular by

Converse® that covered the lower leg above the malleoli are not readily available today. The trend has shifted towards a midcut shoe that ends at the level of the malleoli. Both midcut and high-top shoe may be used interchangeably as the 'true' high-cuts no longer exist.

Purpose Statement

The purpose of this study was to determine if the ankle braces and volleyball shoes chosen were able to provide increased resistance as measured by moment of force to prevent inversion to reduce ankle injury, without limiting ankle plantar flexion or dorsiflexion which would hinder performance. Based on this, there were four hypotheses for the study:

1) High-top volleyball shoes would increase the resistance to inversion, as compared to low-top volleyball shoes.
2) Braces would increase the resistance to inversion force, as compared to the unbraced condition.
3) The combination of high-cut volleyball shoes and a brace would increase the resistance to inversion force to the greatest extent.
4) There would be no reduction of plantar flexion and dorsiflexion with the various support conditions.

Rationale

Ankle sprains affect all segments of the population, from the athletic to the elderly. Recovery from ankle injuries is often not complete, and many people continue to suffer chronic problems as a result. By understanding which of the ankle braces increase the resistance to inversion, will allow people to chose the best brace available to reduce injury. Determining if ankle braces decrease active range of motion will explain why braces are seen to reduce performance. If we are able to identify which brace is able to prevent inversion injury without being detrimental to performance, this will help athletes understand what they must do in order to maintain a high level of performance while protecting themselves against injury.

The use of the KinCom and the method used to evaluate the ankle braces have not been used before. This will fill the gaps in the available literature. Furthermore, there has not been enough research on the role of shoes in preventing injuries. The use of both ankle braces and shoes in the same study will add to the knowledge on the subject of ankle braces. There has been a lack of studies including both weight-bearing subjects and footwear (Hartsell & Spaulding, 1997). Examining the force that the ankle support provides to act against inversion is a new way of approaching the research. It allows a more precise measurement of the supports ability to prevent injury.

Prevention of volleyball injuries has not been examined, and studies involving volleyball shoes are non-existent. While volleyball and basketball shoes are similar each shoe type is designed especially for the sport. It would be of interest to the over 800 million volleyball participants worldwide to see a study examining a volleyball shoe. Ankle injuries account for 15-60% of all volleyball injuries (Briner & Kacmar, 1997). More injuries to the ankle occur in indoor volleyball as compared to beach volleyball. In beach volleyball there is a softer surface and less players. Most volleyball ankle injuries occur from landing on the floor or another person's foot (Aagard, Scavenius & Jørgensen, 1997). In volleyball, there was found to be 1 ankle inversion injury per 1000 playing hours. That means that during a volleyball season at least one player will be injured (Bahr, Karlsen, Lian, & Øvrebø, 1994). If this number can be reduced by determining which ankle support can best resist inversion without limiting athletic performance, it would be very beneficial. The studies on volleyball only report either the mechanism of injury during play or the injury rates. The biomechanical considerations had not yet been examined.

Limitations

The limitations of this study were that the forces being tested will not replicate actual injury causing forces. This is due to the fact that actual subjects were used instead of cadavers to be able to examine the dynamic interaction that occurs in a live ankle. Actual subjects could not be harmed during testing. The active measurement of plantar flexion and dorsiflexion may not have tested the limits of the brace. This was only measured to ensure that the brace would allow normal movement and not interfere with athletic performance.

Delimitations

This study only examined ankles that were free of injury at the time of testing. This was to ensure that all ankles tested had relatively the same stability. There is such a variance in previously injured ankles that those ankles would have to be completed tested for ankle stability before the study. To eliminate this, only non-injured ankles were studied. Only inversion and eversion were examined for force resistance.

Chapter 2: Review of Literature

Role of shoes in injury prevention

High-top athletic shoes are supposed to help prevent ankle sprains. Ankle instability occurs during loading and unloading of the foot, so the shoe should reduce impact, alter the pressure distribution and provide stability during the push-off phase of gait (Barnes & Smith, 1994). The increased shoe height should help to prevent excessive movement. However, problems may be caused by stress being redirected from the ankle to the shins during extended periods of running, causing lower leg problems. High-top shoes are not recommended for running, they are better suited to sports which require short bursts of speed and quick lateral movements.

Barrett and associates (1993) studied the incidences of ankle sprains in collegiate intramural basketball players. The players wore low- or high-top basketball shoes for the entire season. Any injuries that occurred during the games were recorded. It was found that there was no difference between high- and low-top basketball shoes in the prevention of ankle sprains. The study had a low incidence of ankle injuries in all of the groups, which may have affected their results.

Another study, looking at football injuries while wearing higher cut football shoes, in one team there was only one ankle injury over two full seasons (Bauer, 1970). While this value seems low, it was not compared to any control group. It is assumed that the normal rate of injury is greater than 0.5 injuries per season, and that the high-top football shoe decreased the injury rates. The higher cut shoes slightly decreased performance on a forward run, backward run and agility run. This was only significant in the forward run. The lower cut shoes may slightly decrease performance on tests, but actual play did not seem to be altered with either of the shoes.

In laboratory studies, high-top shoes decreased the amount of plantar flexion and inversion allowed which should relate to a decrease in ankle injury (Ottavini, Ashton-Miller, Kothari, & Wojtys, 1995). As well, the amount of inversion allowed was decreased at varying degrees of plantar flexion.

Cadaveric studies have also shown that the use of high-top shoes can increase the effectiveness of the applied brace (Shapiro, Kabo, Mitchell & Loren, 1994). The more support that the ankle has, the less forced inversion that will occur. The high-top shoe had twice the resistance to inversion at both positions, neutral and 30° of plantar flexion, than the low-top shoe.

Stiffness is affected by the height of soccer shoes. In measurements of torque and deflection (Johnson, Dowson & Wright, 1976) the old fashioned high boot was 50% stiffer than either of the low-cut shoes examined. The increased stiffness of the shoe was seen to reduce the loads carried by the collateral ligaments in potential inversion or eversion injury situations. The shoes with lower stiffness values increased the load carried by the ligaments and therefore increased the possibility of injuries. Actual injury rates were not described.

While it seems that popular belief and personal preferences have made high-top shoes the shoe of choice for volleyball and basketball, there is not research that validates this notion in real life situations. Research has shown that shoes can increase the effectiveness of a brace and reduce excessive motion. This should translate into decreased injury rates, but this has not been shown conclusively.

Ankle braces

A variety of ankle braces were tested in the literature. The effectiveness of braces were mainly tested by the amount of inversion they limited. Several testing devices were used, including the Cybex II+ isokinetic dynamometer (Alves, Alday, Ketcham, & Lentell, 1992) and the pedal goniometer (Tweedy, Carson & Vincenzino, 1994).

The research on the ability of ankle braces to limit ankle inversion found that inversion was reduced with the application of any ankle brace. Braces were effective even after extended periods of exercise (Tweedy et al., 1994). Braces also provided support in resisting external inversion moments (Bunch, Bednarski, Holland, & Macinanti, 1985). This testing was done on an anatomically correct foot form which could only do inversion and eversion. All of the braces limited inversion, even after repeated trials. The lace-on brace loosened during testing but still reduced the range of motion from the unbraced condition. The original level of support was restored when the brace was relaced. As the braces were being compared to tape, the loosening was not significant. The decrease in support from the tape loosening was much greater.

Both active and passive range of motion was reduced with the Malleoloc semi-rigid orthosis (Wiley & Nigg, 1996). Active plantar flexion and dorsiflexion were reduced but it was not considered physiologically relevant. Passive inversion was reduced with the ankle in four different flexed positions, ranging from 40° of plantar flexion to 20° of dorsiflexion.

Using the Cybex II+ isokinetic dynamometer, Alves and colleagues (1992) found that semi-rigid plastic orthoses were better at limiting passive inversion and eversion than the neoprene or lace-on braces. The total range of motion, not just inversion, was measured, therefore, it was not clear if the inversion or eversion aspect had been reduced. Limiting inversion is more important than limiting eversion, since less eversion injuries occur. The researchers should have been clearer in describing what was limited. The subjects chose the neoprene brace as their brace of choice, based on perceived support and comfort. None of the other studies reviewed factored patient preference into the evaluation of the braces.

Inversion alone is not the main cause of ankle injuries. Shapiro and associates (1994) looked at the ability of ankle braces to resist externally applied inversion moments at 30° of plantar flexion and at the neutral position. The ankle braces increased the moment that could be resisted, as compared to the unsupported ankle. At 30° of plantar flexion, less force was required to invert the ankle than at the neutral position. This was true for both the supported and unsupported conditions. Cadaveric ankles were used, so no muscle support was available to resist the inversion forces. This demonstrated the effect of the ankle braces alone; the ankle brace resisted force even when there was no other support available. This is essential for people with damaged ligaments or limited motor control of the leg.

The Ankle Flexibility Tester was used to determine the passive support of four braces along all three axes of rotation (Siegler, Lapointe, Nobilini & Berman, 1996). All of the braces limited internal rotation, inversion and eversion. Ankle braces should not limit pure plantar flexion and dorsiflexion, as it can be detrimental to athletic success (Bot & van Mechelen, 1999). All of the braces limited flexion to some extent, but this may have been due to the construction of the brace and the materials used (Siegler et al., 1997).

The lateral ligaments of the ankle can be stressed with horizontal rotation causing ankle sprains, making reduction of rotational movements an important component of ankle brace design. In the horizontal plane there is a lack of supporting muscular structure, so the passive strength of the ligaments is important (Bruns, Scherlitz, & Lussenhop, 1996). All of the braces studied were able to significantly reduce internal rotation of cadaveric ankles with severed ligaments. External rotation was also reduced, but it was not as significant as internal rotation. External rotation does not result in as many ankle sprains, so it does not need to be reduced to as great an extent.

It has been shown that braces do not absorb external inversion forces. Ground reaction forces did not differ between braced and unbraced conditions. (Cordova, Armstrong, Rankin & Yeasting, 1998). It was concluded by the researchers that bracing may only be effective early in the motion by supporting the peroneus longus activity and stabilizing the foot against forced inversion.

Although not as prevalent in the literature, studies have also been done to determine the effects of braces on inversion during actual movements. Simpson, Cravens, Highbie, Theodorou and DelRey (1999) studied the amount of inversion during a side-shuffle while braced and unbraced. This movement is representative of lateral movements in sports such as basketball and football. It was found that the braces did not reduce the inversion of the foot in the landing aspect of the shuffle step as had been hypothesized. This may have been because the degree of inversion did not exceed the normal range of motion and therefore it did not need to be reduced. It may have also been due to the type of subjects chosen for the study. The subjects had all participated in sports involving lateral movements and may have been able to protect themselves from injury by modifying their landing pattern.

The passive ankle inversion and eversion studied by Gross, Ballard and Watkins (1992) was not pure inversion or eversion. The inversion measured by the Biodex dynamometer was actually a triplanar movement incorporating plantar flexion, inversion and adduction. Eversion was comprised of abduction, eversion and dorsiflexion. This meant that it was not clear which movement was reduced by the application of the braces. It could have been that the braces reduced plantar flexion which was measured as part of inversion. This could be detrimental to athletic performance. The braces tested were the DonJoy Ankle Ligament Protector and the Ankle Support. After the application of the braces the angular displacement was measured before and after a brief exercise period. Angular displacement was measured with three different maximum moments of force. Eversion displacement was measured until the maximum resisting moment occurred, the attachment then moved the foot into inversion. The maximum force at the end of the range of motion was not measured, since the predetermined maximums occurred within the normal range of motion. The authors found that both of the ankle braces restricted ankle eversion, before and after exercise. The Ankle Ligament Protector (ALP) restricted inversion to a greater extent than the Ankle Support (AS). Since there are more lateral ankle injuries the ALP was seen to provide greater protection against injury.

Ankle injuries should be treated immediately after injury to reduce posttraumatic complaints. This treatment usually involves a period of rest and then functional treatment. Functional treatment can involve the wearing of a brace. Vaes and associates (1998) compared eleven different subsamples to "examine the influence of different types of external support on pathological mobility" (Vaes, et al., 1998: 158). Roentgen stress tests were done at least six months after the injury. A variety of support devices, including braces and bandages, were used. All of the ankle support conditions were tested without footwear. The ankle was plantar flexed and then stressed into inversion with a 15 kg force. Two of the braces studied were found to influence talar tilt to the greatest extent. Talar tilt was limited to within normal physiological ranges. The Aircast brace and the Step-in-Safety brace were recommended for those with chronic instability to prevent further injury. This study tried to examine too many different combinations and was unable to reach strong conclusions. With all of the subjects having previously injured ankles and complaints of chronic problems the study was best suited to answering the questions of which external support helps chronically unstable ankles. During testing the subjects did not wear shoes. Many of the braces are designed to be worn inside shoes and are not as effective otherwise. It was assumed that those participating in sports would be wearing shoes. To be more applicable to the real world, studies should attempt to replicate the conditions of the sporting environment.

To reduce injuries, inversion should be limited without affecting the normal ranges of plantar flexion and dorsiflexion. By measuring the peak torque at three different speeds on the Cybex 340 isokinetic dynamometer, it was found that the plantar flexion peak torque was reduced at 30°/s and 120°/s with the application of ankle support (Gehlsen, Pearson & Bahamonde, 1991). Dorsiflexion work was not reduced. By only examining plantar flexion and dorsiflexion it is unclear if the braces reduced inversion, helping to prevent injury. Plantar flexion work and range of motion should not be limited by the application of external support as this may result in decreased athletic performance.

Chronic instability of the ankle results in excessive motion in the ankle joint and "reduces the ability of the foot to adapt to changing terrain and to act as a shock absorber, rigid lever, or torque converter." (Hartsell & Spaulding, 1997: 144). Those with chronic instability should benefit more from the application of external support. It was seen that the Swede-O and Sure-Step braces restricted inversion and increased torque to a greater extent in those with chronic instability. The Sure-Step semi-rigid brace was more effective than the flexible Swede-O, in decreasing the range of motion and increasing the force necessary to achieve the maximum angle. This study used barefoot subjects in non-weight bearing positions. The braces are designed to be worn in athletic footwear and should be tested in this way. By not using weight bearing positions, there is a difficulty in correctly extrapolating the results to weight bearing situations. It is in weight bearing positions that the majority of ankle injuries occur.

There has been discussion and debate over the best way to protect ankles from injury. Braces available on the market have been seen to reduce ankle inversion but may also adversely affect performance. The impact of strong evertor muscles on injury reduction is not clear. Strong evertor muscles should be able to act against external inversion moments. However, these muscles would have to be recruited quickly as ankle injuries occur rapidly and unexpectedly. At 15° of ankle inversion the greatest resistance, three times the normal, was provided by the evertor muscles, peroneal muscle group. Without these muscles activated, the combination of 3/4 height shoe and orthoses doubled the ankle resistance. It was concluded by Ashton-Miller and research team (1996) that the "precontracted and strong evertor muscles appear to be the most effective form of ankle protection at foot strike"(Ashton-Miller, Ottaviani, Hutchinson & Wojtys, 1996: 807). The external inversion moment was applied by the body. The subjects had to balance unipedally with their ankles at 15° of inversion. Injuries normally occur rapidly and the force exerted on the ankle is typically greater than the weight of the body, such as when landing from a jump or during running. The force exerted on the ankle at this time can be four or five times the body weight, thus, the testing did not accurately represent the stress placed on the ankle during a normal athletic event.

It has been shown that braces do not completely restrict inversion and eversion during running. Scheuffelen, Rapp, Gollhofer, and Lohrer found that there was increased plantar flexion during running (1993). Braces restricted dorsiflexion in treadmill running. This could be due to the construction of the brace. The braces laced up starting parallel to the malleoli and ended 10 cm up the leg. The braces did bring the range of angular displacement closer to neutral condition by maintaining the angle of the Achilles tendon at 180°. Inversion and eversion were limited as the foot stayed in a neutral position.

While braces do provide more stabilizing support to the ankle than tape, their effectiveness can decrease over an exercise period. However, the braces continue to reduce inversion and eversion significantly when compared to the unsupported condition. Since extended activity periods do not hinder an ankle brace's ability to limit movement it is acceptable to only test braces immediately after application. The braces can be re-tightened easily during a sporting event, so loosening should not be a problem in real life situations (Paris, Vardaxis & Kokkaliaris, 1995).

Role of braces in injury prevention and rehabilitation

Ankle braces have been shown to reduce the rate of ankle injuries in football, basketball, and soccer. In a study using the Wake Forest University men's football team over a seven year period it was found that the use of any ankle stabilizer was better at lowering injury and re-injury rates than tape application (Rovere, Theodore, Yates & Burley, 1988). All of the players wore either stabilizers of their choice or ankle tape. The low-top shoe with stabilizer was the best combination examined, followed by the high-top shoe with stabilizer and low-top shoe and tape. The worst condition was the high-top shoe and tape. It had been expected that the high-top shoe and injury would lower injury to the greatest extent, and the fact that it did not was very puzzling to the researchers. They felt that the low-top shoe made it easier to re-tighten the ankle stabilizer during the game or practice. The high-top shoe may also have been too bulky with the stabilizer and additional pairs of socks the players wore.

Reduction in ankle injuries in soccer has been examined in South Africa and Sweden. Surve, Schwellnus, Noakes and Lombard (1994) examined South African players in four divisions. Any ankle injury that occurred during a scheduled match or practice and caused a player to miss the following practice or match was recorded. The athletes were separated into two main groups, previously injured and no history, and each group was then subdivided into control and support wearing groups. The only statistically significant difference was found between the previously injured support wearing group and control groups. There were less severe injuries with the ankle support groups. The researchers found that the beneficial effects of the ankle supports were limited to the participants who were previously injured.

In the Swedish national league division VI, 450 players were observed over the course of one season (Tropp, Askling, & Gillquist, 1985). Injury was defined as any injury to the lateral ankle ligaments as in the previous study. Sixty players wore the Step 1 Orthosis, with medial and lateral supports that allow for plantar flexion and dorsiflexion, which is similar to the Active Ankle brace. Sixty-five previously injured players completed disc training. Only 3% of the players wearing the ankle support were injured as compared to 5% of the disc training group and 17% of the control group. The researchers felt that the ankle orthosis may prevent injury by working to hold the ankle in a neutral position, preventing initiation of inversion and externally supporting the ligaments.

Ankle injuries, in West Point Cadet intramural basketball players, were significantly reduced in those participants wearing the Air Cast Sport Stirrup (Sitler, et al., 1994). All 1601 players wore the same shoes, played on the same court, and were free of pathological deficiencies and ankle instability at the beginning of the season. Those without the support were three times more likely to injure their ankle than those wearing the brace. The differences occurred across all basketball positions. It was found that contact injuries, such as landing on an opponents foot, were reduced in the support group but there was no significant difference in the incidence of non-contact injuries. As the season progressed the subjects became more comfortable with the ankle brace and were less adverse to wearing the brace.

While the role of an ankle brace is very valuable for injury prevention, braces also play a significant role in injury rehabilitation. Ankle braces as a means of early mobilization decrease time away from work and facilitate a quicker return to normal mobility and force production. In a study done to evaluate ankle treatments in the military, it was found that the patients who received the Aircast Sport Stirrup at least three days after injury were able to return to active duty an average of 7 days sooner than those who did not receive the brace (Weinstein, 1993). All of the patients followed the same procedure during the rehabilitation phase, which included passive and active range of motion tests and strengthening exercises. It was concluded that a standardized treatment for ankle sprains should include the use of an ankle orthosis for early mobilization.

In another study comparing operative or non-operative techniques for repair of ruptured fibular collateral ligaments, those not operated on were placed in the Aircast brace (Provacz, Unger, Miller, Tockner, & Resch, 1998). All patients were instructed to complete range of motion exercises. The braced group was able to return to work sooner than those who underwent surgery. There were no long-term differences between the group after a two year follow-up. The researchers concluded that the use of a rigid brace was a viable alternative to surgery.

The use of early mobilization via braces can also be an effective alternative after reconstructive surgery (Karlsson, Lundin, Lind & Styf, 1999). After ATFL and CFL reconstruction, thirty patients were seperated into two groups. The first group was immobilized in a plaster cast for six weeks, while the second group was placed in the Aircast brace after 7 to 10 days in a cast. The brace allows for free movement in plantar flexion and dorsiflexion. Range of motion training and coordination and strength exercises were started three weeks post-surgery for the braced group. The patients from both groups underwent the same rehabilitation protocol in weeks 7 to 12. The athletes were only allowed to return to their sport when they had achieved full functional stability and range of motion. At three and six months after surgery ankle torque, anterior translation and talar tilt were measured. At three months, peak torque in plantar flexion was greater in the braced group but the difference was no longer apparent at six months. The early mobilization group resumed sport activities three weeks earlier than the casted group and regained plantar flexion strength more rapidly.

Studies comparing ankle braces to plaster casts have found that there are no long term differences, but patients wearing the braces instead of casts perform better earlier on in the rehabilitation program. In a study of 53 patients with dislocated malleolar fractures, 25 were placed in walking casts and 28 in an unnamed ankle braces (Hedstrom, 1994). All patients were weightbearing, and those in the brace completed plantar flexion and dorsiflexion exercises five times a day without the brace. After three, six and eighteen months all patients were tested on loaded plantar flexion and dorsiflexion. The subjects from the braced group performed better at the initial test, but all later trials had similar results between the two conditions. Konradsen and associates (1991) performed a similar study which examined the use of plaster casts or Aircast functional braces in subjects with severe grade three ruptures to the lateral ankle ligaments. Subjects either wore the Aircast brace for six weeks, or one week in a plaster cast (non-weightbearing) and five weeks in a short walking cast. Examinations occurred one week, seven weeks and three months post-injury. There was also a follow-up phone interview one year after the initial injury occurred. Function, pain and swelling were measured objectively and subjectively at the examinations. At seven weeks there was a significant difference between the two groups, with the braced group scoring lower on all aspects except for swelling. The patients treated with the ankle brace allowing for early mobility returned to work and activity sooner than those who were placed in a cast. Early mobilization does not affect mechanical stability, as it was achieved in 95% of the subjects by the end of the time period observed.

The benefits of ankle brace treatments were described by Regis, Montanari, Magnan, Spagnol, and Bragantini (1995). They used the dynamic orthopaedic PUSH brace to replace plaster casts. The PUSH brace allows for controlled joint movement and accelerates time required for functional recovery. There were no long term effects seen by those subjects in the braced group. Brace treatments were seen as more beneficial because of the elastic control over joint effusion, the restraint towards pronation and supination, the mechanical adjustable support was easy to assemble and remove, and the brace could act as a splint during sport activities.

Braces are able to reduce injury rates and severity of injuries. The use of braces in early mobilization also facilitates a quicker return from injury without compromising mechanical stability or long term benefits.

Effect of ankle supports on performance

There has also been some dispute over the effect of ankle supports on athletic performance. Athletes have argued that wearing ankle supports inhibits their ability to perform. In four measures of athletic ability used to test highschool basketball players, no decrease in performance was evident with any of the three braces studied (Pienkowski, McMorrow, Shapiro, Caborn & Stayto, 1995). The athletes were tested on vertical jump, standing long jump, shuttle run and cone run (agility) performances. All of these components are very important for athletic performance. As the athletes became accustomed to the brace over a one-week period there was a slight increase in performance as compared to the initial test immediately following brace application. Athletes who are concerned with braces decreasing their performance may just need to become comfortable with the brace.

Various ankle braces were shown to have no impact on performance in tests for agiiity, speed over a short distance, and jump height (Gross, Everts, Roberson, Roskin, & Young, 1994; Verbugge, 1996). The braces were found to be preferred over taping for subject comfort (Verbugge, 1996).

The impact of a brace over an entire season has rarely been examined. The majority of studies used short term measures. However, one long term study on a highschool basketball team had all of the players bilaterally braced for their entire three month season (Locke, Stitler, Aland, & Kimura, 1997). The brace used was the DonJoy Rocket Soc, and all players wore their own shoes. Prior to inclusion in the study all players were examined for functional stability. The players were tested before the season and four times during the season. Testing consisted of a sprint, a shuttle run and a vertical jump test. There were no differences in any of the tests between the control and braced subjects. It was concluded by the researchers that softshell prophylactic ankle stabilizers had no effect on performance.

The PUSH brace was examined for its effects on ankle movement during track running (DeClerq, 1997). The subjects were filmed while running and the ankle angles, speed, and force were measured. The brace did not significantly affect speed or the production of force. There was a reduction in subtalar eversion and over-pronation was prevented. The brace did not interfere with running performance and may have actually helped by limiting unnecessary movement of the ankle, eversion and over-pronation.

In another study, Lindley and Kernozek (1995) demonstrated that braces have no effect on functional ranges of motion during performance. Braces should only limit movement outside the normal ranges of motion to prevent injuries. The study only examined the effect of the braces within the normal limits. The closed kinetic chain studied (foot stance during running)could more accurately represent actual movements in sport better than an open kinetic chain movement. It is important to know if an ankle support can limit inversion and eversion to prevent injury without affecting performance.

Agility is one of the most important skills required for sports performance. It involves the ability to change direction and speed quickly. Ankle braces which limit range of motion could affect agility by reducing speed when changing direction. Agility tests can be greatly affected by the learning curve. Once the athlete understands the course, they are able to perform better. This may have affected the results of Beriau, Cox and Manning (1994). They found no difference in performance between the initial control trial and the braced conditions, but there was a difference between the final control trial and the previous conditions. Application of the braces increased the time needed to complete an agility course. The DonJoy Ankle Ligament Protector had a significantly lower time than the Aircast training brace. The DonJoy ALP is a much more rigid brace and does not rate highly with subjects on comfort level. Since this brace is more rigid it is recommended for more serious or repeated injuries.

Another study on speed, balance, agility and vertical jump performance only reported differences on vertical jump performance (Paris, 1992). Use of the brace or tape did slightly decrease performance, but it was not statistically significant. In athletic performances, an added 0.1 second can make a difference, so statistical significance may not be needed to negatively affect performance. The need for a brace may outweigh the minuscule effect on performance.

Performance in the broad jump, vertical jump, shuttle run and sprint can also be negatively affected by the application of ankle braces (Burks, Bean, Marcus & Barker, 1991). Not all of the differences were statistically significant. The decrease in vertical jump performance was significant for both of the braces, the Swede-O and Kallassy braces. The Swede-O brace also significantly decreased performance in the broad jump and sprint. Nine of the participants felt that their performance was negatively affected by the Swede-O.

While braces may negatively affect performance the reasons for this have not been looked at quantitatively. Braces may affect performance by reducing the normal plantar flexion and dorsiflexion, and by interfering with muscle activation. Macpherson, Sitler, Kimura and Horodyski felt that if a brace did not interfere with normal motion in the sagittal plane then performance should not be impacted (1995). They examined high school football players with two braces and three performance tests. Neither the DonJoy RocketSoc nor the Aircast Sport Stirrup had an effect on vertical jump, sprint or agility performance. There was also no interaction between playing position and performance in the brace. It was felt that since the braces had been shown to allow normal plantar flexion and dorsiflexion in previous studies this was why it did not negatively impact on performance.

The same two braces were also tested on subjects with recurrent lateral ankle sprains (Gross, Clemence, Cox, McMillan, Meadows, Piland & Powers, 1997). All 23 subjects had more than two sprains of one ankle and no injuries to the other ankle. They were tested on jump height, speed and agility. It was determined that the braces did not affect performance either negatively or positively when compared to the unbraced condition, and furthermore there were no differences between the braces.

Ankle braces should aid those athletes with previous ankle injuries or chronic ankle instability. The additional support should allow the athlete to be more confident in their movements and perhaps provide increased proprioception and better reactions to unbalanced positions. A one-legged jumping test and modified Japan test (4 m side step run, twelve repetitions) were used to determine if braces can improve performance of those with unstable ankles (Jerosch, Thorwesten, Frebel, & Linnenbecker, 1997). All subjects (healthy and unstable ankles) were tested in four conditions and a control trial. Jumping backward was improved with an orthoses for all subjects. The injured ankles performed better in the Japan test when braced. The increased proprioception from the braces improved the sideways running of functionally unstable ankles. The healthy ankles were not affected by the braces. Tape did not make a significant improvement on the injured ankle scores. It may have also been that the added support prevented the ankle from going beyond the normal range of inversion and eversion. By staying within the normal ranges less muscular energy would need to be used returning the ankle to the correct position. This would increase the speed at which the test could be completed. The actual reasons for improved performance were not explained and only hypothesized by the researchers.

Few studies have looked at the impact of shoe height on athletic performance. High-top shoes are worn by basketball players in an attempt to lower the risk of ankle injuries involved in that sport. However, this can reduce jump height which is important in rebounding and general performance during a game. Brizuela and associates designed two shoes to "analyse the effects of increased ankle support on ankle motion and shock attenuation during landing after jumping, and on motor performance in running and jumping" (Brizuela, Llana, Ferrandis & Garcia-Belanger, 1997: 506). The high-top shoe had an added heel counter and a rear-foot controlled lacing system. The low-top shoe had no added features. The high-top shoe increased the impact forces on landing in the forefoot impact. The high-top shoe reduced ankle range of motion, but had greater maximum inversion forces during landing. The shoe was very rigid vertically which may have caused the increased inversion. The high-top shoe also resulted in decreased performance in both the counter-movement jump and the obstacle course run. The added heel counter may have resulted in this affect on performance but it was unclear. The heel counter forces the foot into slight plantar flexion and does not allow the heel to touch the ground. By limiting the force that can be generated in the jump, the height was reduced. To determine if it was the heel counter rather than shoe height that affected performance, the high-top shoe should have been tested without the heel counter as well.

Gaps in the literature

In all of the studies reviewed, none of the researchers used the KinCom isokinetic dynamometer. This is an excellent tool for force and angle because it allows for both concentric and eccentric movements and is able to record force, angle and velocity. The KinCom has been shown to be very reliable for torque measurements (Kaminski, Perrin, Mattacola, Szczerba & Bernier, 1995). The measurement tools previously used were not as accurate or reliable. For example, the Biodex dynamometer did not measure inversion, but instead it measured a triplanar movement; it was unclear which aspect of the movement was being limited. Most of the studies focussed on only one aspect, either limiting inversion or plantar flexion or the effect on performance. Both dynamic and static conditions need to be examined to ensure that the brace functions in a manner that will benefit the athlete. It is difficult to merge research that has been done on the same brace in different conditions if the same controls are not in place. In general, there has not been enough research on dynamic conditions within a laboratory setting.

The studies that have looked at the role of athletic shoes have not been able to come to any consensus. The longitudinal studies found results contrary to what was expected, but this could have been due to the lack of total injuries within the participants. There has also been limited study in the area of shoe height and the effect on limiting ankle movement. The lack of research on the combination of braces and shoe height is astonishing. Braces and high-top basketball shoes were both designed to prevent ankle injury, but quantitative measurement of this is not readily available. The studies done on performance have been unable to determine why braces decrease performance if, in fact, they do decrease performance. It seems that the brace may reduce initial performance but that there is no effect after the participant becomes more comfortable with the brace. It might not be the brace itself that decreases performance by any biomechanical means, but rather that the wearing of the brace requires a change in the movement pattern to be effective and to aid in injury reduction. There have been no studies examining volleyball shoes, even though ankle injuries are prevalent volleyball injuries.

Chapter 3: Methodology

Subjects

Thirty subjects (14 male and 16 female; mean age 21.8 ± 3.8 years, mean height 172.4 ± 5.8 cm, mean weight 68.3 ±13.8 kg) volunteered for the study. The subjects met the following criteria: they had no history of ankle sprains requiring the cessation of activity in the past year and no history of severe ankle injury requiring the wearing of a brace in the past five years; they were moderately active; and they fit the braces and shoes provided by the researcher (sizes 8-10 mens). 'Moderately active' was defined as 30 minutes of exercise four or five times a week at a moderate intensity, as judged by the individual. Ankle injuries can vary in their severity and effect on ankle mobility, which makes it difficult to find subjects with identical injuries. By limiting the study to individuals with healthy ankles there was a more level starting point. All subjects read and signed the consent form and information letter prior to testing, according to the Human Research Ethics guidelines from the University of Ottawa.

Braces and shoes

The shoes used for the study were ASICS Gel-Airier volleyball shoes in a low-cut and midcut model (see Figure 3.1). The Gel-Airier shoes have a Thrusstic System which reduces weight and provides midfoot support. The sides of the volleyball shoe were designed to help prevent the ankle from collapsing over the shoe and assist in stabilizing the foot. There is increased traction for wet surfaces and room to accommodate foot splay after landing.

Figure 3.1. Low-top and midcut (high-top) ASICS Gel-Airier volleyball shoes.

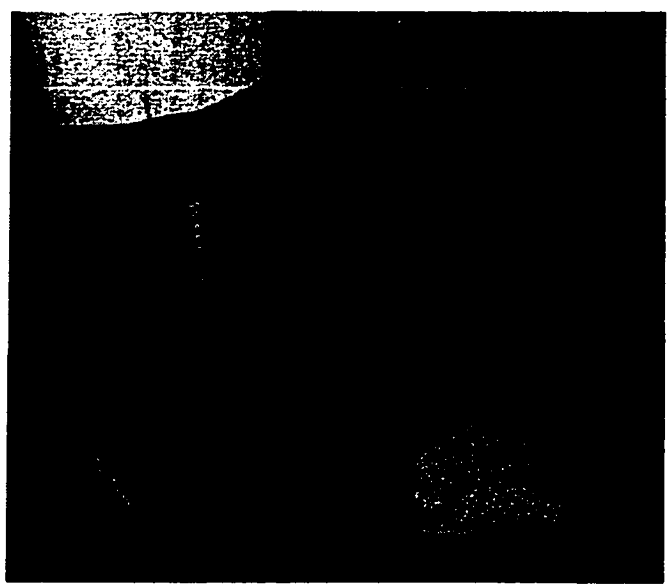


Figure 3.2. Ankle Stabilizing Orthosis, neoprene lace-up brace.

The braces used were the Ankle Stabilizing Orthosis (ASO) and Active Ankle Trainer T1(AA). The ASO is representative of lace-up braces and is one of the most popular soft braces available. The figure-eight straps mirror the stirrup technique of an athletic taping application (see Figure 3.2). The calcaneus is captured by the straps, which effectively locks the heel. This brace fits easily into any shoe. The Active Ankle is representative of molded braces (see Figure 3.3). The bilateral hinge theoretically prevents excessive inversion while allowing unrestricted plantar flexion and dorsiflexion. There is also a strap around the Achilles tendon to limit excessive motion in the posterior direction.

The support condition consisted of either the low-top or midcut shoe alone or with one of the braces. All six possible combinations were tested: low-top shoe alone, low-top with ASO, low-top with AA, midcut shoe alone, midcut shoe with ASO, and midcut shoe with AA.

Experimental protocol

The KinCom (500H) Isokinetic Dynamometer (Chattanooga Group, Hixson, TN) was used to determine the inversion/eversion range of motion for the ankle and the force applied by the ankle support for the various support conditions (brace-shoe combinations). A modified ankle inversion/eversion attachment was used (see Figure 3.4).

The KinCom was in the passive continuous mode for all of the testing. In the passive mode the subject was not required to provide the force to move the ankle. If force above a specified threshold was applied, the lever arm stopped moving. The ends of the range of motion were set while the subject was wearing the low-top shoe.

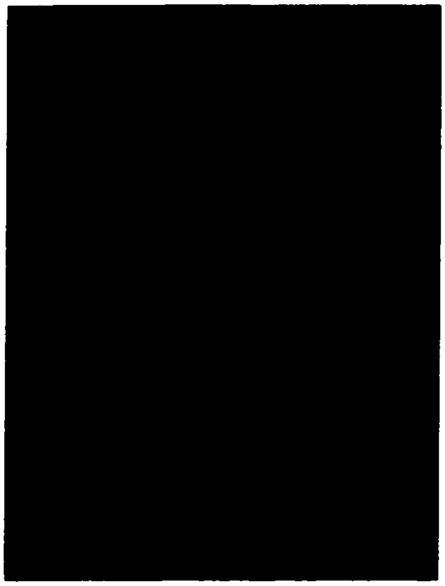


Figure 3.3. Active Ankle T1 Trainer, semi-rigid orthosis.

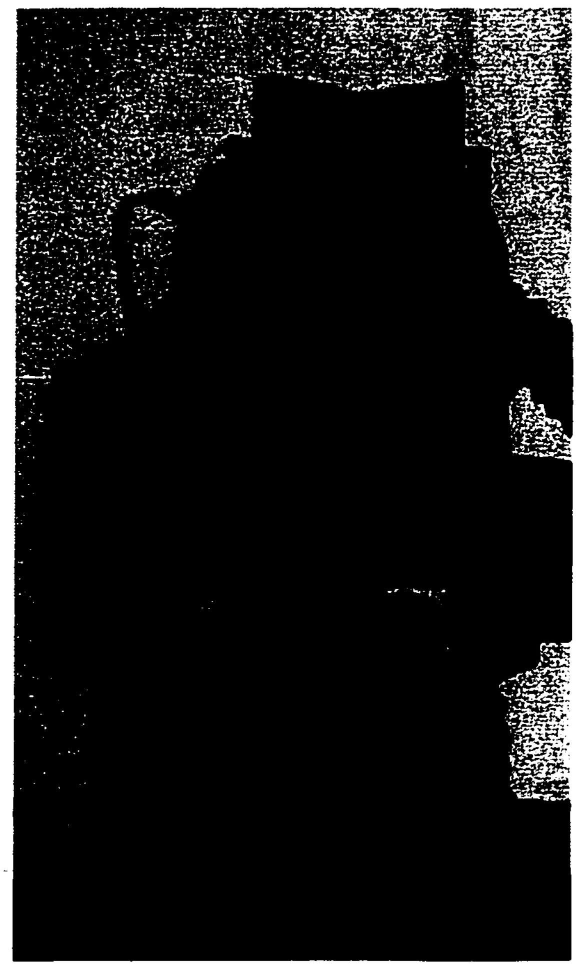


Figure 3.4. Modified Inversion/Eversion attachment for KinCom.

The KinCom was chosen for this phase of the study because of its similarity to other equipment used in previous studies, such as the Cybex II+ and the pedal goniometer. It is the most comprehensive isokinetic dynamometer available since it allows for both concentric and eccentric muscle contractions, as well as passive movement. In this way, the full range of motion could be determined for a subject at the same time. Both inversion and eversion could occur in the same testing pattern. A goniometer was used to measure plantar flexion and dorsiflexion range of motion.

The KinCom force measurements are accurate to ± 1 N, and the angle measurement is accurate to ± 1°. These were tested prior to data collection. The manual goniometer was accurate to ± 2° for the plantar flexion and dorsiflexion range of motion.

The subjects were tested on their left ankle in all of the support conditions. The order of support condition was randomized for each of the subjects. The control condition (low-cut shoe only) was the first trial for each subject. The testing was done individually, each session lasted approximately one hour.

Plantar flexion and dorsiflexion range of motion was determined in each of the support conditions prior to the inversion-eversion measurement. The subject maximally plantar flexed and then dorsiflexed their left foot. Measurements were made using a manual goniometer. All measurements for the subjects were done by the same researcher.

To measure the resistance force during inversion and eversion, the subjects stood on a surface level to the KinCom, with their left foot strapped to the ankle inversion/eversion attachment (see Figure 3.4). While in the control condition (low-top shoe only), the subjects inverted and everted their foot to the limit of their normal range of motion without compensatory movement of the hips or knees. This range of motion was set as the limits for the following support conditions. The limits were set by software stops to prevent injuries from occurring during the testing. The mechanical stops were placed at least two degrees outside of the range of motion. The mechanical stops must be placed beyond the software stops so that there is no sudden stoppage of motion which could have resulted in injury to the subject, or erroneous readings. The apparatus moved at a rate of 30°/sec, in both directions at a low acceleration. This speed was chosen because it was the fastest speed that was comfortable for the subjects. Lower speeds did not accurately represent injury causing speeds. Faster speeds would have more closely represented injury conditions, but these were felt to be too dangerous for the participants. The force applied by the support condition at the end of the range of motion was measured. The majority of the external force came from the brace as the leg muscles were in a relaxed state.

Seven continuous trials were performed for each of the support conditions. The range of forces were recorded for each condition, in inversion and eversion. The first and last trials were discarded because the ankle was not moving at a constant speed. The initial movement of the apparatus caused the foot to jerk into motion, and the final stop also caused jerking or sliding of the foot to occur. This created larger variability in the force readings. Movement of the hips and/or knees was controlled by the researcher. Subjects were instructed to remain stationary except for their ankles. The subjects were asked to stand normally with equal weight distributed between the right and left (ankle being tested) feet. This was monitored by the researcher. The subjects applied the braces individually according to the manufacturer's instructions. Where necessary the researcher aided the subject, to ensure that the brace was properly adjusted and adequately tightened.

Analysis of Data

The moment of force to resist inversion for each trial was determined during the period from 0° to the maximum inversion angle. The difference between the lowest force and highest force was recorded. This was done to prevent the variability caused by body weight and initial force readings. Customized software, BioProc (http://www.health.uottawa.ca/biomech/csb/-software/bioproc.htm), was used to obtain the graphs necessary for analysis. Eversion resistance force was determined from 0° to the maximum eversion angle (minimum angle). The force value was then multiplied by the length of the lever arm, 0.201 m for each trial, to calculate moment of force.

Comparisons were made between all conditions using a repeated-measures analysis of variance, for both inversion and eversion resistance moment of force and plantar flexion and dorsiflexion range of motion. The Tukey HSD *post hoc* test was used to determine differences between the individual conditions for moment of force and range of motion. The alpha level was set at 0.05. The null hypothesis for the resistance force was that there was no difference between the range of moments of force produced by any of the support conditions. Statistically significant differences were considered to demonstrate effectiveness. If a support condition increased the magnitude of the moment of force applied at the end of the range of motion that support was considered to effectively reduce injury. The null hypothesis for the plantar flexion and dorsiflexion range of motion was that there was no difference between the range in any of the support conditions. The conditions that did not affect plantar flexion and dorsiflexion range of motion were considered effective.

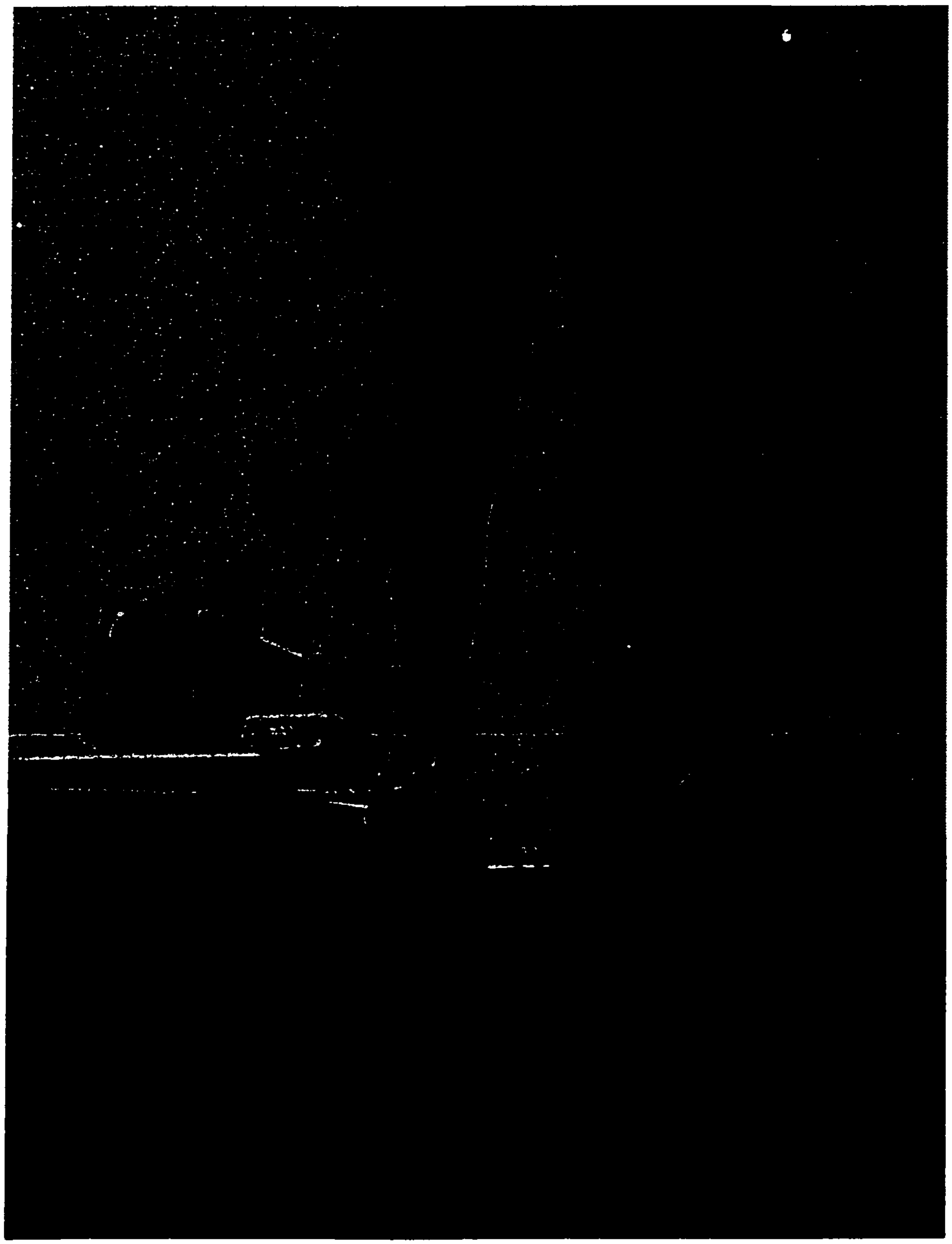


Figure 3.5. Subject in modified attachment.

Chapter 4: Results and Discussion

Results

Description of Data

The data for moment of force production and range of motion were analysed using a repeated-measures ANOVA and the Tukey HSD *post hoc* test. *Post hoc* tests were completed on Corel QuattroPro.

Figure 4.1 shows sample data for one subject in one of the support conditions, all seven trials are shown. Angle, velocity and force are shown on the three axes. Inversion force was measured for each trial during the period between 0° and the maximum inversion angle. Eversion force was measured for the period between 0° and the minimum angle (maximum eversion angle), as seen on the graph. Moment of force was calculated by multiplying the lever length by the force. The lever length was measured from the load cell to the attachment centre of rotation. It was 0.201 m for all trials.

Effect on inversion and eversion

There was a significant difference between the moments of force produced by the different ankle supports for inversion; $F(5,145)= 2.95$, $p< 0.05$. Tukey *post hoc* tests showed a significant difference between the low-top shoe with the AA and the midcut shoe alone. There was an increase in the moment of force produced with the low top shoe as compared to the midcut shoe (Figure 4.2). The low-top shoe and brace combinations created greater moments of force than the midcut shoe and brace combinations, but not all of these were

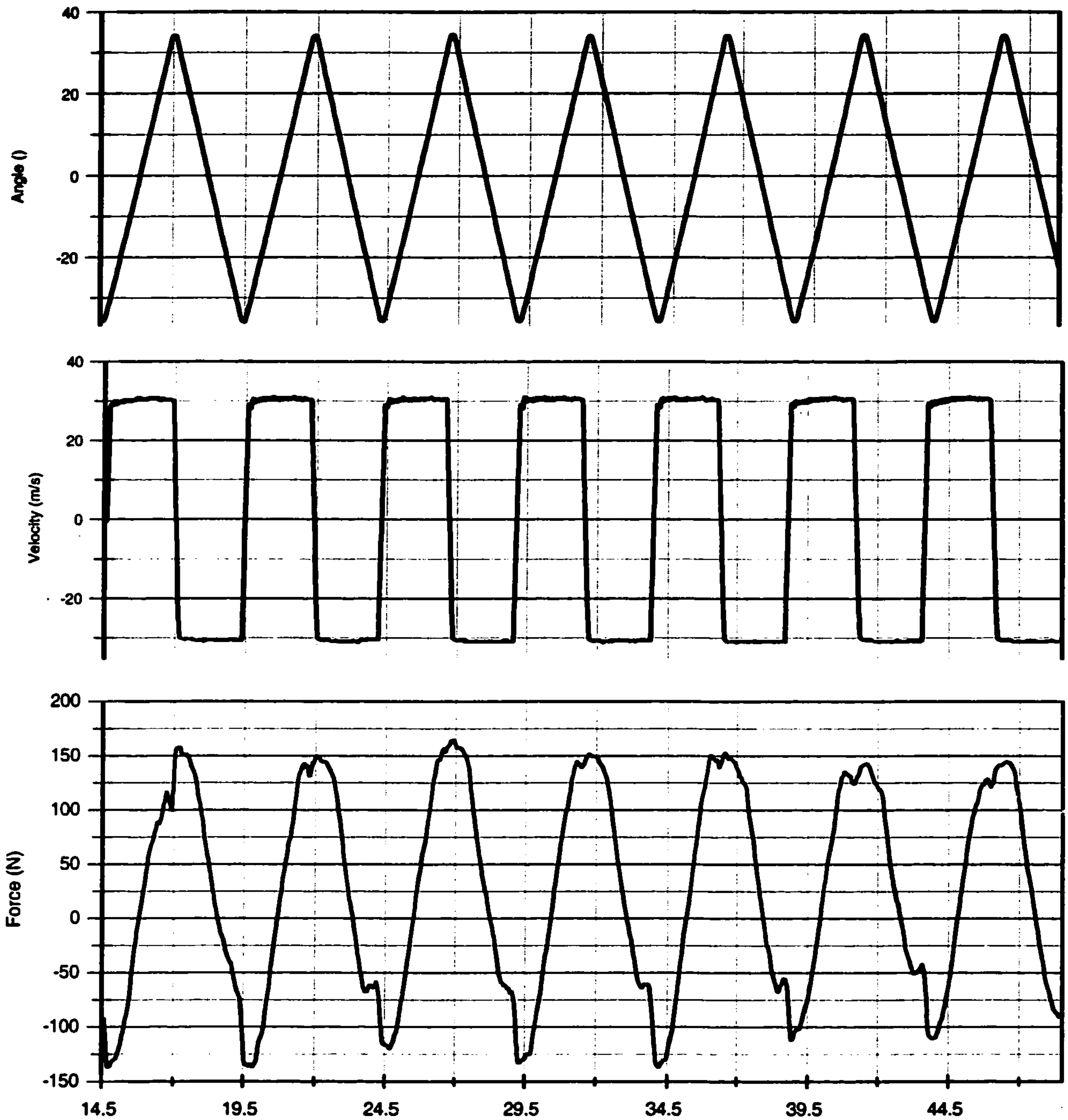


Figure 4.1. Sample graph for one support condition, showing angle, force and velocity.

significant. There were no significant differences between any of the support conditions in terms of eversion moment of force production (Table 4.1).

Table 4.1. Range of eversion moment of force production with the support conditions.

Support Condition	Mean Range of Moment of Force (N.m) ± s.d.
Low-top shoe alone (control)	6.67±7.03
Low-top shoe with ASO	6.28±7.06
Low-top shoe with AA	6.47±7.07
Midcut shoe alone	6.71±7.65
Midcut shoe with ASO	5.36±5.76
Midcut shoe with AA	6.30±6.29

Effect on range of motion

Significant differences were seen in both plantar flexion ($F(5,145)= 8.264$, $p=0.00$) and dorsiflexion ($F(5,145)= 9.743$, $p=0.00$) range of motion during the repeated measures ANOVA. The significant differences in plantar flexion were found between the control condition (LT) and all support conditions except for the midcut shoe (see Figure 4.3, and Table 4.2). The dorsiflexion differences existed between the control condition (low-top shoe alone) and all support conditions (see Figure 4.4 and Table 4.2).

Range of motion in the braces and midcut shoe was not significantly different from the midcut shoe alone. The midcut shoe alone did not decrease plantar flexion when compared to the low-top shoe. The highest mean value for both plantar flexion and dorsiflexion was seen in the control condition. The lowest mean value for plantar flexion occurred in the midcut shoe with ASO. The dorsiflexion mean values for the low-top shoe with the ASO and the midcut shoe with the ASO were identical and the lowest recorded.

Table 4.2. Significant differences found in sagittal plane range of motion ($p<0.05$).

	Plantar flexion	Dorsiflexion
Repeated Measures ANOVA		
	F(5,145) = 8.264 p= 0.000	F(5,145) = 9.743 p= 0.000
Tukey HSD *post hoc* tests		
Low-top shoe alone and low-top shoe with ASO	HSD = 5.20	HSD = 4.80
Low-top shoe alone and low-top shoe with AA	HSD = 3.23	HSD = 2.53
Low-top shoe alone and midcut shoe alone		HSD = 3.67
Low-top shoe alone and midcut shoe and ASO	HSD = 5.77	HSD = 4.80
Low-top shoe alone and midcut shoe and AA	HSD = 5.33	HSD = 4.13

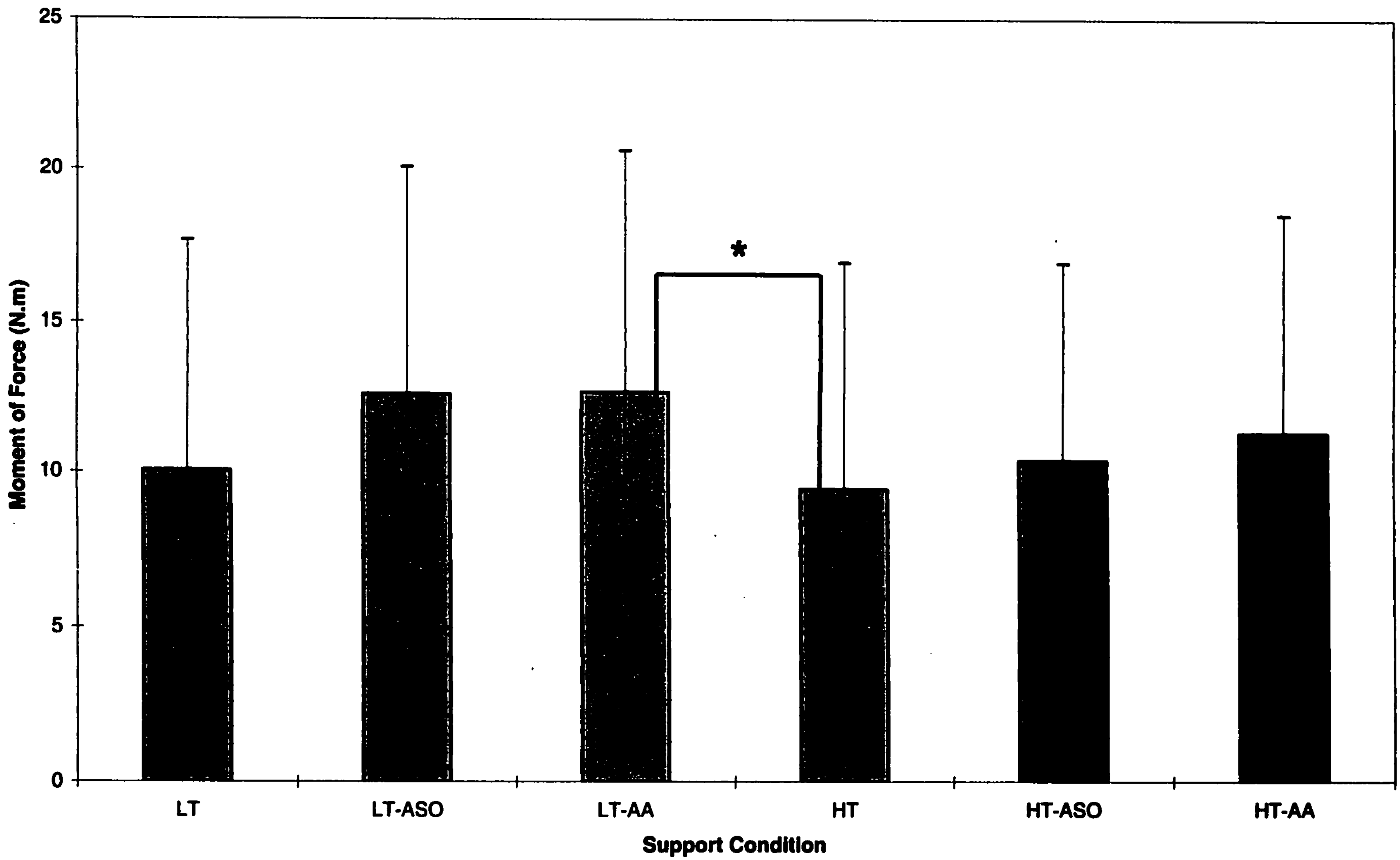


Figure 4.2. Inversion moment of force for all support conditions. (*) The mean difference is significant at the 0.05 level.

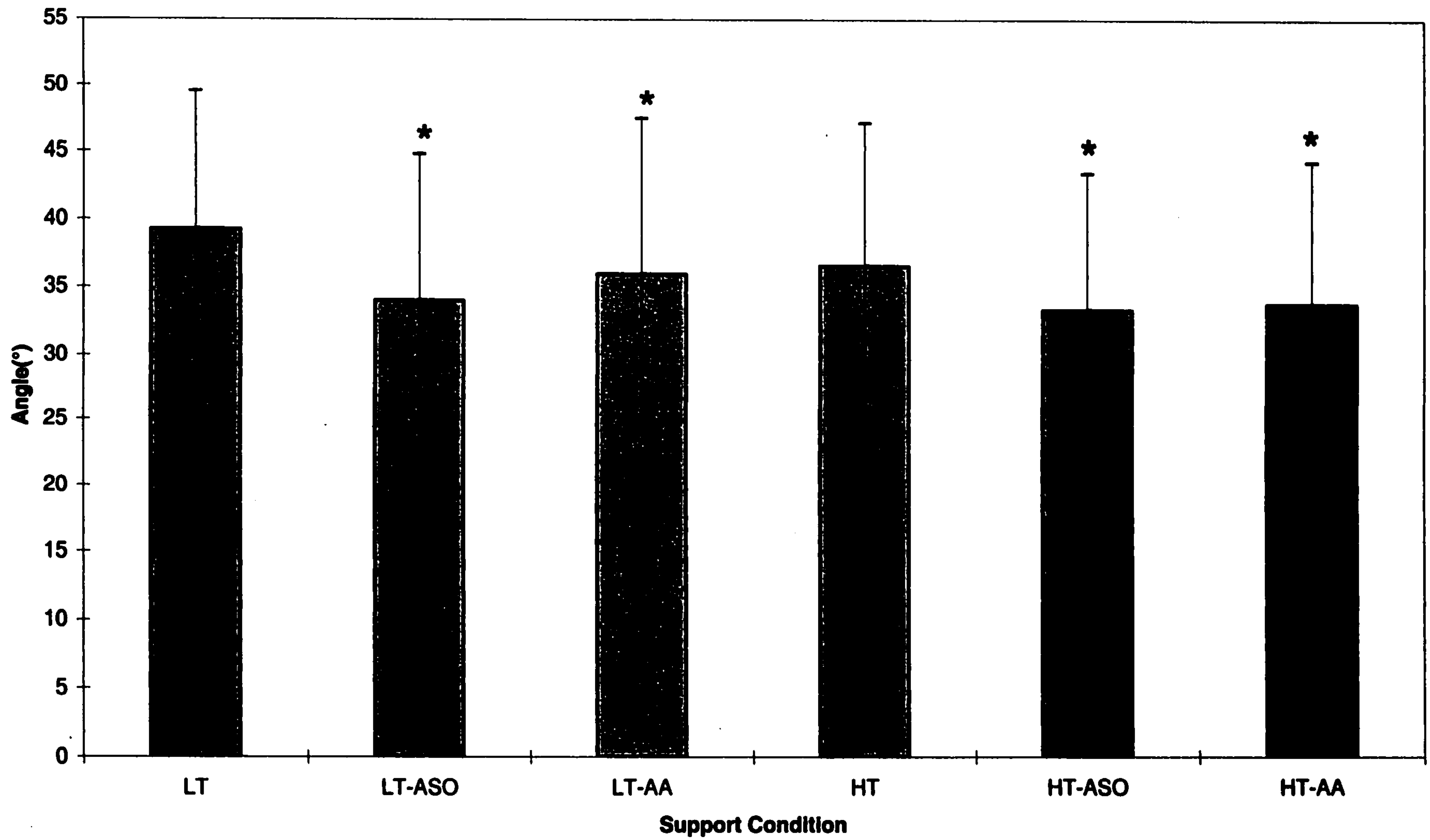


Figure 4.3. Plantar flexion range of motion for all support conditions. * The mean difference as compared to the control condition (LT) is significant at the 0.05 level.

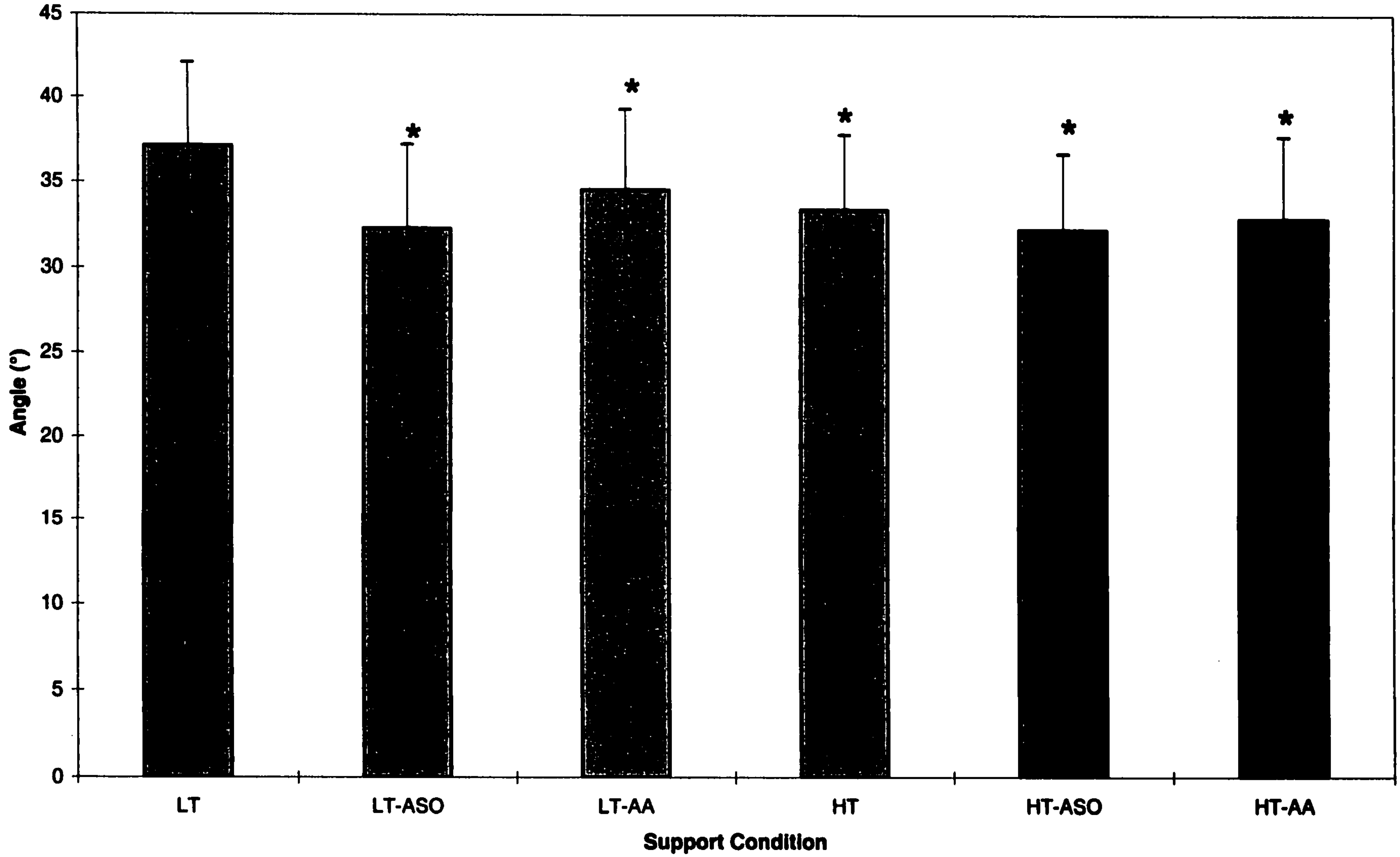


Figure 4.4. Dorsiflexion range of motion for all support conditions. * The mean difference as compared to the control condition (LT) is significant at the 0.05 level.

Discussion

The purpose of this study was to determine if the ankle braces and shoes chosen were able to increase the force produced to resist inversion to reduce ankle injury, without limiting ankle plantar flexion or dorsiflexion which may hinder performance. Previous research showed that braces reduce both passive and active range of motion (Alves, Alday, Ketcham & Lentell, 1992; Bruns, Scherlitz & Lessenhop, 1996; Shapiro, Kabo, Mitchell & Loren, 1994; Siegler, Liu, Sennets, Nobbling, & Dunbar, 1997; Tweedy, Carson & Vincenzino, 1994). The force produced at the ends of the range of motion had not been examined. Higher cut athletic shoes are supposed to provide additional support, and do limit range of motion, but studies have not show any difference in injury reduction when examined over a basketball season (Barrett & Bilisko, 1998). Braces have been shown to reduce injury rates in various sports (Rovere et al., 1988; Surve et al., 1994; Tropp et al., 1985) but the reasons behind this reduction have not been quantified.

Volleyball shoes have not been examined extensively in the research available. According to the manufacturer, volleyball shoes are specifically engineered to assist in preventing the ankle from collapsing over the side of the shoe and aid in stabilizing the foot. Volleyball is a fast-paced sport with lateral movements and jumping. This can result in ankle injuries, most commonly lateral ankle sprains. These sprains injure the lateral ligament complex and can be difficult to rehabilitate fully. The lateral ligament complex includes the anterior talofibular ligament (AFL), the calcaneofibular ligament (CFL), the posterior calcaneofibular ligament (PTFL),and minor subtalar ligaments.

The most common ankle injury occurs from a combination of plantar flexion and inversion. The AFL is the first to tear or be damaged, followed by the anterolateral capsule. If there is enough inversion the CFL will also rupture. In the most severe ankle sprains both the PTFL and the anterior portion of the deltoid ligament can also be damaged (Renström & Konradsen, 1997).

The use of ankle braces is very common in volleyball and other sports, to help prevent further injury and to support damaged or weakened ligaments. The two braces examined were representative of the two main brace types, soft lace-up braces and more rigid plastic orthoses. The Ankle Stabilizing Orthosis (ASO) is representative of lace-up braces. The figure-eight straps mirror the stirrup technique of an athletic taping application (see Figure 3.2). The calcaneus is captured by the straps, which effectively locks the heel. This brace fits easily into any shoe. The Active Ankle Trainer T1 (AA) is representative of molded braces (see Figure 3.3). The bilateral hinge theoretically prevents excessive inversion while allowing unrestricted plantar flexion and dorsiflexion. There is also a strap around the Achilles tendon to limit excessive motion in the posterior direction. The shoes used in this study were ASICS Gel-Airier volleyball shoes in a low-cut and midcut model (see Figure 3.1).

Inversion resistance force was measured on the KinCom isokinetic dynamometer in the passive mode at 30°/s. This speed was chosen to prevent injury from occurring to the subject and to prevent the leg muscles from reacting to the movement and interfering with the force readings. The subjects were weight-bearing to replicate injury conditions. The range of the inversion resistance force was compared across the six different support conditions. Eversion resistance force was also compared. Eversion injuries are less common because of the strong medial ankle ligaments, including the deltoid complex. The deltoid ligament is divided into four parts, with the tibiocalcaneal ligament as the most superficial layer (Hintermann, 1999).

The range of motion for plantar flexion and dorsiflexion was measured. This was done to ensure that the ankle supports did not affect normal motion and would not impede athletic performance.

The greatest moment of force produced to resist inversion occurred in the low-top shoe and AA combination. The high-top shoe created the least moment of force. It had been hypothesized that the high-top shoe and AA brace would create the greatest moment of force, because it had the most support for the ankle. The rigid orthoses are designed to prevent excessive inversion and eversion. Other studies have found that range of motion in a rigid brace is significantly reduced as compared to a soft brace. A study on passive inversion and eversion (Alves et al., 1994) found that semi-rigid plastic orthoses were more effective than neoprene braces in limiting motion. Lace-up braces were seen to loosen during activity, and as they loosened more inversion and eversion was allowed (Bunch et al., 1985). The rigid brace did not loosen, so it was found to be more effective over their entire testing session. As our trials were short, any loosening of the ASO should not have been a factor. Both braces maintained the same level of support throughout the seven trials. The subjects felt they were as tight at the end of the trial as at the beginning. Any difference in force production between the braces was due to actual construction or brace and shoe interference.

The high-top shoe and brace combinations did not create the greatest moments of force, as had been expected. The actual construction of the high-top shoe may have interfered with the brace application. It was more difficult to lace the high-top shoe tightly when a brace was applied to the ankle. The AA brace had to be placed into the shoe before being attached. In the high-top shoe it was difficult to make sure that the brace was directly under the heel. In the low-top shoe, the brace could be held as the foot entered the shoe. Also, the Achilles strap could not be properly tightened as the back of the high-top shoe covered this area.

The low-top shoe did not interfere with the brace's application. It was easier to fully tighten the low-top shoe even when the subjects were wearing the ankle braces. Similar problems were found by researchers examining football injuries (Rovere et al. 1988). They also had expected the combination of high-top shoe and ankle stabilizer would result in the fewest injuries, but it did not. This was explained by the brace and shoe combination preventing the re-tightening during play and being excessively bulky and cumbersome. Re-tightening did not play a role in the current study but the brace being cumbersome and difficult to fully tighten may have had an impact on the moment of force produced.

It has been shown that high-top shoes do not decrease the injury rates of basketball participants or football players (Barrett & Bilisko, 1998; Rovere et al. 1988). However, the increased shoe height is supposed to decrease forced inversion and increase the effectiveness of the applied brace, as seen in cadaveric studies (Shapiro, Kabo, Mitchell & Loren, 1994). The more support that the ankle had, the less forced inversion that occurred at increasing plantar flexion positions. In the current study, the same inversion range of motion at a constant speed was measured for all of the conditions, with the foot at a neutral plantar flexion position. This may have negated the effects of the increased shoe height in supporting the ankle.

In other studies on the force and degree of movement needed for injury to occur, it was found that injury occurs at 34 N·m in inversion and 48 N·m in eversion (Funk, Tourret, George, & Crandall, 2000). The maximum force produced in any of the six support conditions was 34.2 N·m. The maximum mean value was for the low-top shoe and ASO brace combination, and it was only 12.7 N·m. The forces produced by the testing procedure did not compare to the forces required to cause injury. This was a result of the need to keep the subjects safe from harm. Perhaps, testing on cadaveric ankles in which injury causing forces could be applied to the ankle in different support conditions would give an indication of which support condition provides the most moment of force to resist inversion.

Using cadaveric ankles to test dynamic conditions does have its pitfalls. The live human ankle is much stiffer than that of a cadaver (Funk, Tourret, George & Crandal, 2000)l. The innate stiffness of the ankle and the dynamic interaction of muscles are ignored when testing is done on a cadaver. In a cadaver the ligaments have lost some of their elasticity and are not as effective in preventing excessive motion. Even though, not enough force was applied to the subjects to cause injury it may be possible that the trends seen between the support conditions would continue in the presence of greater forces. This would mean that the low-top shoe and brace combinations would provide the greatest support to prevent against injury as compared to the high-top shoe and brace combinations, while at a neutral plantar flexion position based on the results in this study.

Studies have shown that injury to the ankle tends to occur between 35-60° of inversion (Begeman, Balakrishnan, Levine, & King, 1993; Parenteau, Viano, Petit, 1998). Begeman and associates showed injury occurring at greater than 60°, whereas Parental and his colleagues showed injury occurring between 30-35°. The range of motion examined for each subject was within their comfort zones. It varied between 29 and 43° for the current study. The subjects were able to reach the end of this range for both inversion and eversion without discomfort in all of the six support conditions. Again, the subjects were not asked to go out of their pain-free range to prevent injury from occurring during testing. The range of motion was set with the knee and hip joints relatively stable. None of the support conditions interfered with the passive range of motion as compared to the control condition, but the active range was not tested. This may have been decreased because of pressure from either the brace or high-top shoe.

It has been shown that the proprioceptive effect of the brace may play a role in preventing excessive motion (Thacker et al., 1999). The brace may encourage earlier activation of peroneal muscles which are able to protect the ankle at foot strike by everting the foot back towards a neutral position (Ashton-Miller et al., 1996). Even in cadavers with a severed ATFL and CFL, applied peroneal muscle strengths were able to reduce talar tilt and anterior drawer signs, but they were still not in normal stable ranges (Bruns & Staerk, 1992). The application of a brace may also encourage correct alignment of the foot and ankle joint to prevent against injury occurring situations. By moving the subject through a pre-determined range the proprioceptive effect may have been nullified, as excessive motion did not need to be prevented. It had been hypothesized that not all of the different support conditions would be able to complete the preset range of motion, but this was not the case.

There were significant differences in plantar flexion and dorsiflexion range of motion in the support conditions, as compared to the control condition. Dorsiflexion was reduced by the ASO and AA in both of the shoes. The high-top shoe limited the range of motion. The tongue of the shoe pushed into the foot making it difficult to move further into dorsiflexion. The AA hinge allowed for freer plantar flexion and dorsiflexion motion in both of the shoes, as any reductions were less than those caused by the ASO. The AA in the high-top shoe did create reductions in range of motion as compared to the control condition, but not as compared to the high-top condition. The brace did not cause the reductions, but the reduction in motion was due to the shoe construction. The normal ROM in the sagittal plane is approximately 45°, with 20° from dorsiflexion and 20-25° from plantar flexion.

The values for range of motion during walking are 43.0 ± 12.7°, as determined by Nordin and Frankel (1989). This is a combination of plantar flexion and dorsiflexion. They tested 245 subjects ranging in age from 20 to 60 years, on range of motion during walking. The maximum range of motion was 75°, and the minimum was 24°. The range of motion decreased with age (Nordin & Frankel, 1989). All of the subjects tested in the present study were under 30 years of age, so it was assumed that during walking their range of motion would be near the higher range of motion. The support conditions did not decrease the range of motion so that it would interfere with normal walking parameters. The smallest value for plantar flexion and dorsiflexion combined was 39° in the low-top shoe and ASO combination. The smallest mean combined value was 65.8° for the high-top shoe and ASO combination. Both of these minimum values are above the needed range for walking.

Running requires a different range of motion in the ankle, but there are very small differences between running at different speeds. The total range of motion for speeds between 3.4 and 5.0 m/s was 48.2° and 53.7° for four treadmill runners (Milliron & Cavanaugh, 1990). The maximum dorsiflexion away from the neutral position was 23° and the maximum plantar flexion was 64.2°. Uphill running required a greater range than downhill running for both plantar and dorsiflexion. The ankle was found to be mostly in plantar flexion during the stride. The supports tested did not reduce plantar flexion below the minimum values, so it is assumed that the braces will not interfere with the normal motion of the ankle needed for running or walking.

Ankle braces do not significantly hinder performance when the athlete has adjusted to the brace. In testing vertical jump, standard long jump, shuttle run and agility performance there were no significant differences in performance with any of the three braces. Performance after a one week adjustment period was marginally better than the original tests immediately after the brace was applied (Pienkowski et al., 1995). Since our support conditions did not reduce range of motion so that it would interfere with normal gait parameters it is concluded that the support conditions tested will not impede athletic performance. Athletes should not use the fear of decreased prowess as an excuse to avoid an ankle support. The benefits of an ankle support can greatly outweigh any minor reductions in performance during the adjustment period.

The resistance to inversion provided at the tested speed was not enough to prevent total injury from occurring, but it may decrease the severity of injury. The combination was not considered uncomfortable by the subjects. It was also easy to apply the brace in the low-top shoe. Due to the design of the AA as compared to the ASO it was simpler to attach, with only three Velcro straps which wrapped around the lower leg. The laces and figure-eight straps of the AA were more complicated and time-consuming to apply.

The high-top shoe and brace combinations may not have been as effective as was hypothesized due to the interference between the brace and shoe design. The pressure from the high-top shoe may have interfered with the dynamic stability of the ankle. The subject may have unintentionally relaxed because they felt that they were safer from injury. This was not measured as EMG was not used due to the interference from brace and attachment. The braces rubbed against the electrodes distorting the signal, and the attachment made it difficult to correctly apply the electrodes without hindering the movement of the attachment.

The high variability in the study made it difficult for significant differences to be found, if in fact they exist. This study looked at a new aspect of ankle supports and their role in injury prevention. There were no previous studies available as reference for number of subjects or variability in results. It was felt that 30 subjects would be a large enough sample size to correct for within group variation, but this was not the case. The within group variability was larger than expected. This shows that the force provided to resist inversion is individual and not completely controlled by the support. The role of the braces and shoes may only be to supplement the existing support of muscles and ligaments, and cannot replace them. Some people may be more susceptible to injury because of decreased force provided by passive structures to resist movement beyond the normal limits. It may also have been a result of each individual's range of motion. All of the subjects were tested at their individual limits and these were not common between subjects. The subjects set their limits in the control condition and were then tested in the control condition. The control results may be higher as a result of the subjects' unfamiliarity with the protocol and nervousness. It may have been beneficial to alter the order of the control condition testing with the other support conditions. It would be interesting to see if this would alter the control results.

Chapter 5: Summary, Conclusions and Recommendations

Summary

Ankle sprains account for 15-60% of all reported volleyball injuries, and 85% of all ankle injuries (Briner & Kacmar, 1997; Garrick, 1977). Injuries are most commonly inversion sprains to the lateral ligaments while the foot is plantar flexed. This can occur from landing on an opponent's foot. Ankle braces were designed to provide support to ligaments weakened by injury or as a preventive measure. High-top athletic shoes are also believed to provide ankle support. Ankle braces have been proven to reduce both active and passive range of motion (Alves, et al., 1992; Bruns, et al., 1996; Shapiro, et al., 1994; Siegler, et al., 1997; Tweedy, et al., 1994), but the amount of additional force provided to reduce the ROM has not been examined. Midcut or high-top athletic shoes have been shown to reduce inversion range of motion. (Ottavini, et al., 1995). The use of high-top shoes can also increase the effectiveness of the applied brace as seen in cadaveric studies (Shapiro, et al., 1994). The purpose of this study was to determine the amount of resistance to inversion force that is provided by the various ankle supports tested. The main hypothesis for the study was that the midcut shoe and Active Ankle brace condition would provide the greatest resistance to inversion and would not interfere with normal range of motion.

Thirty subjects (14 male and 16 female; mean age 21.8 ± 3.8 years, mean height 172.37 ± 5.76 cm, mean weight 68.28 ±13.75 kg) volunteered for the study. The shoes chosen were the ASICS Gel low-top and midcut volleyball shoe in mens sizes 8-10. The midcut shoe has additional ankle support, because the shoe laces to the level of the malleoli.

This was the highest shoe available. The two braces used were the Aircast Active Ankle T1 Trainer (AA) and the Ankle Stabilizing Orthosis (ASO). The Active Ankle is a rigid hinged orthosis and the ASO is a more flexible lace-up brace with additional neoprene straps in a figure-of-eight pattern.

The subjects were tested for the increase of resistance to inversion force on the KinCom isokinetic dynamometer with a modified ankle inversion attachment (Figure 3.4). The modified attachment allowed the subjects to be weight-bearing during testing (Figure 3.5). The KinCom operated in the passive mode for all measurements at a slow acceleration and a velocity of 30°/s. The limits for the range of motion were set while the subject was wearing the low-top shoe (control condition). The subjects moved from maximal eversion to maximum inversion and back again. Five trials were completed for each of the six support conditions. A support condition consisted of the low-top shoe or midcut shoe, one of the two braces or no brace.

A repeated-measures ANOVA was done on the difference in force production during inversion, eversion and on range of motion for plantar flexion and dorsiflexion. Plantar flexion and dorsiflexion were measured actively using a hand-held goniometer. Tukey HSD *post hoc* tests were completed.

The Tukey *post hoc* test revealed significant differences between the low-top shoe with the AA and the midcut shoe alone for inversion force production. There were no differences between any of the support conditions in terms of eversion force production. There were significant differences in both plantar flexion and dorsiflexion range of motion. There was a significant reduction in dorsiflexion range of motion in all support conditions, as compared to the low-top shoe alone (Figure 4.4, and Table 4.2). The low-cut shoe and AA had the smallest reduction. The reductions in plantar flexion were found between the low-top shoe and all support conditions except for the midcut shoe alone (Figure 4.3, and Table 4.2).

The reductions in dorsiflexion and plantar flexion with the ankle supports may have been statistically significant but there were not biomechanically significant. The reductions did not interfere with the range of motion needed for walking, as reported by Sammarco and associates (1973). The ankle supports should not have any effect on athletic performance.

The force provided to prevent inversion was less than the force required to cause injury. The speed the subjects were tested at was not severe enough to cause damage to the ankle ligaments. It may be possible to extrapolate that the best ankle support in this study would continue to provide increased resistance force to balance an increased applied force. This would mean that it is the best support available to prevent injury or decrease the severity of injury. From the present study the best ankle support is the combination of low-top shoe and Active Ankle.

Conclusions

Based on the results obtained and the four proposed hypothesis the following conclusions can be made.

1) The higher athletic shoe (midcut) did not provide an increased moment of force to resist inversion. In fact, the athletic shoe with the lower ankle support in combination with the rigid orthosis had greater resistance to inversion force than the

midcut shoe alone.

2) There were no significant differences between the braced and unbraced conditions for either of the shoes. However, there was a tendency for an increase in moment of force for both shoe heights with the addition of either brace.

3) The combination of midcut shoe and either brace did not provide a greater resistance to inversion moment than the low-top shoe and brace combinations. This again was contrary to the original hypothesis. The construction of the midcut shoe may have interfered with the application of the brace. The midcut shoe may have felt more secure to the subjects so that they unconsciously relaxed their muscles to a greater extent than when wearing the low-top shoe. Although the subjects were passively moved by the attachment the actual muscle activation (EMG) was not recorded. Electrodes could not be used because there was interference from the KinCom attachment and the braces.

4) There was a reduction in both dorsiflexion and plantar flexion range of motion as compared to the control condition (low-top shoe). There were no significant differences between support conditions. These reductions should not effect normal motion as the range permitted was still greater than that necessary for walking and running.

The conclusion is that the best ankle support tested was the low-top shoe and Active Ankle brace combination. This combination produced the greatest resistance to inversion force and only slightly decreased plantar flexion or dorsiflexion. The hinged ankle orthosis moves freely in the sagittal plane while restricting inversion and eversion. It was also easy to apply and comfortable to wear in the low-top shoe. In the midcut shoe the brace was awkward to apply and difficult to fully tighten.

Recommendations

The amount of force ankle supports provide to resist injury needs to be studied further. There should be an increase in the testing speed to better simulate ankle injury conditions. If this is to be properly done both cadaveric lower legs and actual human subjects should be tested, with the cadaveric ankles being pushed to the injury limits. The cadaveric lower limb should be used to try to maintain some of the structural integrity of the leg, and perhaps the ligaments will be able to play a role as they do in the human leg.

A variety of braces and shoes should be examined to determine if the problems which were attributed to the midcut shoe construction were unique to the specific combinations researched or if they were really due to actual construction. It is felt that all higher cut athletic shoes will interfere with ankle braces.

Non-athletic shoes should also be tested. It is not only during athletic events that ankles are injured. Higher cut construction boots and casual shoes should be tested. The testing set-up in this study would be unable to examine high heeled women's shoes but this would be an important addition to the literature on ankle sprains. Since high heeled shoes force the foot into a plantar flexed position less inversion force would be needed to cause injury. In a study by Shapiro and colleagues (1994) less force was required to invert a foot if it was already plantar flexed.

Another interesting study that could be done to expand the general knowledge of injury prevention would be to see if the occurrence of other joint injuries increase with the application of ankle supports. The force that is dissipated by the ankle support must be transferred to another joint or soft tissue. This may cause an increase in knee injuries or injuries to the soft tissue of the foot. Some of these injuries may be more severe than ankle injuries. It is assumed that there might be an increase of injuries to the foot caused by the brace application. The brace itself may cause injury by being improperly applied or shifting during an activity.

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Appendix A

Université d'Ottawa • University of Ottawa

Faculté des sciences de la santé
École des sciences de l'activité physique

Faculty of Health Sciences
School of Human Kinetics

Name of researchers:	Alison Cronin and Dr. D.G.E. Robertson
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Whenever a research project involves humans, the written consent of the research subjects must be obtained. This does not imply that the project necessarily involves a risk. In view of the respect owed to the research subjects, the University of Ottawa and the research funding agencies have made this type of agreement mandatory.

I,__________________, am interested in collaborating in the research conducted by Alison Cronin, a Masters student in the School of Human Kinetics, Faculty of Health Sciences at the University of Ottawa, under the supervision of Professor Robertson of the School of Human Kinetics, Faculty of Health Sciences at the University of Ottawa, and their assistants. The purpose of the research is to determine the effectiveness of ankle supports in preventing injury while not impairing normal movement.

My participation will consist essentially of attending one session lasting approximately one hour. In the session I will have to wear shorts and provide my own socks. I will have my ankle range of motion measured wearing the control condition (low-top shoe) by the Kin-Com® 500H Isokinetic dynamometer. The dynamometer is a machine designed to measure angle and force. I will be seated and attached to the lever arm which will move my foot within my normal range of motion. For each of the ankle supports, the lever arm will move to the ends of my inversion (turning foot inward) range of motion, the force produced by the support will then be recorded. As well, the plantar flexion (pointing toes downward) range of motion allowed by the ankle supports will be measured on the Kin-Com. An ankle support consists of a combination of brace and shoe type, there will be six different ankle supports. There will be ten continuous trials for each support. ~~The electrical activity of my gastrocnemius and soleus muscles in my lower leg will be measured by EMG. Electrodes will be placed on my skin. My skin will have to be prepared by shaving excess hair and rubbing with alcohol swabs. I will be able to prepare my skin if I wish to~~. The session has been scheduled at my convenience.

Session Date and time :______________________________________

I understand that before any of the trials in the testing session I will be given a ten minute warm-up period so that I may become comfortable with the ankle support. Testing will not begin until I am ready. My height, weight and age will also be recorded to aid in the analysis of the data. I understand that the data collected will be used only for research purposes and that my anonymity will be respected by the experimenter because my name will not be recorded with my data. In fact, I will be assigned an anonymous identification code which will be used throughout the investigation. All results and data pertaining to this study will be kept in a secure area during the thesis process, to ensure confidentiality. At no time will my individual results be made available to anyone outside the researchers except to myself upon request. The thesis will be written in such a way as to conceal the identity of all participants.

I understand that since this activity deals with the Kin-Com® Isokinetic dynamometer there is a low risk of discomfort as the lever arm moves the ankle through its normal range of motion. I have received assurances that I can notify the researcher when I feel any discomfort, and that testing will end if I do feel discomfort or no longer wish to continue.

I understand that by participating in this research I am helping to identify the best available ankle support. This will allow others to select the best support to prevent common ankle injuries. As well, determining if ankle supports decrease plantar flexion range of motion will help to explain why braces are perceived as reducing performance. This will help athletes understand what they must do to maintain a high level of performance while protecting themselves against injury.

I am free to withdraw from the project at any time, before or during any testing condition and have the freedom to refuse to participate in any one of the testing conditions.

Any information requests or complaints about the ethical conduct of the project may be addressed to Lise Frigault (Protocol Officer for Ethics in Research):Room 302, Tabaret Hall,
University of Ottawa 550 Cumberland, Ottawa, ON
Phone: 562-5800 ext.1787
E-mail: lfrigaul@uottawa.ca

There are two copies of the consent form, one of which I may keep.
If I have any questions about the conduct of the research project, I may contact the researcher or her supervisor at the numbers provided at the top of the page.

Researcher's signature:______________________ Date:______________

Research Subject's signature:_________________ Date:_____________