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A COMPARATIVE ANALYSIS OF TWO PROPHYLACTIC ANKLE SUPPORTS

by: Dale John Stewart

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A Thesis/Practicum submitted to the Faculty of Graduate Studies of The University

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ABSTRACT

There has been a substantial amount of research done in the field of prophylactic ankle supports. Tape has been the standard by which all other supports were measured. However, the inconsistency in tape application, unreliable methods of ROM measures, variances in testing protocols, and the wide variety of semirigid ankle orthoses, have all contributed to research that may lack external validity. The ideal prophylactic support would allow normal functional ROM, while limiting the extremes where lateral injuries are known to occur (in plantar flexion and inversion particularly). Such a device must also be comfortable and stable to instill confidence and increase compliance. This study attempted to build on previous studies, and evaluate the effectiveness of one particular semirigid orthosis, with no previous independent research.

The purpose of this study was to determine if any differences existed between a semirigid orthosis and adhesive support, in terms of prophylactic support, function, and comfort. Twenty seven female subjects who met the inclusion criterion were recruited to participate in the study and were tested on 3 consecutive days. They were randomly assigned to one of 3 test orders which included control, semirigid orthosis, and adhesive support conditions. Their active and passive ranges of ankle motion (inversion, eversion, plantar flexion, and dorsiflexion) were measured 3 times per test session. Once prior to the application of any support (Time 1), once after the support had been applied (Time 2), and again after exercise (Time 3). Subjects were also asked to complete a questionnaire to assess their perceived comfort and stability of each of the treatment conditions.

The data was analyzed and the study concluded that prior to exercise, a semirigid orthosis and prophylactic ankle tape both produced a significant reduction in ankle inversion and eversion, but not in plantarflexion or dorsiflexion. Following exercise, both demonstrated less restriction than before, but were both significantly more restrictive than the control.

This study also concluded that the brace did not lose its supportive function as much as did the adhesive support, after exercise. The exercise was found to affect the support provided by the tape more so than the brace in active ankle inversion, active ankle plantar flexion, and passive ankle inversion. These three motions are particularly relevant to the mechanism of injury for lateral ankle sprains.

The brace was perceived by subjects to be significantly more supportive than the tape prior to exercise. There was no perceived difference during or after exercise.

Of course, there are advantages and disadvantages to both techniques, regardless of their efficacy. For instance, the adhesive support requires a trained person with experience at taping in order to achieve the desired result. Such an individual offers the advantage of being able to customize the support to achieve a greater number of effects (related to the injury). The brace on the other hand can be applied very quickly and with minimal instruction. It can also be retightened in the middle of a practice or a game if necessary.

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The completion of this thesis has been a process that has tested my endurance and commitment. It would have been impossible without the efforts of many.

I owe so much of my educational and professional development to my advisor, Dr. Glen Bergeron. He has taught me to never accept my education as complete, and to always strive to improve myself, and those around me. I thank him for both his past patience and guidance. I hope to continue to learn from him.

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DEDICATIONS

The support shown by my family has been second to none. They have stood by me, and their ceaseless encouragement has given me the strength to pursue my goals. They have never let the light at the end of the tunnel grow dim. I dedicate this work to my father Dale, my mother Joan, and my sister, Lisa.

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Chapter 1: Introduction

The ankle is arguably the most critical link in the human kinetic chain. In addition to supporting the weight of the entire body, it functions as a shock absorber during weight-bearing, to help control foot rigidity during locomotion, and as a torque converter during locomotion (Nordin & Frankel, 1989). It also performs a proprioceptive role that affects the rest of the body. Any action, movement, or pathology occurring at this joint potentially affects the function of the lower limb, hips, back, or neck.

The ankle is placed under considerable stress during sports movements (Garrick & Requa, 1988) and is therefore very susceptible to injury. The ankle is injured in athletics more often than any other single body part (Balduini, Vegso, Torg, & Torg, 1987; Burks, Bean, Marcus, & Barker, 1991; Derscheid & Brown, 1985; Firer, 1990; Greene & Hillman, 1990; Greene & Wight, 1990; Gross, Bradshaw, Ventry, & Weller, 1987; Gross, 1987; Gross, Lapp, & Davis, 1991; Karlsson & Lansinger, 1992; Lassiter, Malone, & Garrett, 1989; Lofvenberg & Karrholm, 1993; Miller & Hergenroeder, 1990; Rovere, Clarke, Yates, & Burley, 1988; Vaes, Boeck, Handelberg, & Opdecam, 1985). In the United States, 15% of all injuries in athletics were to the ankle and 80% of these were to the lateral ligaments (Greene & Roland, 1989; Gross, et al., 1987; Gross, 1987). Among American high-school athletes, the ankle was implicated in 14% of all injuries with 85% of these being sprains (of which 85% were to the lateral ligaments) (Gross, 1987; Miller & Hergenroeder, 1990). Lofvenberg & Karrholm (1993) reported that anywhere from 13 to 56% of all sport injuries are to the ankle and 85% of these are to the lateral ligaments. Lassiter et al. (1989) show that 45% of basketball injuries, and 31% of soccer injuries in high school sports (in the United States) were to the ankle; the majority of which were to the lateral ligament complex. Athletes with a history of ankle sprains are twice as likely to sprain their ankle as are athletes with no history of injury (Garrick & Requa, 1973). As many as 33% of individuals who suffer "severe trauma" to the lateral ligaments of the ankle will experience chronic laxity of that ankle (Bosien, Staples, & Russell, 1955; Lofvenberg & Karrholm, 1993), and functional instability occurs in 40% of people who experience some lateral ligament injury (Freeman, Dean, & Hanham, 1965). With numbers such as these, there is an understandable need to develop a method of ankle support that is both cost efficient and effective in preventing such injuries.

In terms of injuries that occur to athletes during competition, available methods of support can be categorized as either prophylactic, or functional. Theoretically, the aim of prophylactic support is to provide external support to the ankle without hindering its normal range of motion (ROM) or function. It is designed to protect an athlete's healthy ankle from injury during activity (Pinkowski & Paulos, 1993). Functional support, on the other hand, also refers to a means of providing external support to the ankle but in this case the idea is to protect a previously injured ankle from reinjury (Pinkowski & Paulos, 1993). The support must therefore be designed with the protection of a particular anatomical structure in mind.

Many kinds of prophylactic and functional supports have been developed, including ankle taping, the Aircast Sport-Stirrup brace, Safe - T brace, Active Ankle Trainer brace, laced stabilizers, and elastic sleeves, among others. While elastic sleeves have been shown to provide very little support (Myburgh, Vaughan, & Isaacs, 1984), the Aircast Sport-Stirrup and laced stabilizers have been shown to be effective at reducing the risk of injury in many cases (Garrick & Requa, 1973; Gross, et al., 1987; Rovere, et al., 1988; Stover, 1986).

The use of ankle taping (with adhesive tape) to support the ankle is a traditional practice that has been done for more than 100 years (Hughes & Stetts, 1983) and it has since become a ritualistic part of many athletes' precompetition routine. It has also become a very controversial practice and its effectiveness has been questioned by many. Some researchers (Ferguson, 1973; Rovere, et al., 1988) claim that taping is not the best method for preventing injuries, while others have shown it to be an effective way of increasing the mechanical stability of the ankle (Larsen, 1984; Vaes, et al., 1985). This is an important relationship as it has been theorized that the level of mechanical stability is related to the incidence of injury (Garrick & Requa, 1973; Gross, 1987). Controversy also exists among those who advocate ankle taping; over which taping technique is better; and there are still others who claim that the best method depends on whether the athlete is wearing high or low cut shoes, and on the length of the exercise period (where such a variable was incorporated into the study) (Rovere, et al., 1988).

While there has been substantial research done in the area of ankle support for the prevention of injury, the results are conflicting and the evidence is inconclusive. Much of the controversy stems from the fact that the literature only examines certain aspects of the problem and in some cases the fault is in the methodology employed by the researchers. For example, some studies look only at comfort level or isokinetic ankle strength, or look retrospectively at incidence of injury. For any method of support to be effective, it must allow normal range of motion (what is normal will depend on what is required for optimal performance), normal strength, be comfortable, and provide adequate mechanical support.

1.1 Statement of the Problem

To compare the effects of selected ankle support techniques on active and passive ranges of ankle motion in pre - and post - exercise conditions.

Independent variables:

i) ankle support chosen (semirigid orthoses, ankle taping, no support).

Dependent variables:

i) active and passive ranges of motion (inversion, eversion, plantar flexion, dorsiflexion).

ii) perceived comfort of each support method.

iii) perceived level of support of each support method.

Control variables:

The only control variable is previous injury. All subjects will have been injury free in both ankles in the six months preceding data collection.

1.2 Hypotheses

Research Hypothesis:

It is hypothesized that prior to exercise, that ankle taping and the Active Ankle brace will provide a significant reduction of active and passive ranges of motion of the ankle. Following exercise, the reduced ranges of motion will still be significant when compared to the controls.

Null Hypothesis:

The semirigid orthosis and prophylactic ankle taping and no support will not significantly differ in restricting active and passive ranges of motion, or perceived comfort and support; in pre - and post - exercise conditions.

Sub-Hypotheses:

1) Prophylactic ankle taping and the semirigid orthosis will both provide significant restrictions in ranges of motion prior to exercise compared to a control (no support).
2) Prophylactic ankle taping and the semirigid orthosis will both provide significant restrictions in ranges of motion following exercise compared to a control (no support).
3) The semirigid orthosis will provide the greater restriction of motion than prophylactic ankle taping following exercise.
4) Ankle taping will provide a higher level of perceived support compared to the semirigid orthosis prior to exercise.
5) The semirigid orthosis will provide a higher level of perceived support compared to prophylactic ankle taping following exercise.
6) The semirigid orthosis will provide a higher level of perceived comfort prior to, and following exercise compared to prophylactic ankle taping.

1.3 Delimitations and Limitations

One delimitation is the protocol and intensity of the exercise period. The idea is to utilize an exercise protocol that mimics movements found in most sports (especially those where athletes have traditionally relied on some form of external ankle support). The exercise protocol will therefore incorporate some power work (jumping and stairs), some agility work (agility run), an endurance component (jogging laps), as well as a speed component (running laps). As far as intensity is concerned, the exercises will be performed at a level that is submaximal for all individuals. This must be done in order to ensure that each test condition is exposed to a comparable level of stress (i.e., that a subject will stress the tape just as much as she stresses the semirigid orthoses).

The fact that the exercise period will be of 15 minutes duration is also a delimitation. Most practice and game situations will involve the athlete stressing the ankle support for more than 15 minutes at a time. This standard length of time allows for comparisons to the literature (Alves, Alday, Ketcham, & Lentell, 1992; Gehlsen, Pearson, & Bahamonde, 1991; Laughman, Carr, Chao, Youdas, & Sim, 1980; Martin & Harter, 1993; Rarick, Bigley, Karst, & Malina, 1962). A 15 minute exercise protocol also ensures that substantial stress will be applied to each test condition while at the same time allowing the subject to complete the entire session.

Another delimitation is that all subjects will have been injury-free within the six months prior to the study. In other words, the conclusions that are drawn may be applicable to "healthy" ankles, but not necessarily to an unstable ankle, or one with an acute injury. Similarly, results cannot be generalized to an acutely unstable ankle because individuals may have chronic instability and be fully functional.

One researcher has cautioned against generalizing results from an open kinetic chain test to the ability of an orthosis to function in an environment where injuries occur during weight-bearing activities (Gross, Ballard, Mears, & Watkins, 1992). This is potentially another delimitation because all testing will be performed in this study with the subject's foot and ankle in an open kinetic chain position. This may not be problematic for some results since certain tests may not be affected as much. For instance, it is reasonable to expect that the subtalar movement that takes place during the acceleration phase of a jump is no different than that which takes place during isokinetic plantar flexion testing. However, it could also be argued that the degree of inversion allowed by a support while in an open kinetic chain may be significantly different than would be allowed during full weight bearing. It should also be noted that many lateral ankle sprains begin when the ankle is in a plantar flexed position and then begins to invert (as when coming down from a jump) (Greene & Roland, 1989; Greene & Wight, 1990) so it is usually a combination of movements, as opposed to pure inversion, which result in injury.

Bobbert & Van Ingen Schenau (1990) reported that greater force moments are produced in the plantar flexor muscles during jumping than during isokinetic testing. They suggested that this was due to the plantar flexor muscle fibers being in a more advantageous position with regards to their force-length and force-velocity relationships, than they were during isokinetic testing at the same angular velocities. Gross, et al. (1992) also alluded to this when they said that the moment created by the ground reaction forces is "affected by the magnitude of the ground reaction force and the moment arm of this force for each of the joint axes" of the foot and ankle. They said that moment arm distances will be affected by such perturbances that occur with foot contact on uneven ground or on another player's shoe. Because these are common mechanisms of the very injury that prophylactic ankle supports are attempting to reduce (lateral ankle sprains), it may not be accurate to test such supports in terms of their ability (or lack thereof) to restrict pure, isolated movements such as inversion, eversion, plantar flexion, and dorsiflexion.

A limitation that must be considered pertains to the possibility that a support method will provide relatively more support to someone with chronic instability than it will to someone with no previous ankle injury. In other words, a semirigid orthoses may provide a statistically significant reduction in range of motion, in an ankle that is already hypermobile due to previous injury; but may not do so in an ankle that is hypomobile.

The present study will also be limited to subjects who are free of any acute or chronic ankle pain. Subjects will not be selected based on any predetermined values of ankle range of motion.

The application of the ankle tape itself may be a limitation in the sense that there is the potential for researcher bias. In other words, one could apply the tape in a fashion conducive to greater lateral support, if one wanted the results to favour the tape condition. All previous studies that have been referred to in the literature review used the same researcher to apply the tape to all subjects. The inherent advantage to this is that the tape is applied consistently to all subjects (whether loose or tight, it is at least consistent from time to time). Second, having someone else apply the tape introduces their potential bias, in the same way that has been discussed above. This would not accomplish anything productive so it was not done.

1.4 Definition of Terms

For the purpose of this study, the following definitions will apply:

Injury refers to any trauma to the ankle which necessitated restriction from any activity for more than 48 hours.

Functional instability is the term used to describe a joint that suffers recurrent sprains, and/or feeling of giving way.

A semirigid orthosis is a device that is made of a semirigid thermoplastic material and for the purpose of this study, is designed to limit excessive ankle joint movement that may otherwise result in injury.

Isokinetic strength refers to any contraction that occurs at a set speed, against a resistance that accommodates to the subject's maximum voluntary force output throughout a specified range of motion.

Active range of motion (AROM) refers to the degree of movement about a joint when that movement is produced by the subject, through voluntary action of the muscles acting on that joint.

Passive range of motion (PROM) refers to the degree of movement through the normal range of motion of the joint, when that movement is produced by external forces while the muscles surrounding that joint are relaxed.

1.5 Significance

This research can provide athletes, coaches, and therapists with insight that will allow them to make informed decisions regarding the prevention of ankle injuries that occur in sport. Currently there are many choices available to protect ankles from injury or reinjury. Unfortunately, there is no consensus as to which support is most effective. This study will provide a comparison of two methods currently in use: prophylactic ankle taping and the Active Ankle orthosis. From the perspectives of both the players and the medical profession, there is an obvious need to determine the most effective method of support.

Chapter 2: Review of Literature

2.1 Introduction

Injuries to the ankle already have been shown to be more prevalent in athletics than injuries to any other part of the body (Balduini, et al., 1987; Gross, 1987; Miller & Hergenroeder, 1990). This culminates annually in increased medical costs, as well as pain and suffering to the athletes, lost time from competition, and long term functional instability (which then predisposes the athlete to reinjury). In the United States, there are an estimated 1 million acute ankle injuries annually with an average cost of $300.00 to $900.00 per injury (Miller & Hergenroeder, 1990). Many choices of ankle support are now readily available to athletes who seek protection from either a new ankle injury, or from reinjury. The ideal support must allow full functional ROM, and optimal protection from injury. The support should prevent excessive inversion and eversion movements, without inhibiting normal dorsiflexion and plantar flexion. The support must withstand the rigors of exercise, and lastly, it must feel comfortable if the athlete is going to be expected to wear it at all.

Many different kinds of ankle supports have been designed and as will be discussed further in this review of literature, some offer significantly better ankle stability, function, and comfort than others. Many of the available supports have as many critics as advocates and it remains unclear whether or not they have any effect at all on injury prevention. Several studies have been conducted in an effort to determine which method of ankle support best reduces the number and severity of ankle injuries. Because athletes require maximal inversion, eversion, dorsiflexion and plantar flexion movements and peak torque moments in order to perform well (regardless of the sport), research must be done with these variables in mind. What follows is a detailed literature review incorporating a brief outline of the anatomy of this region, as well as a synopsis of the many studies that have evaluated the various methods of ankle support currently available.

2.2 Anatomy of the Ankle-Foot Complex

Skeletal:

The ankle joint proper is formed by the inferior surface of the tibia, lateral surface of the medial malleolus, medial surface of the lateral malleolus, and the superior aspect (trochlea or dome) of the talus (Appendix A). The ankle is also referred to as the *talo-crural* joint; in reference to the articulations between the talus and the two crural bones (the tibia and the fibula). From a functional standpoint, the proximal and distal tibiofibular joints, the subtalar and midtarsal joints, and the other joints of the foot must be considered collectively due to the interdependence of each upon the other within the kinetic chain. These structures combine to form what is called the ankle-foot complex. This distinction is important because from a medical perspective, one must consider the entire ankle-foot complex, not just the ankle joint. The implications of these relationships have important ramifications for selecting methods of ankle support. Subsequently, when we talk about prophylactic support for the ankle, we must be cognizant of this entire complex.

Ligamentous:

The crural bones form a mortise in which the talus must fit. The integrity of this mortise is maintained by several ligaments. The interosseous membrane is a thin, strong connective tissue that is attached to the shafts of the tibia and the fibula and serves to maintain the proximity of these bones. The ankle mortise is also supported by the distal tibiofibular ligament which consists of anterior and posterior segments.

The medial and lateral aspects of the talocrural and subtalar joints are afforded stability by collateral ligaments which are for the most part, thickenings of the capsule that surrounds the entire joint. The medial portion is referred to as the deltoid ligament and consists of 4 distinct ligaments. From anterior to posterior they are the anterior tibiotalar, tibionavicular, tibiocalcaneal, and posterior tibiotalar ligaments. Similarly, the lateral ligaments also consist of distinct ligaments. From anterior to posterior they are the anterior talofibular, calcaneofibular, and posterior talofibular ligaments. The deltoid ligament complex restricts eversion while the lateral ligament complex restricts inversion.

Muscular:

The muscles of the lower leg, ankle and foot not only produce movement, but also act as dynamic stabilizers of the lower limb. They are divided into 4 compartments by intermuscular septae and the crural bones (anterior, deep posterior, superficial posterior, and lateral compartments).

The posterior compartment has a deep and superficial section which are distinct from one another. Superficially the Achilles tendon inserts into the posterior calcaneus and is comprised of the tendons of the gastrocnemius, soleus, and plantaris muscles. These muscles collectively produce ankle plantar flexion. Deep to these muscles is the flexor hallucis longus, flexor digitorum longus, and tibialis posterior muscles, which all originate in the calf. Flexor hallucis longus inserts into the base of the distal phalanx of the first digit (great toe), and flexor digitorum longus into the bases of the distal phalanges of the lesser toes (2 - 5). The insertions for tibialis posterior are slightly more involved as they include the cuneiforms, navicular, cuboid, and bases of metatarsals 2 - 4. In addition to plantar flexion, these muscles also produce distinct movements such as flexion of the first digit, flexion of the lesser digits (2 - 4), and inversion of the ankle respectively. All three cross the medial aspect of the ankle posterior to the medial malleolus and act as medial stabilizers of the joint.

Dynamic lateral stability is attained from the 2 muscles of the lateral compartment which are collectively known as the peroneal muscle group. Peroneus brevis and peroneus longus both originate from the fibula. Peroneus brevis inserts into the base of the fifth metatarsal whereas peroneus longus inserts into the plantar surface of the first metatarsal and the medial cuneiform. Both evert and plantar flex the ankle.

Four muscles are found within the anterior compartment of the leg. Extensor hallucis longus is found deep in the anterior compartment. It attaches to the tibia and fibula as well as the interosseous membrane, and inserts into the dorsal surface of the base of the distal phalanx of the great toe. Extensor digitorum longus is more superficial and has multiple origins including the lateral tibial condyle, the interosseous membrane, and the fibula. It inserts into the middle and distal phalanges of the lateral four toes. This allows it to extend these toes as well as dorsiflex the ankle. Tibialis anterior is medial to the extensor digitorum longus and originates from the superior half of the tibia. It inserts into the medial cuneiform and the base of the first metatarsal. It dorsiflexes and inverts the ankle.

Peroneus tertius is a small muscle that originates from the distal fibula and interosseous membrane, attaches to the dorsal surface of the fifth metatarsal, and dorsiflexes and everts the foot. The muscles of the deep posterior compartment and those of the anterior compartment are "tied down" by strong connective tissues called flexor and extensor retinaculae respectively. They essentially prevent the tendons from bowing when the muscles contract.

2.3 Mechanisms of Injury

Inversion has been shown by some authors to be the single most common injury mechanism resulting in lateral ligament sprains (Bunch, Bednarski, Holland, & Macinanti, 1985; Greene & Hillman, 1990; Greene & Wight, 1990; Miller & Hergenroeder, 1990; Paris & Sullivan, 1992; Tropp, 1986; Tropp, Askling, & Gillquist, 1985) but other authors suggest that the combination of plantar flexion and inversion place the ankle in an unstable position which is how most lateral injuries occur (Alves, et al., 1992; Greene & Roland, 1989; Lane, 1990; Lassiter, et al., 1989; Rarick, et al., 1962). And there are others still who feel that most injuries occur when the ankle is in a plantar flexed position (Derscheid & Brown, 1985; Karlsson & Lansinger, 1992).

Table 2.1 (Andrews and Harrelson, 1991) outlines two sets of normative data for average ranges of motion of the lower leg and ankle (Andrews & Harrelson, 1991). These figures show that average amount of inversion is 15 to 20 degrees more than is the average amount of eversion (Andrews & Harrelson, 1991). This relates to several anatomical considerations which result in the consistency of ankle injury mechanisms. Because the lateral ligaments exist as three distinct fascicular bundles, they are not as strong as the broad, expansive deltoid ligament on the medial side (Greene & Hillman, 1990). In other words, the ligaments are more resistive to eversion than inversion. There are also 2 skeletal factors to be considered. First, the superior aspect of the talus is wedge shaped. When the ankle is in neutral position, the wider part of the wedge articulates with the crural mortise. As the ankle moves into plantar flexion however, the anterior-superior aspect of the talus narrows resulting in a looser fit (i.e., less stability) within the crural mortise (Derscheid & Brown, 1985; Karlsson & Andreasson, 1992; Lassiter, et al., 1989). Lassiter, et al. (1989) also refer to the fact that this looser fit further reduces bony stability because the articular surfaces are not fully loaded, leaving the ligaments to absorb greater levels of stress . And second, the lateral malleolus extends distally further than the medial malleolus. This provides a bony block that effectively limits eversion (Derscheid & Brown, 1985; Lassiter, et al., 1989) as the talus would be everted into the medial aspect of the lateral malleolus.

Table 2.1 Two sets of normative data for average ranges of motion of the lower leg and ankle.

	Data Source	
Motion	American Academy of Orthopaedic Surgeons	Kendall & McCreary (1983)
Inversion	0-35 °	0-35 °
Eversion	0-15 °	0-20 °
Plantar flexion	0-50 °	0-45 °
Dorsiflexion	0-20 °	0-20 °

2.4 How Prophylactic Ankle Supports Work

It has been suggested that prophylactic taping and bracing offer distinct benefits to athletes but there are many theories as to how these benefits are achieved. It may be through provision of mechanical support (i.e., a physical barrier to excessive motion), proprioceptive support (i.e., increased sensory feedback and muscle firing due to the warmth and/or pressure provided by the support), or psychological support (i.e., the comfort of feeling that the ankle is protected). In all likelihood, it is a combination of all three of these that contribute to the overall effectiveness of any prophylactic ankle support. The following review of literature will summarize what is reported in the literature, and will do so from these three perspectives.

Injury prevention via mechanical support has been extensively studied (Alves, et al., 1992; Bunch, et al., 1985; Burks, et al., 1991; Capasso, et al., 1989; Carne, 1989; Firer, 1990; Garrick & Requa, 1973; Gehlsen, et al., 1991; Greene & Roland, 1989; Greene & Hillman, 1990; Greene & Wight, 1990; Gross, 1987; Gross, et al., 1991; Gross, et al., 1992; Gross, et al., 1994; Hughes & Stetts, 1983; Karlsson & Andreasson, 1992; Lane, 1990; Larsen, 1984; Lofvenberg & Karrholm, 1993; Lutz, et al., 1993; Martin & Harter, 1993; Miller & Hergenroeder, 1990; Morris & Musnicki, 1983; Myburgh, et al., 1984; Pope, et al., 1987; Quigley, et al., 1946; Rarick, et al., 1962; Robinson, et al., 1986; Rovere, et al., 1988; Rovere, et al., 1989; Stover, 1986; Tropp, et al., 1985; Vaes, et al., 1985). Mechanical stabilization concentrates on physically limiting undesired ranges of motion such as inversion and plantar flexion. This can be achieved by either completely limiting a specific movement, or by allowing said movement but restricting excessive amounts of it. The former may be undesirable since in the case of the ankle-foot complex, some inversion and plantar flexion is required for normal gait. Restriction of excessive motion may be preferable since it allows for the required functional ranges while preventing the terminal ROM where injuries may be more likely to take place. For example, a casted ankle is very safe, but completely nonfunctional. The ultimate prophylactic support then would only limit the ranges of motion wherein tissues are being stressed to the point of injury.

The second theory in support of the prophylactic effects of ankle taping and bracing focuses on the proprioceptive benefits that are achieved. To fully appreciate the importance of proprioceptive abilities of the ankle, three things must be done. We must define proprioception, establish a relationship between proprioception and ankle injuries, and demonstrate the ability of prophylactic supports to enhance proprioceptive qualities of the ankle.

Proprioception is defined as the "awareness of body position in space" (Kent, 1994) and relies on proprioceptors to function. Proprioceptors are sensory receptors located within the muscles, tendons, joint capsules, and ligaments of the body. They are responsible for conveying information about the state and position of body parts to the brain. The brain processes this information on an ongoing basis and initiates a variety of muscular responses when required. In the case of the peroneal muscle group reflex, it appears that upper motor control is unlikely and that peroneal response to sudden perturbations may be conducted via a reflex pathway (Konradsen & Ravn, 1991). Gross (1987) has shown that joint receptors are primarily responsible for signaling joint position, and muscle receptors signal joint movement. The mechanism by which this relates to the ankle is as follows. An athlete who is running on uneven ground may suddenly invert his/her foot. The proprioceptors detect this and convey a message along a reflex pathway. Consequently, efferent neurons signal the appropriate muscles (the peroneal muscle group in this particular example) to rapidly contract in an effort to prevent an inversion injury.

Several researchers (Derscheid & Brown, 1985; Firer, 1990; Freeman, et al., 1965; Greene & Roland, 1989; Gross, 1987; Karlsson & Lansinger, 1992; Karlsson & Andreasson, 1992; Konradsen & Ravn, 1991; Moller-Larsen, Wethelund, Jurik, Carvalho, & Lucht, 1988; Pope, et al., 1987; Rovere, et al., 1989; Staples, 1975; Tropp, 1986; Tropp, et al., 1985) have investigated the claim that prophylactic ankle supports may enhance the proprioceptive qualities of the ankle. Freeman (1965) showed a relationship between talar tilt and contraction of peroneus brevis. Subjects with significant talar tilt were shown to have premature contractions of the peroneus brevis muscle (presumably in an effort to correct the talar tilt). When these same subjects were taped, the peroneus brevis contracted earlier, and remained contracted for a longer period of time as it worked to increase subtalar stability. This is suggestive of an increased proprioceptive effect on the muscles in question. The importance of the peroneal muscle group in ankle stability is crucial as these muscles act as dynamic stabilizers in support of the lateral ligaments (Reid, 1992).

Tropp (1986) conducted a study which was designed to assess postural control in soccer players with and without functional instabilities. He used a single leg stance technique to determine stabilometry values and found that both the affected and unaffected limbs of soccer players with known functional instabilities were shown to have less postural control than the functionally stable control group. The differences between the affected and unaffected sides were not significant. Tropp concluded that muscle strength does not correlate with postural control (as determined by single leg stance tests), and that peroneal muscle weakness is a contributing factor to functional ankle instability.

Konradsen and Ravn (1991) also incorporated a single leg stance and found a high correlation between postural control and peroneal reaction time; suggesting that functional stability (as determined by single leg stance tests) depends on peroneal muscle reflexes. All of these factors have been shown to be predictors of future injuries to the lateral ankle ligaments (Freeman, et al., 1965; Tropp, 1986; Tropp, et al., 1985).

Konradsen and Ravn (1991) offer several plausible explanations for the increased peroneal reaction time that they found in unhealthy ankles compared to healthy ankles.

They too hypothesize that the initial ligament sprain also damages receptors and nerve fibers within the capsular and ligamentous tissues. They also noted that after injury, the viscoelastic properties of receptors and nerve fibers were altered in such a way as to make their function less efficient. This may force the impulses to travel along a longer, less efficient pathway. A third possibility is that the mechanical instability itself is the reason for the delay. This is derived from the work of Karlsson who proposed that "receptor stimulation takes place at a fixed fraction of talocrural joint inversion" (Konradsen & Ravn, 1991). There was no evidence to support the theory that prophylactic supports are effective because of stimulation of skin afferent nerve endings.

Karlsson and Andreasson (1992) measured the reaction times of peroneus brevis and peroneus longus in stable and unstable ankles, under taped and non-taped conditions. They found that without tape, the reaction times of both muscles were significantly slower in unstable versus stable ankles. The reaction times were also significantly shorter when the ankles were taped. And lastly, the greatest reduction in reaction times were seen in ankles that had the highest degree of instability to begin with. Based on this data, Karlsson and Andreasson (1992) concluded that prophylactic ankle taping did have a significant proprioceptive effect which contributes to the effectiveness of prophylactic ankle taping. Rovere, et al. (1989) concur with Karlsson and Andreasson in saying that most prophylactic supports work not only because of mechanical principles, but because of other factors at work, namely enhanced proprioception.

Staples (1975) performed a survey of patients who had previously suffered "severe" injuries to the lateral ligaments of the ankle and concluded that no proprioceptive deficits were found after a two and one-half year period. No quantitative tests were performed however and these conclusions were drawn from survey data. This may have resulted in incorrect assumptions being drawn.

Greene and Roland (1989) performed a study in which they found higher isokinetic torque values in healthy ankles that were braced versus non-braced. They concluded that enhanced proprioception may have been a contributing factor. They also suggested that repeated ligamentous sprains not only cause damage to the joint ligaments, but also result in muscle atrophy which would interfere with normal functioning of the receptors found within the muscle itself.

In what is arguably the most referred to article on the subject of the relationship between proprioception and ankle stability, Freeman, et al. (1965) sought to identify causal factors of functional instability of the foot, and suggested preventative measures. They claimed that functional instability occurs in 40% of people who experience some lateral ligament injury and the cause is a disruption of motor coordination secondary to receptor deafferentation. Karlsson and Lansinger (1992) stated that it is the "most common and serious residual disability" following injury to the lateral ligaments of the ankle. Since articular nerve fibers have a lower tensile strength than the collagen in which they lie (Freeman, et al., 1965; Gross, 1987), it stands to reason that a ligamentous injury will also include damage to these fibers. Freeman, et al. (1965) arrived at three conclusions. One, that some degree of proprioceptive deficit is displayed following a lateral ankle sprain. Two, that this deficit remains in those subjects who display a functional instability. And three, treatment that is designed to improve balance and motor coordination will alleviate (to some extent) the functional instability and the proprioceptive deficit.

After all is said and done, several questions remain. For instance, it is well established that chronic ankle instability and proprioceptive deficits of the ankle are related. What has yet to be determined however, is whether or not there is a causal relationship between the two, and if there is, in which direction does it run? In other words, do the proprioceptive deficits cause the ankle sprains, or do these deficits result from said sprains?

Yet another point of contention is peroneal muscle strength. Even if the peroneal muscles reflexively contract to protect against a sudden inversion motion, they are not likely strong enough to prevent an injury (although they may slow the inversion sufficiently to reduce the severity of the injury).

The third mechanism by which prophylactic ankle supports may work is via psychological effects. In an article in which Firer (1990) examined the various mechanisms through which prophylactic ankle support was attained, he did not even consider the possible psychological effects. Greene and Roland (1989) evaluated subjective responses in subjects who wore a semirigid orthosis while performing isokinetic strength evaluations. They found that subjects produced much higher torque when they wore the semirigid orthosis . The same subjects also reported feeling more secure with the orthosis on. Greene and Roland (1989) felt that this may have been due to an increased sense of security felt with the orthosis . What is especially interesting was that all 30 subjects in this study had healthy ankles. It is possible then, that an athlete with an unstable ankle would be even more aware of the increased sense of support provided by the orthosis (the suggestion being that the difference in torque output between braced and non-braced conditions would be much greater in unstable ankles versus stable ones).

2.5 Elastic Wraps

Elastic wraps have been used in the past as prophylactic supports but as we will see, they have been shown to be very inadequate (Bunch, et al., 1985; Miller & Hergenroeder, 1990; Myburgh, et al., 1984). Such devices can take the form of elastic sleeves that slide over the ankle or they can take the form of elastic bandage wrap. The literature does not differentiate (as it does with tape) between different wrapping techniques employed with such wraps. However the consensus is that regardless of the wrapping technique used, no mechanical stability is gained via this method (Miller & Hergenroeder, 1990). Garrick and Requa (1973) completed a two year study of the intramural basketball program at the University of Washington. Although they found a lower number of ankle sprains in players who wore elastic wraps than those who were taped or wore no support, they attribute this to the fact that 66% of the people in the taped group had been previously injured whereas only 39% of those in the untaped group had previous injuries. An even smaller percentage of those in the elastic wrap group had sustained previous injuries (although the exact figure is not provided). Another noteworthy item from this study however is that of the 1107 players designated as untaped, 132 of them did in fact wear some form of external support. Since these were self applied however, there was no control over them. The researchers considered this to be a "conservative" bias and included them in the study.

Myburgh, et al., (1984) examined the use of two different kinds of elastic guards as prophylactic ankle supports for high level squash players. They measured the amount of support provided by each device before, during (ten minutes into the game), and after exercise. Each game was one hour long and players were comparatively matched. Their findings showed that at no time did either of the elastic guards provide significant support for plantar flexion, dorsiflexion, plantar flexed eversion, plantar flexed inversion, neutral eversion, or neutral inversion movements. All movements were measured using a custom-built, electronic goniometer based on a design by Inman (1976). One potential bias that is not discussed within the article itself involves treatment selection. All subjects were right foot dominant but the ankle guards were always worn on the right feet, and the tape on the left feet. Players will likely favour one foot over the other so a logical conclusion can be derived that one method of support was sustaining greater stress than the other.

Elastic guards are inherently poor ankle stabilizers because by their very nature, they must be flexible enough to slide over the foot and ankle, much in the way that one would pull on a sock. This type of support may not be entirely useless however as many studies have shown ankle stability to be a function of the surrounding musculature (especially the peroneal muscles) (Konradsen & Ravn, 1990). The elastic guards may offer proprioceptive benefits (Glick & Nishimoto, 1976) by applying pressure to the musculature that surrounds the ankle joint. This would result in increased awareness of joint position, and faster firing times of the muscle receptors that lie within the muscle fibers and surrounding tissues. Theoretically, this would in turn decrease the response time of the muscles responsible for stabilizing the joint. Increased proprioception has been shown to play an important role in the prevention of ankle sprains (Freeman, et al., 1965; Gross, 1987) so the elastic guards may indirectly provide some protective function by enhancing the proprioceptive mechanisms of the ankle.

One definite benefit is their ability to exert compression (Capasso, et al., 1989), thereby limiting edema once an injury does occur. They may also provide some degree of psychological support to the athlete although this is more anecdotal and not yet quantified. Regardless, any proprioceptive or psychological effects would presumably be attained with other methods such as taping or a semirigid orthosis, which offer a significant amount of mechanical stability as well.

2.6 Ankle Wraps

Another method of ankle support is the use of canvas or cotton wraps. While they have the advantage of being reusable, no research has ever shown them to offer any level of mechanical support which could be considered significant enough to assist with injury prevention. Ankle wraps have been shown to be 70% less effective than tape in terms of ankle support and stiffness (Bunch, et al., 1985). In addition, because wraps are nonadhesive, they tend to loosen and/or slip with time which results in a progressive decrease in stability. Unfortunately however, no studies have examined the stabilizing effect of wraps during or after exercise, so exactly how much stabilization they afford is open to speculation.

As shown below, some researchers use the degree of talar tilt (TT) as a measure of ankle stability. In the simplest sense, talar tilt is the angle that is formed in the frontal plane, by a vertical line that bisects the talus, and a line down the midline of the crural bones. It stands to reason that the greater the amount of TT, the more movement will take place in the frontal plane (in other words, the more inversion and eversion the joint will be capable of). Vaes, et al. (1985) demonstrated that the degree of talar tilt was not reduced significantly by the application of ankle wraps compared to that of an unsupported ankle.

However some researchers have questioned the use of TT as an indicator of ankle stability (Baumgardner, 1976; Elmslie, 1934; Johnson & Markolf, 1983; Rubin & Witten, 1960; Staples, 1975). According to Vaes, et al. (1985), it provides specific information about only one ligament (the calcaneofibular), as opposed to overall ankle joint stability. The calcaneofibular ligament provides minimal support to the ankle during movements such as plantar flexion and inversion; when the ankle is most susceptible to lateral sprains. The anterior drawer test may be a better indicator of external support because it more effectively isolates the anterior talofibular ligament (Arnheim, 1989; Magee, 1992; Reid, 1992). It is this ligament that is usually the first to be injured in a lateral ankle sprain (Andrews & Harrelson, 1991) and therefore it plays a very significant role in the prevention of such injuries.

Such criticisms are moot however because while the above points may be true as they pertain to ligamentous stability, they are an over simplified representation of what happens in vivo. Ankle stability is not the result of any one particular ligament. It is the combined efforts of all of the surrounding ligaments, bony articulations, and musculature that provides one with stability in any joint, and the ankle is no exception.

There is generally a lack of research on the effectiveness of wraps and their ability to offer protection to the ankle joint. This makes more detailed comparisons impossible.

2.7 Lace-on Stabilizers

The use of lace-on stabilizers to protect the ankle from injury is a relatively common practice. Several studies have been conducted and not surprisingly, they have produced mixed results. A lace-on stabilizer is a thin, somewhat flexible shell that is slid over the foot and ankle (similar to a sock) in such a way that it can surround the entire joint. The stabilizer extends from the midfoot, up to and above the level of the malleoli. It is thought to offer more support than the elastic guards mentioned above because it has laces along the front edge (similar to a shoe) which can be tightened and retightened as required. Lace-on stabilizers are worn over a regular sock. It is the ability to easily retighten them that gives them an advantage over many other forms of support.

Bunch, et al. (1985) conducted the largest study to date in evaluating the effectiveness of 5 different stabilizers and comparing them to prophylactic ankle taping. The 5 stabilizers were: the Mikros 9in., Swede-O, Ank-L-Aid, Mikros 7in., and the Cramer stabilizer. The amount of inversion allowed by each support was considered to be indicative of overall support. They were tested for inversion immediately after application, and then retested for the amount of inversion allowed after a 20 minute exercise period.

The methodology employed by Bunch, et al. (1985) is noteworthy for several reasons. First, the stabilizers and tape were not applied to a real foot. A polyurethane foot model was created, complete with a ball joint that was positioned along the axis of the two malleoli. This left the researchers with what they referred to as an "anatomically correct foot form". There are many inherent problems with such a model however. It cannot possibly be representative of the skin texture of a real foot and ankle. This may affect the adherence qualities of the support to the model. In addition, the axis that they refer to is an approximation of the axis of rotation about which plantar flexion and dorsiflexion occur. The movement that is being evaluated in this study however is inversion, which takes place about a completely different axis. The main axis of rotation about which inversion takes place extends superiorly at a 42 degree angle from the horizontal plane, and 16 degrees from the sagittal plane (McPoil, & Brocato, 1990; Sammarco, G.J., 1989) (Appendix B).

Additionally, the exercise period used in this study consisted of 350 cycles of passive inversion, performed by a machine over a 20 minute period. The model was affixed to a machine that moved it into 30 degrees of inversion and returned it to neutral, 350 consecutive times. Using this as an exercise protocol may be inappropriate for three reasons. First, although this is supposed to mimic an exercise condition, one might question whether or not the stresses at the ankle are equal to that of 20 minutes of squash (or any other activity for that matter). Second, the 350 cycles of inversion were applied passively, and did not include any active component as would be found in most sport events. Third, all of these stresses were applied in an open kinetic chain. Most stress, and consequently most injuries to the ankle, will occur in a closed kinetic chain. Inevitably then, the changes in levels of support measured in this study may be conservative compared to what may occur in more realistic sport situations.

Rovere, et al. (1988) completed a retrospective study with an American University football team. They compared ankle injury rates in players who used ankle tape to players who wore no support, to players who wore a lace-on stabilizer (the brand of the stabilizer is not provided). They found that players who wore tape were twice as likely to sustain an ankle injury as players who wore ankle stabilizers ($p < 0.003$). They even stratified their findings across player positions but the relative effectiveness of the stabilizers remained consistent. When shoe type was considered, the results continued to favour the stabilizers over ankle taping. A more detailed analysis of this study is provided in the section on ankle taping (Section 2.9).

2.8 Semirigid Orthoses

Use of a semirigid orthosis for prophylactic as well as functional purposes is gaining popularity among athletes and therapists. As a result of this popularity, many studies have been done to determine if they offer as much support as their manufacturers claim. Collectively they are referred to as semirigid orthoses but many different models are available for use.

Hughes and Stetts (1983) designed and constructed one such support from a thermoplastic material that was cut and molded to fit an athlete's ankle. The "splint" as the manufacturers referred to it, was then secured to the ankle with an elastic bandage. This particular orthosis is obviously one of a kind. It was custom built (using supplies found in most clinics) to fit the ankles of the subjects being tested. As a result, this study cannot be exactly replicated and there may be inconsistencies in the manner in which each subject was fitted for the splint. It is not surprising then that the literature does not contain any other research that is similar to this. In addition, there are flaws within the methodology itself and these will be addressed below. With these factors in mind, any comparisons to other studies is not possible at this time although a review of this research is warranted.

Hughes and Stetts (1983) noted that the range of inversion is substantially more when the ankle is plantar flexed than dorsiflexed, and opted to assess ankle stability with the ankle in neutral position. It would seem that this presents a serious threat to external validity however as it is in the plantar flexed position that the ankle is most unstable and therefore most susceptible to injury. If nothing else, testing should have been done with the ankle in two positions; in neutral and in some degree of plantar flexion. This would have effectively removed this threat to external validity.

Inversion ROM was evaluated for each ankle of each subject under three different conditions: (1) presupport, (2) pre-exercise, and (3) post-exercise. Exercise in this study consisted of a 20 minute period during which the subjects ran several sprint relays (including forward, backward, and lateral movements) and ran/walked 1.25 miles. Both the prophylactic tape and the semirigid orthosis provided similar levels of stability under all conditions. The results of Hughes and Stetts (1983) did not show either method to be superior to the other but given that tape requires a trained therapist to apply and is significantly costlier over the long run (Gross, et al., 1987; Rovere, et al., 1988), the splint may be a better choice for athletes looking to protect their ankles.

The semirigid orthosis that is most prevalent in the literature to date is the Aircast Sport-Stirrup. It is applied directly over top of a sock and consists of two outer plastic shells that are positioned on the medial and lateral aspects of the ankle and lower leg; with an inflatable air cell on each of the inner walls, against the leg (Appendix C). The heel of the foot stands on a small piece of plastic which connects the two sides of the support via a thin nylon strap. The two sides then run approximately half way up the leg in a stirrup fashion. The two sides are secured to the leg with two horizontal velcro straps which wrap completely around the circumference of the leg. The orthosis itself is designed to allow maximal plantar flexion and dorsiflexion, while limiting inversion and eversion movements.

The air cells make custom fitting unnecessary as they can be inflated or deflated to suit the needs of the athlete. And the increased comfort should result in better compliance with wearing the orthosis. Functionally, the air cells also apply compressive pressure on the lower leg and ankle which, as the manufacturer's claim, alternates between sides with ankle movement (Stover, 1986). This pumping action serves two important purposes. First, it increases blood flow and proprioception to the area. Proprioception has been shown to be a contributing factor in aiding ankle stability (Derscheid & Brown, 1985; Firer, 1990; Freeman, et al., 1965; Greene & Roland, 1989; Gross, et al., 1987; Moller-Larsen, et al., 1988; Pope, et al., 1987; Rovere, et al., 1989; Tropp, et al., 1985) and hence injury prevention. Second, the pumping action of the air cells plays a role that is important in the recovery process should an injury occur. The pumping helps to milk away swelling which in turn reduces pain and facilitates the healing process (Stover, 1986). This is not only important during initial rehabilitation, but also during that time when the athlete is just returning to activity following an injury.

In comparing the Aircast Sport-Stirrup and ankle taping, restriction of ROM was assessed prior to application of the support, pre-exercise, and post-exercise (Gross, et al., 1987). In this study, exercise consisted of 10 minutes of running around a figure eight course and 20 heel raises. The figure eight course was performed at the subject's own pace. Total ROM (the amount of motion available between the extremes of inversion and eversion) was assessed but they also measured the ROM for each of these movements separately. This is in contrast to the work by Alves, et al. (1992) as they chose to look exclusively at total ROM in what was otherwise a similar study. By measuring only total ROM, external validity may be reduced because while a change in the total ROM would be detected, it would not be certain where that change was occurring. For instance, an orthosis that restricts total ROM by 12 degrees will not prevent many injuries if all of the restriction occurred in eversion (i.e., inversion was not affected by the orthosis).

In the study by Gross, et al. (1987), the total ROM was significantly reduced by both the tape and the Aircast Sport-Stirrup (under all three conditions) but the tape was less restrictive by 9.03 degrees prior to exercise, and by 14.31 degrees after exercise ($p < .01$). Interestingly, with the pre-exercise assessment they found a significant difference between the two for eversion but not for inversion. This would imply then that the Aircast Sport-Stirrup's greater pre-exercise restriction in total ROM was due to differences in limiting eversion since both supports were similarly adept at limiting inversion. This was a significant finding since 85% of all ankle sprains are caused by excessive inversion movements (Gross, et al., 1987; Miller & Hergenroeder, 1990). This also serves to reemphasize the point above regarding the importance of measuring individual ranges of motion versus total ROM.

Therefore, to be effective in preventing the most common kind of ankle injury, the support, above all else, must prevent excessive inversion of the ankle. And given that both supports are capable of this in the preexercise condition (to a statistically significant level), then both should be similarly effective at preventing injuries at the onset of exercise. Perhaps more critical however, is the fact that although the tape loosens to a greater extent than does the Aircast Sport-Stirrup following exercise, they both continue to restrict motion (total, and inversion and eversion individually) to a significant level.

Because athletes require maximal dorsiflexion and plantar flexion movements in order to perform well (regardless of the sport), it is just as important to know to what degree any prophylactic support restricts these movements. The researchers have erred by not assessing this in their study. A true comparison of any supports must incorporate movements in the sagittal plane as well as those in the frontal plane.

Greene and Wight (1990) evaluated the support effectiveness of three ankle orthoses before, during, and after a 90 minute softball practice. They used the Aircast Air-Stirrup, Donjoy Ankle Ligament Protector (ALP), and Swede-O Universal ankle orthoses. They measured three variables: passive inversion, eversion, and total ROM prior to exercise, after 20 and 40 minutes of exercise, and following exercise.

Prior to softball practice, each orthosis provided significant restriction of inversion and eversion although the Swede-O was significantly less effective than the Air-Stirrup and the ALP. Twenty minutes into practice, ROM was evaluated a second time. The Swede-O demonstrated a significant loss of support for inversion, eversion, and total ROM after 20 minutes of practice, and the Air-Stirrup and ALP demonstrated an insignificant change of support. After 40 minutes of practice, the Swede-O had experienced a further significant decline in support, but the Air-Stirrup and ALP had not changed significantly. At the conclusion of the 90 minute practice, the Swede-O had not lost any further support against eversion but support against inversion and total ROM was significantly less. The Air-Stirrup did not undergo any significant change in eversion or total ROM but did allow significantly more inversion. The ALP did not have any significant change in support following the 90 minute practice.

As summarized by Greene and Wight (1990), the changes in support that took place from initial application to completion of practice are as follows: the Swede-O experienced significant loss of support for all 3 ROM variables as exercise progressed. The Air-Stirrup experienced significant loss of support for inversion and total ROM without any significant change in eversion. The ALP experienced no drop in support for any of the ROM variables throughout the 90 minute practice. When the athletes were asked to subjectively rank their preference for each support (based on perceived comfort, stability, and performance) they ranked the ALP as first, followed by Swede-O, and Aircast as last.

Several major criticisms of the above article were put forward by Gross, et al. (1992). They pointed out that although Greene and Wight (1990) examined the amount of support that was lost with exercise, they did not compare the pre- and post-exercise levels of support to see if significant restriction remained. Post-exercise results were not compared to determine which orthosis provided significant support after exercise. They only indicated how much support was lost as practice continued. While it is clear which orthosis lost the least support compared to its pre-exercise level, it is not clear as to whether or not the remaining support was significant. Additionally, Greene and Wight (1990) did not indicate what activities were involved in the softball practice, nor the intensity of those activities.

Gross, et al. (1992) conducted a study in which passive inversion and passive eversion were measured before and after a set exercise period on subjects who wore the Donjoy Ankle Ligament Protector (ALP) and the Aircast Sport-Stirrup. In this study, exercise consisted of 10 minutes of running around a figure eight course and 20 heel raises. The figure eight course was performed at the subject's own pace (a limitation in itself).

Gross, et al. (1992) found results that were consistent with previous research. Both orthoses provided significant restriction prior to exercise, and both lost significant restriction (to inversion and eversion) following exercise. Both orthoses provided significant restriction of eversion following exercise when compared to pre-exercise measurements. Subjects were also asked to rank the orthoses in terms of perceived comfort and stability provided by each. The majority of subjects preferred the ALP as the most supportive (which confirms the quantitative data which indicated that the ALP was better at restricting inversion). Most subjects also chose the ALP as the more comfortable of the two orthoses.

Tropp, et al. (1985) indicated that a semirigid orthosis such as an Aircast Sport-Stirrup will prevent all inversion and eversion movements by maintaining the ankle in a neutral position. At first this would appear to be a desirable goal but this may not necessarily be so. A limited amount of inversion and eversion are necessary throughout the normal gait cycle (McPoil & Brocato, 1990) and limiting either of these movements completely may hinder athletic performance, not to mention the possibility of creating undesirable conditions (such as bunions, shin splints, and patello-femoral pain to name but a few) due to altered biomechanics. This concern would appear to be unnecessary however, since not a single one of the prophylactic supports that has been studied to date has accomplished complete restriction of movement.

Stover (1986) has indicated that the Aircast Sport-Stirrup can also be used as a functional brace; expediting an athlete's return to activity more rapidly following a ligamentous injury. Plaster casting offers the most effective rehabilitative external support according to Rovere, et al. (1989) but the trend in sports medicine today is towards an aggressive treatment protocol (active rehabilitation) in an effort to reduce such undesirable effects as muscle atrophy, adhesions, and scar tissue build up. In other words, the old treatment of casting sprains is too restrictive.

The Aircast Sport-Stirrup is easily applied and reusable so at approximately $80.00 per brace, it is relatively cheap over the long run. It may also provide the external support necessary for the athlete to return to regular training without putting excessive strain on injured ligaments. It is said to assist the therapist and the athlete in adopting an aggressive treatment protocol which facilitates an early and safe return to a preinjury level of competition. Arguably, the most important advantage of the Aircast Sport-Stirrup is the fact that regardless of injury severity, people treated in an Aircast Sport-Stirrup return to activity in less than half the time of those treated with plaster casts (Stover, 1986). What Stover does not allude to however, is the reason for this. In other words, this claim may not be exclusive to the Aircast Sport-Stirrup. Given current philosophies for treating ligamentous injuries to the ankle, one could safely argue that the return to activity may be half the time when compared to casting (regardless of the kind of semirigid orthosis used) only because aggressive therapy is administered.

The Aircast Sport-Stirrup is rather unique in that it can be used as a functional orthosis and as a prophylactic orthosis without changing the orthosis itself or the way it is applied. However, evidence to this effect is not irrefutable. There is no conclusive proof to substantiate the claim that it is better able to protect the ankle than is adhesive tape or other methods of support (stabilizers or other semirigid orthoses). It is not recommended as a primary line of defense for a healthy ankle against ligamentous sprains (Miller & Hergenroeder, 1990). This is in spite of its apparent effectiveness as a functional support to prevent reinjury while rehabilitation is ongoing.

The Active Ankle is a relatively new semirigid orthosis that is similar in many respects to the Aircast Sport-Stirrup; although it has yet to be evaluated to the same extent. The Active Ankle (Appendix C) consists of two semirigid plastic shells that are positioned on the medial and lateral aspects of the ankle and lower leg. A soft foam lining separates the athlete's leg from the outer shells. The heel of the foot rests on a piece of plastic which is connected to the two sides of the support via a bilateral hinge. The orthosis extends approximately half way up the leg, and is secured with two horizontal velcro straps which wrap completely around the circumference of the leg. Like the Air-Stirrup, Active Ankle is designed to allow maximal plantar flexion and dorsiflexion, while limiting inversion and eversion movements.

This orthosis has two features which make it unique. The first is its bilateral hinge which should allow full range of plantar flexion and dorsiflexion, without compromising its ability to prevent excessive inversion or eversion. These hinges are situated to approximate the axis about which plantar flexion and dorsiflexion take place. The second is the design of the two outer shells. The human leg and ankle are not perfectly symmetrical and the manufacturers of the Active Ankle must have been cognizant of this. While the Aircast Sport-Stirrup consists of two identical outer shells, the Active Ankle's outer shells are noticeably different. The lateral shell extends lower than the medial shell (just as the lateral malleolus extends lower than the medial malleolus), and the orthosis has a varus shape which approximates the shape of the leg and ankle. The result should be an orthosis that is not only more anatomically correct, but also more comfortable.

2.9 Prophylactic Taping

In many respects, prophylactic tape is the ruler by which all other methods of ankle support are measured. This is evidenced by the number of studies that compared that support to prophylactic tape (Bunch, et al., 1985; Burks, et al., 1991; Capasso, et al., 1989; Garrick & Requa, 1973; Gehlsen, et al., 1991; Gross, et al., 1987; Hughes & Stetts, 1983; Martin & Harter, 1993; Miller & Hergenroeder, 1990; Myburgh, et al., 1984; Rovere, et al., 1988; Rovere, et al., 1989) in terms of its ability to protect the ankle from injury. Realistically, the ability of prophylactic tape to protect the ankle from injury is very difficult to ascertain. The reasons for this are many and include the inconsistency in application of the tape, the brand of tape used, the taping technique employed, and the amount of time between application and exercise. Depending on the requirements of the individual athlete, a number of different kinds of tape can be used, and they can be applied using a number of "proven" techniques. The exact same kinds of tape must be applied by the same therapist, using the same techniques before valid comparisons can be made, and conclusions drawn. Even then, the individual athlete as well as his/her sport must be considered.

For instance, Bunch, et al. (1985), found that prophylactic tape can lose as much as one-third of its ability to support the ankle when it is applied by "inexperienced personnel". Obviously then, factors such as those identified above are critical when making direct comparisons. Such threats to external validity are not present to the same degree when evaluating other methods of prophylactic ankle support since stabilizers and semirigid orthoses are usually applied according to manufacturer's guidelines which are very simple and allow for consistency of application over time and among different individuals.

In addition, it may not be accurate to say that if prophylactic taping reduces ankle injuries in football players, that it will provide similar results for athletes in different sports, or even in football players of a different skill level or player position. It is also conceivable that a particular taping technique that gives the best results for one sport will not produce similar results for other sports.

The literature contains a variety of studies that employ different research methodologies. While many authors are proponents (at least to some extent) of prophylactic ankle taping (Bonci, 1982; Bunch, et al., 1985; Burks, et al., 1991; Capasso, et al., 1989; Garrick & Requa, 1973; Gehlsen, et al., 1991; Gross, et al., 1987; Hughes & Stetts, 1983; Martin & Harter, 1993; Miller & Hergenroeder, 1990; Myburgh, et al., 1984; Rovere, et al., 1988; Rovere, et al., 1989), most of these same authors concluded that a semirigid orthosis may be a better alternative. There is only one author (Ferguson, 1973) who argued against the use of prophylactic ankle taping all together. Regardless of the position taken, the research is primarily empirical and provides the researcher(s) with an opportunity to base a conclusion on some variable such as the number of ankle injuries per season when a particular support was used. I would suggest that although such information is important, it does not tell the entire story. It is one thing to say that brace "A" is better than tape, but it is quite another to prove why this is so.

Only one group (Andreasson, Edberg, Peterson, & Renstrom, 1983) has analyzed the mechanical properties of tape in an attempt to determine why, or even how it achieves these purported effects. They reported that medical tape had a tensile strength of 187 Newtons. They did not however, indicate what kind or brand of tape they were testing, nor how it was tested. Pope, et al. (1987) found that tape tears away from the skin at a force of 75-101 Newtons (depending on whether or not an aerosol skin adherent was used). As noted below, these are important considerations.

Although prophylactic ankle taping is designed to contribute to total ankle stability, it is the lateral ligaments that are most prone to injury. The weakest of these ligaments is the anterior talofibular ligament (Lassiter, et al., 1989). These researchers reported that a force of 138.9 (+/- 23.5) Newtons was found to be the maximum force tolerated by this ligament before fiber disruption occurred. Because this force is substantially greater than that required to break the medical tape tested by Andreasson, et al. (1983), one might suggest that taping is unnecessary (Firer, 1990). If tape breaks with a force of 75 Newtons but damage to the ligament it is supposed to be protecting does not occur until a force of 138 Newton's is sustained, then the tape is the weak link in the chain so to speak. While this may initially appear to be true, closer examination shows that such numbers may be misleading.

First, Andreasson, et al. (1983) neglected to consider the fact that tape is applied in layers, using a variety of orientations (such as heel locks and basket weave techniques) which make it substantially stronger than the 187 Newtons reported above (assuming that the whole is greater than the sum of the parts) (Larsen, 1984; Pope, et al., 1987; Rarick, et al., 1962). Second, the tape, in combination with the ligaments and surrounding musculature, could conceivably offer more combined support to the ankle than the sum of these structures individually; not to mention the psychological (Greene & Roland, 1989) and proprioceptive benefits (Bullard, Dawson, & Arenson, 1979; Derscheid & Brown, 1985; Firer, 1990; Freeman, et al., 1965; Glick & Nishimoto, 1976; Greene & Roland, 1989; Gross, 1987; Karlsson & Lansinger, 1992; Karlsson & Andreasson, 1992; Konradsen & Ravn, 1991; Moller-Larsen, et al., 1988; Pope, et al., 1987; Rovere, et al., 1989; Staples, 1975; Tropp, 1986; Tropp, et al., 1985) which have been suggested by several authors.

Traditionally, the basket weave, heel locks, and figure eight wraps have been used in various combinations to provide mechanical support to the ankle. One study (Rarick, et al., 1962) tested five conditions: unsupported, basket weave, basket weave with stirrups, basket weave with heel locks, and basket weave with heel locks and stirrups. They reported that all of the taping techniques lost support (approximately 40%) after a ten minute period of "vigorous exercise". They summarized that the basket weave with heel locks and stirrups was the most supportive both before and after exercise (but underwent the greatest reduction in support because of the exercise); whereas the basket weave by itself was the least supportive both before and after exercise (but underwent the least reduction in support because of the exercise). There was no reference to statistical significance. A final conclusion was that any loss in tape support was due either to slippage of the anchor strips, or to rupture of one or more strands of tape.

One interesting finding that went unexplained by Rarick, et al. (1962) was the fact that the combination that was most supportive prior to exercise (i.e., the basket weave with stirrup and heel locks) was weaker relative to the other combinations, after exercise. This is an important consideration since whatever method of support is selected, a critical factor is how well that support holds up to the stresses of exercise.

One threat to the validity of Rarick's study is that the subjects were asked to relax their leg muscles while being tested so that the muscles could not effect the results by restricting passive range of motion in any one direction. "Periodic palpations" of the leg muscles were done to assess muscle tension but this method may be unreliable because the support would cover a substantial portion of the musculature (making palpation difficult). Also, the term "periodic" was not defined. Palpations should be performed at the same time as the ROM measure is being taken otherwise it may be impossible to determine if muscle activity was restricting ROM. And lastly, the sensitivity of such a technique can be questioned. As the ankle is passively moved into inversion for example, the everters are going to be stretched, making them tight. It does not seem likely that palpation alone could differentiate between muscle tightening versus muscle contraction. This results in the possibility that muscle tension may have been overlooked by the researchers. This is especially true if prophylactic ankle supports enhance the sensitivity of the lower leg musculature (the peroneals in particular).

A more appropriate approach may have been taken in a study (Vaes, et al., 1985) that involved an electromyogram biofeedback apparatus to control for this potential problem. In brief, biofeedback provides immediate feedback to the subject and the researcher as to when a muscle or muscle group is being stimulated.

The work of Larsen (1984) is interesting because he radiologically measured the degree of TT and anterior drawer before and after exercise, and used these figures as indicators of ankle stability. He found that the degree of TT and anterior drawer displacement was in fact reduced significantly through the use of prophylactic ankle taping but only in pre-exercise conditions. Only TT was reduced following exercise.

The work of Vaes, et al. (1985) has already been mentioned with regards to the effects of strapping on ankle stability but they also studied the ability of tape to stabilize TT, and the relative change in TT support after a 30 minute exercise period. Prior to exercise, TT was significantly reduced by tape as compared to the same ankle without support. As found in other studies, the tape provided less support after a 30 minute exercise period, but the level of support remained statistically more significant than it was for the unsupported ankle. Vaes and his colleagues do not make any reference to the overall increased ROM in the unsupported ankle following exercise. This "warm-up" effect was noted by Myburgh, et al. (1984) and is likely attributable to the activity causing a warming of the soft tissues around the ankle, resulting in increased flexibility and therefore a greater ROM after exercise than before.

The validity of using TT as such an indicator however has been called into question by some authors (Baumgardner, 1976; Elmslie, 1934; Johnson & Markolf, 1983; Rubin & Witten, 1960; Staples, 1975) who suggest that it provides specific information about only one ligament (the calcaneofibular), as opposed to overall ankle joint stability. This point has been alluded to in the section on "ankle wraps". In fact, one study (Colville, Marder, Boyle, & Zarins, 1990), concluded that the calcaneofibular ligament was not an independent ankle joint stabilizer. Rather, it was deemed to be a guide that facilitated subtalar motion. These authors also suggested that the calcaneofibular ligament may only restrict subtalar inversion if the anterior talofibular ligament was disrupted. They did conclude however, that both ligaments play a significant role in lateral ankle stabilization. Because the most common mechanism of injury is inversion (with some degree of plantar flexion), and since inversion takes place at the subtalar joint, the assumption is that the degree of TT can be used as an indicator of ankle stability. This remains a controversial area that has yet to be resolved.

To date, the work of Vaes, et al. (1985) is one of the few studies to incorporate both anterior drawer and talar tilt in a study regarding prophylactic ankle supports. Not surprisingly, a radiological examination of TT and anterior drawer revealed that the higher the degree of ankle instability, the more supportive was the tape (Larsen, 1984). Unfortunately however, no steps were taken to demonstrate whether TT was a more valid indicator of ankle instability than was anterior drawer. Taped ankles were statistically more stable than untaped; both before and after 20 minutes of running on uneven ground (Larsen, 1984). This particular study did not incorporate braces as a prophylactic support so no comparisons can be made to taping. The results also suggest that TT can be used as an indicator of ankle stability, thereby validating the work of Larsen (1984).

Karlsson, et al. (1992) studied the effects of prophylactic ankle taping on radiologically evaluated anterior talar translation and on talar tilt. Tape was found to have an insignificant level of reduction of both of these variables. This led the authors to believe that the mechanical effect of prophylactic ankle tape is limited, and therefore, another mechanism must exist. Their research also incorporated an analysis of peroneal muscle reaction time under taped and untaped conditions. As discussed previously, the taped ankles had a significantly reduced peroneal reaction time and the authors concluded that prophylactic ankle taping was beneficial largely because of the enhanced proprioception that is associated with it. Unfortunately, no exercise component was incorporated into their study.

A rather unique approach was taken by Lofvenberg and Karrholm (1993). They performed radiographic examinations of 14 ankles of patients with chronic instability. Tantalum markers were implanted on the talus, calcaneus, and tibia, which allowed for radiographic measures of calcaneal and tibial rotations with and without support. The Strong ankle orthosis was the support that was used in this study. This is a thermoplastic semirigid orthosis that has been used by Lofvenberg and Karrholm as a functional support for patients with chronic lateral instability. Their results show that it significantly reduced the amount of talar and calcaneal plantar flexion, internal rotation, and varus angulation. Comparisons to other studies are difficult however due to the methodology and the orthosis used here.

Pope, et al. (1987) did a study involving a prosthetic model of the ankle. They constructed a wooden model and then used a cast of a human leg and ankle to form an acrylic "skin". They found that a combination of basket weave and figure eights was the most supportive taping technique when compared to basket weave, figure eights, figure eights with calcaneal strips, and figure eights with stirrups. Bullard, et al. (1979) arrived at a similar conclusion when they also found that the basket weave with heel locks was the most supportive compared to a basket weave by itself (which was the least supportive both prior to, and following exercise).

Despite the steps that were taken to make the model accurate, it did not replicate the complex triplanar movements that occur at the ankle and subtalar joints. Their model incorporated a hinge which allowed movement in a single plane. It would also be unable to replicate the high loading conditions that an athlete's ankle would undergo throughout the course of competition. And finally, when an athlete exercises, there is a build up of heat within the working muscles, an increase in skin temperature, and sweat and oils are excreted through pores in the skin. These factors have been shown to reduce the adherence of the tape to the skin (Bunch, et al., 1985; Capasso, et al., 1989; Ferguson, 1973; Greene & Wight, 1990; Gross, et al., 1991; Gross, et al., 1994; Larsen, 1984; Lutz, et al., 1993; Martin & Harter, 1993; Myburgh, et al., 1984; Pope, et al., 1987; Rarick, et al., 1962; Rovere, et al., 1988), but would not be incorporated into the prosthetic model.

Pope, et al. (1987) noted that the main reason for failure of prophylactic ankle aping is that it loses its adherence to the skin. Actual rupture of the tape itself is not a common cause of failure. This is in sharp contrast to the findings of Rarick, et al. (1962) who claimed that either mechanism of failure was likely. Pope and his colleagues did not note any statistically significant difference in adherence to the skin with 1, 2, or 3 layers of tape applied. A "layer" in this case refers to one application of a particular component of the tape. There was a significant decrease in the amount of adherence with the addition of a fourth layer of tape. This is surprising as the tape was applied in such a way that each successive layer overlapped the previous one by half of its width. It would seem then, that with additional layers, the tape should be less likely to loosen from the surface of the skin.

Pope, et al. (1987) also reported that the figure eight wrap gave greater deflection at yield than any other individual wrap, but the combination of figure eights with calcaneal strips provided the greatest deflection at yield compared to all other combinations of wraps. Deflection at yield can be defined as the amount of loading that a structure or material can endure before some permanent deformation takes place. Load to failure on the other hand refers to the amount of loading that a structure or material can endure before complete failure takes place. The combination of figure eights with calcaneal strips provided the greatest load to failure compared to all other combinations of wraps investigated in this study.

A calculation based on the dynamic load typical of sports was performed by Pope, et al. (1987) to estimate the load to failure that tape must endure during athletic competition to protect the ligaments of the ankle. Based on this calculation, only the figure eight and calcaneal strips combined provided sufficient support. Since there was no mention of when this measure was taken, we can only assume that it was done prior to exercise and subsequently, the ability of the tape to withstand such loads would progressively decrease with activity. Another point worth considering is that the above calculation was based on a load of 3 times body weight. The actual ankle loading in joggers is estimated to be 5 times body weight (McPoil & Brocato, 1990) and as high as 5 to 10 times body weight in more aggressive sports (Reid, 1992) such as basketball or football. It would appear that the formula used by these researchers would underestimate the actual loads through the ankle that must be endured in most sporting endeavors. However, since they stop short of saying that figure eights with calcaneal strips will prevent ankle injuries, any underestimating will have been consistent throughout the study and should not effect their final conclusions.

Myburgh, et al. (1984) compared the ankle stability offered by an elastic tape and a nonelastic tape. They found that before exercise, both tapes provided statistically significant support for all ankle movements except dorsiflexion. This however is not a concern since maximal dorsiflexion is both necessary and desirable for functional performance during running and jumping. After 10 minutes of squash, both tapes remained supportive but the "elastic tape had loosened considerably more". After 1 hour of squash, both tapes had loosened to the point where no statistically significant support was offered based on ranges of motion (inversion, eversion, dorsiflexion, plantar flexion) allowed by each. This suggests that, contrary to Rarick, et al. (1962), maximal loss of support does not occur within the first 10 minutes of exercise (although the kinds of exercise were different in the two studies) but rather, at some time between 10 minutes and 1 hour.

A 3 hour American football practice has been shown to reduce the effectiveness of prophylactic ankle tape from a 30% restriction of ROM before practice, to a 15% restriction after practice (Fumich, Ellison, Geurin, & Grace, 1981). This is in contrast to the above study which only saw a 10% reduction after a 1 hour game of squash. The researchers hypothesized that this difference was primarily due to the higher stresses that are placed on the ankle during a continuous game of squash versus the inconsistency of the loads that are applied during a football practice. There may in fact be other explanations such as those alluded to previously (different taping techniques using different tapes, the intensity levels of the two sports, or the skill levels of the respective athletes).

There has already been a reference to the study by Bunch, et al. (1985) in which 5 different ankle stabilizers were compared to prophylactic ankle taping; both before and after a simulated exercise period which consisted of 350 inversion cycles. They found that although the tape initially provided the most support, it lost the greatest proportion of support following exercise (21%) compared to the pre-exercise condition. Prior to exercise, the tape was 25% stiffer than the best lace-on stabilizer, and 70% stiffer than a cotton wrap. However following exercise, there was no difference between the tape and either of the two best stabilizers.

A study by Capasso, et al. (1989) investigated the compressive action exerted by different kinds of tape (all of which were applied in the same manner). They concluded that a non-elastic adhesive tape provided the greatest restriction of undesired movement but that if the goal was joint compression, then an elastic adhesive was more effective. Capasso, et al. (1989) recommended that the latter be used for acute injuries when decreasing joint effusion was the primary goal. Another benefit which they did not address however was the potential of enhanced proprioceptive qualities of the elastic tape (through its compressive abilities).

Garrick and Requa (1973) studied the intramural basketball program at the University of Washington. During the course of their study, data was gathered from 2562 player games. They employed an experimental design that incorporated a taped group and a control (untaped) group. The taped group applied "prophylactic tape" to their ankles but many of these individuals had experienced varying degrees of ankle injury previous to the study. The kind of shoe worn (high top versus low top) was also recorded. Of the 1107 player games designated as controls, 132 players did use some form of self-applied support on one or both ankles. In spite of this they were considered as controls since there was no quality control over the way in which the support was applied. A better alternative may have been to remove these subjects from the study. The authors considered this bias to be insignificant and included them in the data analysis.

The results of Garrick and Requa (1973) indicated that taping and high top shoes were the combination that had the lowest incidence of ankle sprains. The highest incidence was experienced in individuals who wore no tape and low-top shoes. Both of these were found to be statistically significant. Also noteworthy was that individuals who reported a history of "frequent" ankle sprains were three times as likely to be reinjured as were individuals with no history of ankle injury.

Gehlsen, et al. (1991) examined the effect of various prophylactic devices (Active Ankle, Swede-O Universal, tape, no support) on peak torque, total work, and passive ROM (for dorsiflexion and plantar flexion). They concluded that while tape did inhibit total plantar flexion work (to a significant level when compared with no support and Active Ankle), it did not have any significant effect on plantar flexion strength. They also found that tape was not significantly different in terms of ROM allowed except when compared to Swede-O at high velocities (189 degrees per second).

Greene and Hillman (1990) compared the passive ROM (inversion and eversion) and vertical jumping abilities allowed by prophylactic ankle taping and the Donjoy Ankle Ligament Protector (ALP) before, during, and after a 3 hour volleyball practice. Their conclusions supported much of the previous research. For instance, they found that the tape and ALP were almost identical in restricting ROM immediately after application but that after 20 minutes of activity the tape had lost 37% of its restricting ability. Following exercise, it had been reduced an additional 26% (i.e., it was now only 15% as effective as it was initially). After exercise, the ALP had only lost 5% of its initial restriction. These findings support those of Fumich, et al. (1981) and Gross, et al. (1987), but show the tape to be more restrictive than found by Myburgh, et al. (1984). This may be due to the potentially higher intensity of the squash match used in Myburgh's study, versus the 3 hour volleyball practice used here. Neither support had any significant effect on vertical jumping ability.

Another study (Gross, et al., 1987) compared the effectiveness of a semirigid orthosis (the Aircast Sport-Stirrup) and ankle taping at limiting passive inversion and eversion, before and after a brief exercise period. They found that prior to exercise, both supports offered significant restriction compared to no support. Interestingly however, both supports remained significantly restrictive following exercise (although the Aircast Sport-Stirrup was slightly more restrictive than the tape). The reasoning for this may be the intensity of the exercise period which consisted of 10 minutes of running (self-paced) on a figure eight course followed by 20 heel raises. Such activity is not likely going to stress the support as much as would occur in a competitive sport situation.

Gross, et al. (1991) evaluated the ability of the Swede-O-Universal Ankle Support, the Aircast Sport Stirrup, and tape in restricting passive ROM before and after exercise. As above, exercise consisted of 10 minutes of running (self-paced) on a figure eight course followed by 20 toe raises. All 3 supports significantly decreased inversion and eversion prior to exercise but the Aircast Sport Stirrup was slightly better than the Swede-O Universal and the tape with regards to eversion prior to exercise. Following exercise, all 3 maintained their ability to significantly restrict inversion compared to the amount of inversion when unsupported. The tape did however loosen significantly whereas the two semirigid orthoses did not. All 3 allowed significantly more eversion after exercise (with no one support being any better or worse than another) but still offered significantly greater eversion restriction compared to the unsupported ankle.

Martin and Harter (1993) conducted a study with a very similar protocol to that of Gross, et al. (1991). In this study, the ability of prophylactic ankle tape, the Aircast Sport-Stirrup, and the Swede-O Universal ankle stabilizer to restrict inversion active ROM was investigated in pre- and post-exercise conditions. The exact protocol used was: prophylactic support applied, pre-exercise inversion active ROM (with a hand held goniometer), pre-exercise videotaping of treadmill walking and running, a 5 minute cycle ergometer warm-up, 20 minutes of obstacle course running, post-exercise inversion active ROM, and post-exercise videotaping of treadmill walking and running. Walking and running were performed on a laterally tilted treadmill at speeds of 4 and 9 miles per hour respectively.

Martin and Harter (1993) tabulated the following results. For both pre- and post-exercise conditions when walking on a laterally tilted treadmill at 4 miles per hour, the control group offered the least restriction of inversion, tape was next, Swede-O was next, and the Aircast offered the most restriction of inversion. The results were identical for running at 9 m.p.h. on the same treadmill. When open kinetic chain inversion active ROM was assessed, the Swede-O was found to be the most restrictive, followed by the Aircast, tape, and the control group of course offered no restriction. No reference was made to statistical significance at any time.

Hughes and Stetts (1983) evaluated inversion ROM for each ankle of each subject in presupport, pre-exercise, and post-exercise conditions. Exercise in this study consisted of a 20 minute period during which the subjects ran several sprint relays (including forward, backward, and lateral movements) and ran/walked 1.25 miles. Both the prophylactic tape and the semirigid orthosis provided similar levels of stability under all conditions. The results do not show either method to be superior to the other but given that tape requires a trained therapist to apply and is costlier over the long run (Gross, et al., 1987; Rovere, et al., 1988), they concluded that the splint may be a better choice for athletes looking to protect their ankles.

Researchers at Wake Forest University retrospectively compared ankle stabilizers and prophylactic ankle taping as means of protection for the 297 football players that took part in their study (Rovere, et al., 1988). Overall, players who wore tape were twice as likely to sustain an ankle injury as players who wore ankle stabilizers ($p < 0.003$). Rovere, et al. (1988) even stratified their findings across player positions but the effectiveness of the stabilizers remained consistent. When shoe type was considered, the results continued to favour the stabilizers over prophylactic taping. In descending order of protection (i.e., most protective to least protective) the results were as follows:

1) low cut shoes with lace on stabilizers;
2) high cut shoes with lace on stabilizers, or low cut shoes with prophylactic tape;
3) high cut shoes with prophylactic tape.

In this study, players were instructed to retighten their stabilizers whenever they loosened so this would contribute to their reported effectiveness. Another factor that may have contributed to the efficacy of stabilizers relative to prophylactic tape was the time that elapsed between the application of the tape and participation in the practice or game. Tape has been shown by most authors to break down and/or loosen with time (Bunch, et al., 1985; Miller & Hergenroeder, 1990; Pope, et al., 1987; Rarick, et al., 1962). Thus its ability to prevent injury if it is applied 3 hours prior to an exposure, will likely be significantly reduced.

Relatively few authors (Delacerda, 1978; Malina, Plagenz, & Rarick, 1962) have examined the manner in which a foam underwrap effects the ability of prophylactic ankle tape to support the ankle. Delacerda (1978) compared the plantar flexion and supination support provided by prophylactic ankle tape when a foam underwrap was used, when a gauze underwrap was used, and when the tape was applied directly to the skin. He found that significantly more support was provided when the tape was applied directly to the skin as opposed to being applied with an underwrap. There was no statistical difference between the gauze and the foam underwrap condition. These results support those of Malina, et al. (1963) who found that after 5 minutes of exercise, prophylactic ankle taping that was done directly to the skin was significantly more supportive than that done with underwrap.

Morris and Musnicki (1983) measured the ROM in subjects before, during, and after each of two 10 minute bouts of jogging in a school gymnasium. They examined plantar flexion, dorsiflexion, inversion, and eversion ROM (although they never do identify whether it is passive or active ROM). Their subjects were all prophylactically taped and their ROM prior to taping served as the control. Their results indicate that taping significantly reduced the ROM in plantar-dorsiflexion but that the amount of restriction was less after the initial ten minute period of jogging. Although a further decrease in support occurred after the second 10 minute bout of jogging, there was still significantly less motion than before the tape was applied. Not only did taping significantly reduce the ROM allowed in inversion-eversion, but this restriction was maintained throughout the 20 minute exercise period. In view of this, Morris and Musnicki (1983) concluded that prophylactic ankle taping not only restricts ROM, but that restriction is maintained after a 20 minute period of jogging.

Paris and Sullivan (1992) used a hand held dynamometer to assess the isometric strength of rearfoot inversion and eversion. Isometric strength measures were done with the subjects wearing no support, prophylactic tape, Swede-O ankle stabilizer, Aircast Air-

Stirrup, New Cross ankle brace, and Subtalar Stabilizer (STS). No significant differences were found between the strength values for each of these conditions.

Ankle stability has been shown to be related to both the number and severity of injuries (Firer, 1990). Ferguson (1973) is a critic of prophylactic ankle taping and argues that tape may actually result in an increase in injuries over the long run. His reasons for this are two-fold. First, the additional support results in a de emphasis of conditioning of the surrounding muscles so that they get progressively weaker. Second, surrounding muscles "learn" to relax during activity due to the support from the tape. Any athlete who is running, jumping, or cutting during the course of competition will be placing high demands on his/her leg musculature so these muscles are not likely to be relaxed at any point. In fact there is evidence to the contrary. Freeman and Wyke (1967), Glick and Nishimoto (1976), Moller-Larsen, et al., (1988), and Bullard, et al. (1979) have all demonstrated that one of the benefits of ankle taping is that pressure from the tape increases the proprioceptive feedback mechanisms of the underlying muscles and joints. These same authors showed that this pressure results in faster firing rates of the muscles. Both of these factors would play a significant role in either preventing or reducing the number of or severity of ankle injuries. Two studies (Firer, 1990; Glick & Nishimoto, 1976) have addressed the question of lower limb injuries in athletes who wear ankle supports (not all of which were prophylactic) and the consensus was that there was no reason to suspect that ankle supports were correlated with higher injury rates to those who wear them.

A third argument against prophylactic ankle taping is that the inversion and eversion at the subtalar joint acts as an injury prevention mechanism, but that the function of this accommodation mechanism is hampered by the restrictions of the tape (Ferguson, 1973). It is my opinion that this is not in fact the case. While it is true that the ankle has a variety of accommodating mechanisms to protect it from injury (including a certain degree of inversion and eversion), it is also very well documented that tape is not totally restrictive. In fact, as noted, tape has been shown to loosen following brief periods of exercise. Given this, prophylactic ankle taping is not likely so restrictive as to interfere with the normal function of the foot and ankle.

2.10 Effect on Athletic Performance

And lastly, there is the issue of how athletic performance is affected by prophylactic ankle supports. Although this will not be evaluated in this study, it is a potential concern. Burks, et al. (1991) tested broad jump, vertical leap, shuttle run, and 40 yard sprint performance in subjects who wore Swede-O Universal orthoses , Kallassy orthoses, prophylactic tape, and no support. They found that when compared to unsupported ankles, prophylactic taping resulted in a significant decrease in vertical jump, shuttle run, and sprint performances. The Swede-O Universal orthosis group had significant decreases in performance results in vertical jump, broad jump, and sprints. Only vertical jump scores were decreased significantly in those who wore the Kallassy orthosis. Beriau, Cox, and Manning (1994) concluded that there was a "limited practical performance effect upon agility while wearing an ankle brace". The orthoses used in this study were the Aircast Sport Stirrup, the Aircast Training Brace, Swede-O Universal, and Donjoy Ankle Ligament Protector.

In a similar study that compared the effects of different ankle orthoses on speed, balance, agility, and vertical jump scores, Paris (1992) found that subject's performances were not significantly affected by the use of prophylactic tape or a semirigid orthosis (the Swede-O Universal, McDavid, and New Cross orthoses) except in vertical jump ability. In this test, the only significant decrease in jump height was seen when comparing untaped and New Cross-braced ankles.

Greene and Wight (1990) found that base-running times for softball players were significantly poorer in subjects who wore the Aircast Air Stirrup ankle orthoses. There was no significant effect on times in subjects who wore the Donjoy Ankle Ligament Protector nor the Swede-O Universal orthoses.

Robinson, et al., (1986) also examined the relationship between prophylactic ankle supports and athletic performance. Although they employed a very small sample size and self-designed plastic shoe inserts as the support, they found a significant decline in obstacle course performance that was inversely related to the degree of motion restriction afforded by the supports.

When isokinetic strength was examined, Gehlsen, et al. (1991) found statistically significant differences between no support, prophylactic tape, and Active Ankle semirigid orthoses. In contrast, Paris and Sullivan (1992) found no difference in isometric strength of inversion and eversion between four orthoses (Swede-O, New Cross, Air Stirrup, and Subtalar Stabilizer) and prophylactic tape when compared to unsupported ankles.

2.11 Summary

There are three primary schools of thought as to how/why prophylactic ankle supports are beneficial. Many researchers believe in their mechanical effects (Alves, et al., 1992; Bunch, et al., 1985; Burks, et al., 1991; Capasso, et al., 1989; Carne, 1989; Firer, 1990; Garrick & Requa, 1973; Gehlsen, et al., 1991; Greene & Roland, 1989; Greene &

Hillman, 1990; Greene & Wight, 1990; Gross, et al., 1987; Gross, et al., 1991; Gross, et al., 1992; Gross, et al., 1994; Hughes & Stetts, 1983; Karlsson & Lansinger, 1992; Lane, 1990; Larsen, 1984; Lofvenberg & Karrholm, 1993; Lutz, et al., 1993; Martin & Harter, 1993; Miller & Hergenroeder, 1990; Morris & Musnicki, 1983; Myburgh, et al., 1984; Pope, et al., 1987; Quigley, et al., 1946; Rarick, et al., 1962; Robinson, et al., 1986; Rovere, et al., 1988; Rovere, et al., 1989; Stover, 1986; Tropp, et al., 1985; Vaes, et al., 1985), increased proprioceptive effects (Derscheid & Brown, 1985; Firer, 1990; Freeman, et al., 1965; Greene & Roland, 1989; Gross, 1987; Karlsson & Lansinger, 1992; Karlsson & Andreasson, 1992; Konradsen & Ravn, 1991; Moller-Larsen, et al., 1988; Pope, et al., 1987; Rovere, et al., 1989; Staples, 1975; Tropp, 1986; Tropp, et al., 1985), as well as associated psychological benefits (albeit unquantifiable ones) (Greene & Roland, 1989).

While it is clear that many methods of prophylactic ankle support such as elastic sleeves and cotton wraps are essentially ineffective at preventing ankle injuries (Bunch, et al., 1985; Miller & Hergenroeder, 1990; Myburgh, et al., 1984), there remains an abundance of controversy regarding the effectiveness of lace-on stabilizers, semirigid orthoses, and prophylactic ankle taping. There appears to be a general consensus that these latter methods will provide enough support to help reduce ankle injuries (Alves, et al., 1992; Bunch, et al., 1985; Burks, et al., 1991; Capasso, et al., 1989; Carne, 1989; Firer, 1990; Garrick & Requa, 1973; Gehlsen, et al., 1991; Greene & Roland, 1989; Greene & Hillman, 1990; Greene & Wight, 1990; Gross, et al., 1987; Gross, et al., 1991; Gross, et al., 1992; Gross, et al., 1994; Hughes & Stetts, 1983; Karlsson & Lansinger, 1992; Lane, 1990; Larsen, 1984; Lofvenberg & Karrholm, 1993; Lutz, et al., 1993; Martin & Harter, 1993; Miller & Hergenroeder, 1990; Morris & Musnicki, 1983; Myburgh, et al., 1984; Pope, et al., 1987; Quigley, et al., 1946; Rarick, et al., 1962; Robinson, et al., 1986; Rovere, et al., 1988; Rovere, et al., 1989; Stover, 1986; Tropp, et al., 1985; Vaes, et al., 1985), but to what extent remains unclear. To further complicate matters, most researchers have outlined a variety of measurement techniques to evaluate ankle stability, making cross-study comparisons difficult.

Semirigid orthoses such as the Air-Stirrup and the Active Ankle have the advantage of being inexpensive in the long run, easy to apply, and are said to be comfortable. They can be worn under any shoe (although many athletes complain that the support damages the shoe's upper) but they cannot be worn with equipment such as ice skates or ski boots. The Air-Stirrup also has the advantage of being easily retightened in the middle of competition. It has been shown to reduce the number of ankle injuries in those that use it functionally, but it is not recommended as a first-line defense against new injuries (Miller & Hergenroeder, 1990). Active Ankle is a semirigid orthoses that is designed as a purely prophylactic (i.e., first line of defense) ankle support that can also be easily retightened but there is only one published study to date that examines its effectiveness (Gehlsen, et al., 1991).

Prophylactic ankle taping is perhaps the most controversial of all methods. This is due in part to the number of different ways in which it can be applied, and to the number of kinds of tape that can be used. It can be a costly method of support (as much as $3-$6 per ankle) and it does require a certain level of expertise to apply. It has been shown to be as good as (if not better than) any other method of support immediately after application (Bunch, et al., 1985; Greene & Wight, 1990; Gross, et al., 1987; Gross, et al., 1991; Hughes & Stetts, 1983; Karlsson & Lansinger, 1992; Larsen, 1984; Martin & Harter, 1993; Myburgh, et al., 1984; Vaes, et al., 1985), but it also loses a significant proportion of that support after exercise (Bunch, et al., 1985; Ferguson, 1973; Firer, 1990; Greene & Wight, 1990; Gross, et al., 1987; Gross, et al., 1991; Hughes & Stetts, 1983; Martin & Harter, 1993; Morris & Musnicki, 1983; Myburgh, et al., 1984; Rarick, et al., 1962).

Decreased support after exercise may not affect the ability of the tape to protect the joint however as ligamentous injuries occur when range of motion exceeds that which is normally allowed by an individual's anatomical restraints. In other words, the tape would remain intact and provide enough support at the end of the ROM, in spite of losing a substantial amount of its initial support following exercise (Bunch, et al., 1985; Capasso, et al., 1989; Garrick & Requa, 1973; Gross, et al., 1987; Karlsson & Lansinger, 1992; Larsen, 1984; Myburgh, et al., 1984; Vaes, et al., 1985). This "terminal" support is where injuries will occur (i.e., when the physiological ROM is exceeded) so prophylactic tape may be sufficient to prevent injury despite loosening This has been repeatedly demonstrated in studies that show tape to be significantly more restrictive than untaped ankles after exercise (Gross, et al., 1991; Martin & Harter, 1993; Morris & Musnicki, 1983; Rarick, et al., 1962). Tape however can be easily reinforced with additional strips if need be, and it offers the distinct advantage of being able to be used in combination with any other kind of ankle support. It also allows the therapist the freedom to "customize" the application to suit the athlete's needs.

One more factor must be considered. I would suggest that of the many studies that have examined support effectiveness before and after exercise, none of them used an exercise protocol that adequately simulated the stresses and loading that would likely be applied to the ankle during competition. In other words, neither 350 passive inversion cycles (Bunch, et al., 1985) nor 10 minutes of jogging at a self selected pace (Gross, et al., 1987) is comparable in intensity to a high impact activity such as a squash match or football practice. This, and the fact that all of the researchers used different exercise protocols also make across-study comparisons difficult at best. The best support for a football player may not necessarily be the best for a jogger or any other athlete for that matter. What is clearly needed then is not only more research, but also better research; with improved methods and procedures.

Chapter 3: Methods and Procedures

The purpose of this study was to compare the effects of selected ankle support techniques on active and passive ranges of ankle motion in pre - and post - exercise conditions; and to assess the perceived comfort and support of selected ankle support techniques.

3.1 Subjects

Subjects were recruited from a variety of sources including the Faculty of Physical Education and Recreation Studies at the University of Manitoba, and the University of Manitoba Athletic Therapy Centre. Volunteers who expressed interest in the study were asked to complete and return the Medical Screening Questionnaire (Appendix E). If they were found to be suitable, they were given a copy of the Informed Consent form (Appendix F) to complete. The first twenty seven female respondents who completed this process comprised the subject pool.

Involvement in the study requires that all subjects meet the inclusion criteria as outlined in the Subject Medical Screening Questionnaire. In other words, they had to be free of any soft tissue ankle injury for at least 6 months prior to participation in the study, and free of any fracture or dislocation for at least 12 months prior to participation in the study. Subjects were between the ages of 18 and 30, and were excluded if they could not complete the prescribed exercise protocol within 2 minutes of the allotted time.

All subjects were students at the University of Manitoba. Seventeen of them were student athletic therapists, with the remainder being students from various other faculties.

All subjects were physically active on a regular basis, representing a broad spectrum of sport backgrounds.

3.2 Instrumentation

All subjects were required to complete the Medical Screening Questionnaire (Appendix E) which is designed to assess subject suitability. At the conclusion of each test session, each subject also completed a questionnaire designed to evaluate their perceived sense of stability and comfort provided by the test condition used that day (Appendix I).

The Exercise Science Department at Concordia University constructed a device based on a design by Inman (1976) and this was used to quantify all active and passive ranges of motion. Two goniometers are fixed to the device, allowing for angle measurements in any plane, to within one degree. The Ankle Range of Motion Goniometer was constructed with aluminum and plastic components. A variety of adjustments could be made to ensure consistency in subject positioning (regardless of height, weight, lower leg girth, and so on). All quantitative data was taken from the goniometers and hand recorded onto data sheets (Appendix H). The results were then entered into a Systat statistical program on an I.B.M. computer for subsequent analysis.

3.3 Pilot Studies

A critical finding of all 8 ranges of motion that were tested, was the consistency of the control condition measures across each of the 3 test times. Another important finding is that the time 1 range of motion measures were very similar for each of the 3 treatment conditions. Both of these suggest a high degree of reliability in the technique used to measure ROM. All mean ROM results have been presented in Appendix K. Pearson correlation coefficients (with regression analyses) were performed on the raw data from these time 1 ROM measures. Non-significant results would show that there were no significant differences between the 3 ranges of motion measured on each subject, at time 1. This would indicate that the subjects could be placed in the goniometer the same way each test time, and that their ranges of motion could be measured reliably each time. Table 3.1 contains the p values for the time 1 comparisons.

Table 3.1 Pearson Correlation Coefficients (With Regressions) for Time 1 ROM Comparisons.

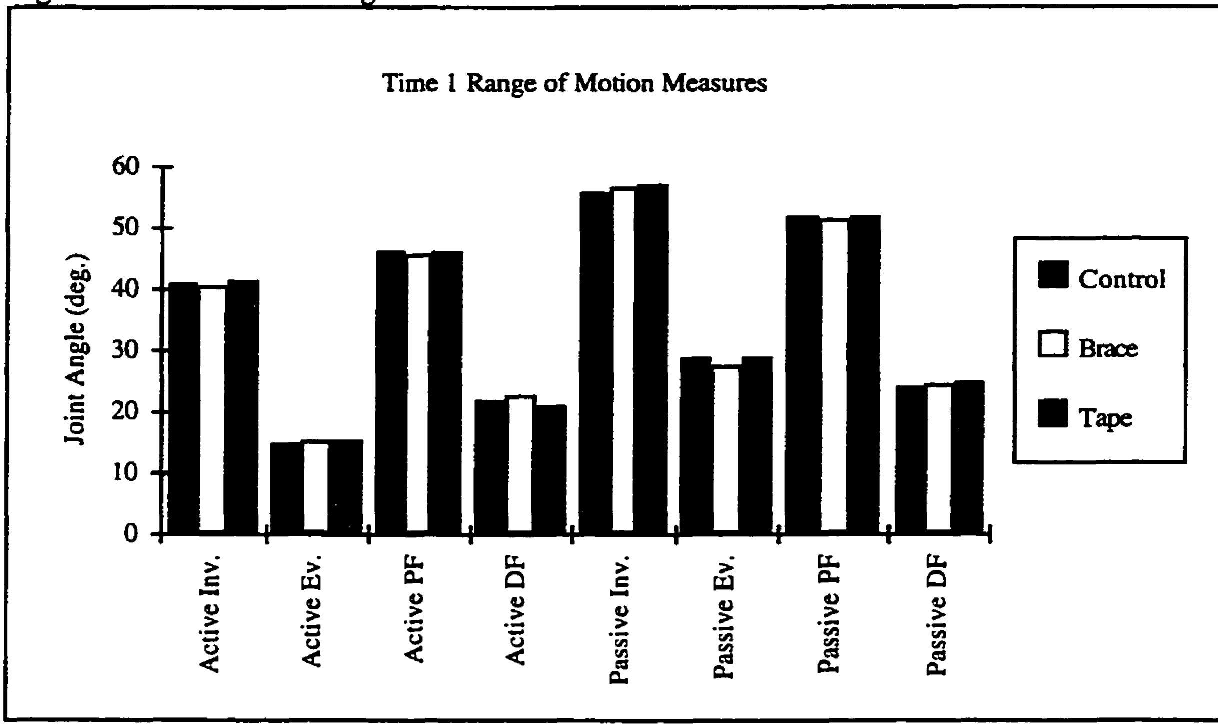
Movement	Support	P value
Active Inversion	Control vs. Tape	.926
	Brace vs. Tape	.850
	Control vs. Brace	.864
Active Eversion	Control vs. Tape	.920
	Brace vs. Tape	.927
	Control vs. Brace	.890
Active Plantar Flexion	Control vs. Tape	.815
	Brace vs. Tape	.792
	Control vs. Brace	.846
Active Dorsiflexion	Control vs. Tape	.734
	Brace vs. Tape	.868
	Control vs. Brace	.928
Passive Inversion	Control vs. Tape	.942

	Brace vs. Tape	.857
	Control vs. Brace	.877
Passive Eversion	Control vs. Tape	.770
	Brace vs. Tape	.775
	Control vs. Brace	.768
Passive Plantar Flexion	Control vs. Tape	.914
	Brace vs. Tape	.629
	Control vs. Brace	.638
Passive Dorsiflexion	Control vs. Tape	.913
	Brace vs. Tape	.880
	Control vs. Brace	.926

*All p values were significant at $p<.05$.

According to Table 3.1, all of the comparisons yielded significant results ($p<.05$). In other words, these numbers suggest that ROM measures at time 1, were able to be performed consistently from day to day. This suggests that both the goniometer and the measuring technique could be relied upon to yield reliable measures. Figure 3.1 shows the consistency in ROM measures, for each movement at Time 1.

Figure 3.1 Time 1 Range of Motion Measures for Each Movement.



Inv. = Inversion
Ev. = Eversion
PF. = Plantar Flexion
DF. = Dorsiflexion

Once the reliability of the goniometer is ascertained, another pilot study of three subjects was completed to determine reliability of the ankle tape support condition. It was deemed appropriate to demonstrate that the tape could be applied consistently with each application, thereby showing that differences in ROM could be attributed to exercise as opposed to the manner and / or quality of the tape application.

Three subjects (all male, ages 21 - 26) were each taped using the same technique as used in the study. Their ranges of motion were measured in all directions that were used in the study, and the tape was then removed. This identical process was then repeated two more times. Their ranges of motion were recorded by another individual to keep the researcher blind to the results. These can be found below in Table 3.2.

Table 3.2 Pilot Study ROM Measures for Ankle Taping.

Subject	Active Ankle Inversion	Active Ankle Eversion	Active Ankle PF	Active Ankle DF	Passive Ankle Inversion	Passive Ankle Eversion	Passive Ankle PF	Passive Ankle DF
1a	18 °	4 °	37 °	14 °	37 °	6 °	40 °	5 °
1b	20 °	4 °	38 °	14 °	38 °	5 °	42 °	7 °
1c	22 °	4 °	39 °	12 °	37 °	7 °	41 °	7 °
2a	23 °	4 °	35 °	23 °	32 °	10 °	34 °	10 °
2b	24 °	4 °	34 °	24 °	34 °	10 °	34 °	10 °
2c	25 °	4 °	34 °	25 °	35 °	10 °	34 °	9 °
3a	18 °	6 °	32 °	17 °	30 °	12 °	34 °	10 °
3b	19 °	6 °	31 °	19 °	31 °	12 °	34 °	10 °
3c	20 °	7 °	32 °	18 °	31 °	12 °	33 °	11 °

1a = Subject 1, trial 1.
PF = Plantar Flexion.
DF = Dorsiflexion.

These results indicate that the tape could be applied in a way that was both consistent and reproducible. These are important considerations in that any differences found between the tape and the control and/or the brace could not likely be attributed to inconsistencies in tape application. In other words, variances in ROM measures were not due to variances in the tape support.

3.4 Experimental Design

This study is experimental research, employing a test-retest design with convenient subject selection. The first 27 female applicants who were willing to participate, and who fulfilled the inclusion/exclusion criteria, comprised the subject pool. Each was tested, given an intervention, retested, exercised, and retested again. All subjects were tested under the three experimental conditions (Table 3.3), allowing for comparisons within, and between subject treatments. The unsupported, experimental condition served as the control.

Table 3.3 Standardized Testing Protocol for all Subjects.

		AROM	PROM	Support	AROM	PROM	Exercise	AROM	PROM	Survey
S1	Day 1									
	Day 2									
	Day 3									

S1 = Subject 1
AROM = Active range of motion.
PROM = Passive range of motion.

3.5 Methods and Procedures

An appointment was made with each subject at which time the testing procedure was explained to them and they were reminded that they were free to ask questions, and free to withdraw at any time throughout the testing process. All subjects were required to read and sign the Informed Consent document (Appendix F). Each subject was randomly assigned to one of three test condition orders using a randomized block design. In other words, the first subject to meet all inclusion criterion was assigned to one test order (control - tape - semirigid orthosis for example), the second subject was assigned a different test order (control - semirigid orthosis - tape), and the third subject was assigned to the other possible test order (tape - semirigid orthosis - control). Subsequent subjects were assigned sequentially in the same manner, until nine subjects were assigned to each possible test order.

Subjects were secured to the range of motion device in accordance with the protocols used by Inman (1976). This protocol involved the subject lying supine on a mat, with her dominant hip and knee both flexed to 90 degrees. To help insure consistency, subjects used their dominant foot (the foot that they would normally use to kick a ball) for all testing. The foot of the test ankle was secured to a plate that was fixed to the platform. The foot was held in place with plastic guides and a metal toe clip which was adjusted to individual foot sizes. The lower leg was supported and held in place under the calf by a padded "trough" (Appendix G). To further reduce movement, the foot was taped to the footrest and two straps of tape were applied circumferentially to the leg to limit extraneous movement. A carpenter's square was used to confirm the 90 degree angle of the knee. The square was aligned with one arm parallel to the long axis of the femur (extending toward the greater trochanter), and the other arm extending along the axis of the tibia, towards the lateral malleolus. The goniometer allowed movements in a variety of planes. For the sake of this study, each axis of rotation was independently fixed so that only uniplanar movement about the desired axis was possible at any one time. Each subject was asked if she was comfortable, and given the opportunity to move the ankle 2 times in each of the 4 test directions to become familiar with the movements allowed by the goniometer.

The initial ROM measures were considered "time 1". The subject performed all active movements first. Maximal active inversion was followed immediately by maximal active eversion, then plantar flexion, then dorsiflexion. All passive movements were recorded without the subject moving from the above position. Movements were performed using the same order as used for active testing. Passive testing involved the subject relaxing her leg muscles while the passive motion was applied using a linear scale that was attached to the goniometer via a steel cable. These cables were incorporated into the device for this purpose. This scale was calibrated prior to each test session, by hanging a known weight from the scale.

A force of 89.2 Newtons (N) was applied for inversion and eversion, while 124.9 N. was applied for plantar flexion and dorsiflexion. Pilot tests on other researchers, using variable overpressures, led to the belief that 89.2 N. and 124.9 N. were appropriate overpressures for the purposes of this study. These amounts of overpressure were also greater than those used in previous research. These forces were applied with no risk to the subject, and were intended to produce realistic stress on the ankle. The researchers reported that 89.2 and 124.9 N. created tension in the desired motion, without discomfort. All felt that greater tension may become uncomfortable. A hand-held scale was used to quantify the constant, passively applied force.

These overpressures were applied at a distance of 13 centimeters (cm.) from the goniometer's axis of rotation for inversion and eversion; and at 7 cm. from the axis, for plantar flexion and dorsiflexion. This translates to a d-perpendicular of .13 meters (m.) and .07 m. respectively. Using the equation of torque = force x d-perpendicular, it can be said that in the cases of ankle inversion and eversion, a torque of 11.6 Nm. was applied for passive ROM testing. A torque of 8.7 Nm. was applied for passive ankle plantar flexion and dorsiflexion.

The above equations were based on the goniometer's axes of rotation. It must be pointed out that these two axes do not exactly replicate those of the anatomical ankle. Therefore, this testing does not test true ankle movements such as inversion, eversion, plantar flexion, or dorsiflexion. The reality is that this protocol employed a co-axial alignment, with the axes of the goniometer not exactly matching those of the ankle. Hence, while true ankle inversion was not being measured, the same co-axial alignment existed for all subjects, on all test days.

The subject received on-going verbal encouragement to relax throughout the passive testing. The subject continued to relax and the measurement was recorded after 3 seconds of overpressure at the desired tension. This 3 second period should have reduced the effects of both antagonistic and agonistic muscle contraction(s), as well as any subject anxiety. In 3 pilot studies that were conducted prior to this research, the overpressure could be applied quickly and steadily, whereafter the ROM would slowly increase due to the creep accommodation that is characteristic of soft tissues (Nordin and Frankel, 1989). During the course of the pilot studies, no change in ROM was found to occur after 3 seconds of hold time at the desired overpressure. Even at 5 seconds, no increase in ROM was found so 3 seconds was deemed appropriate. No other available research has taken this consideration into account.

After recording all eight ranges of motion, the subject was taken off of the AROM goniometer and the ankle support was immediately applied. The semirigid orthosis was applied according to the manufacturer's specifications and the ankle tape was applied by the same Certified Athletic Therapist, using a standardized method of ankle taping (Appendix D). This included the application of an adherent spray, lubricated heel and lace pads, underwrap to hold the pads in place, 3 superior anchors, 1 inferior anchor, a closed basketweave (incorporating 3 stirrups), and 2 heel locks, followed by closing strips. All anchor strips were applied directly to shaved skin. In the case of the control condition, the subject was taken off of the goniometer and asked to walk to the table where the tape was being applied, walk back to the goniometer , and was then positioned for the next series of range of motion measures. Once the prophylactic support was correctly applied, and range of motion measures begun, no further adjustments to the support were allowed. These ROM measures were recorded as "time 2". All subjects were required to wear the same shoes with a single pair of socks for all three test conditions. These steps helped to ensure uniformity of each treatment condition.

Immediately following these measurements, subjects were taken directly to the starting area for the exercise protocol (approximately a 2 minute walk). All subjects had the entire exercise protocol explained to them during that walk, with each individual component being explained in greater detail, immediately prior to commencing that exercise station. There were a total of 12 stations (Appendix J) which incorporated a variety of exercises designed to mimic movements found in a variety of sports. All exercises had to be performed within the allotted time and the same verbal encouragement was given to each subject throughout the exercise period. Subjects were kept on pace with verbal instructions. Each was required to complete the entire exercise protocol within 15 minutes, plus or minus 2 minutes. If they exceeded this allowed variance, the testing was to have been redone on a separate day. All subjects however, completed the exercise protocols well within these limits so no further testing was necessary. Subjects were reminded that they were to stop exercising should they experience any unusual discomfort or pain. No adjustment to the prophylactic support was allowed throughout the exercise protocol. Each subject was allowed to take 1 water break during the exercise protocol. The water fountain was in the immediate vicinity of the test area so no significant bearing on the overall outcomes was anticipated.

The subject then walked back to the area where the previous range of motion values were measured, for retesting of their range of motion scores. This was accomplished using identical criterion as done with the pre-exercise measures, and these were recorded as "time 3" ROM measures. This data was later compared to the pre-exercise data to determine the possible effects of exercise on these parameters.

Following this step, the prophylactic support was removed, and each subject immediately completed the Perceived Comfort and Stability Questionnaire (Appendix I). This questionnaire was designed to provide qualitative feedback as to each subject's perceived comfort and stability afforded by each test condition. This was an important determination for two reasons. First, a support that prohibits excessive range of motion but is uncomfortable on the athlete is not likely to be worn. And second, it is important to know if there is any existing relationship between perceived comfort, perceived support, and functional support (as indicated by restriction of range of motion without restriction of stability measures).

This entire process was repeated on 3 separate days, thereby completing all three test conditions.

3.6 Data Collection

All range of motion data was recorded by hand, on data collection sheets as shown in Appendix H. In an attempt to reduce possible researcher bias, all pre- and post-test results were recorded on separate sheets. All quantitative data was then entered into a Systat statistical program on an I.B.M. computer for subsequent analysis. Qualitative data was analyzed using a Statview program on a Macintosh LCII.

3.7 Statistical Analysis

Pearson correlation coefficient tests were performed on the data from three subjects who were used as part of a pilot study to confirm taping reliability. These tests were done using the StatView SE$^+$ program on a Macintosh LCII computer. The same program was also used to perform Pearson correlation coefficient tests (with regressions) of all Time 1 ROM measures. This was done to show consistency in the manner in which the ROM data was gathered. A repeated measures of variance analysis determined whether differences between groups existed between pre-support, pre-exercise, and post test conditions. These were completed on an I.B.M. computer using Systat.

All qualitative data on perceived comfort and stability was assigned a point value depending on how subjects responded on the questionnaire. The results were totaled (Appendix L) and Wilcoxon signed rank sum scores tests were done (using Systat) so comparisons between brace and tape could be made.

Chapter 4: Results

The purpose of this chapter is to report the results of the investigation of selected ankle support techniques on active and passive ranges of motion, in pre - and post - exercise conditions. Anecdotal evidence (based on subject's responses to the Perceived Comfort and Stability Questionnaires) will also be examined. The first section describes the profile characteristics of the subjects involved in the study. Sections 4.2 through 4.9 deal with the results from each of the active and passive ranges of motion measurements. It is in this section that several critical comparisons are made. Here, comparisons were made between the ROM allowed at time 1 (prior to any support being applied), and time 2 (after the support was applied but before any exercise), and time 3 (after the exercise had been completed). Comparisons were also made between time 1 and time 3; such that the efficacy of the support could be tested after exercise, and compared to the initial ranges of motion. Section 4.11 describes which of the supports the subjects perceived to be more comfortable, and more stable.

4.1 Subjects

Twenty seven female subjects were involved in this study. All subjects were students at the University of Manitoba. Seventeen of them were student athletic therapists, with the remainder being students from various other faculties. All subjects were physically active on a regular basis, representing a broad spectrum of sport backgrounds. Only one of the subjects had previous competitive experience with her ankles taped. Twenty six of the other subjects had their ankles taped as part of their academic course work, but had not been physically active with prophylactic ankle tape. None of the subjects had ever worn any kind of prophylactic ankle brace previous to this study. All 27 subjects were right foot dominant. No subject had experienced any form of ankle injury that precluded them from taking part in the study.

4.2 Active Ankle Inversion

Table 4.1 shows the mean ranges of active inversion across each of the 3 test times, and Figure 4.1 shows a graphic representation of the comparisons of the ROM allowed by each treatment condition, across the 3 test times. The consistency of the control group across all three test times is very encouraging as far as reliability is concerned.

Table 4.1 Changes in Mean Joint Angles for Active Ankle Inversion, for Each Condition Across Test Times.

Active Inversion	Time 1 (SD)	Time 2 (SD)	Time 3 (SD)	Diff. T2-T1	Diff. T3-T1	Diff. T3-T2
Control	40.93 ° (6.92)	41.82 ° (6.71)	42.59 ° (7.95)	0.89 °	1.66 °	0.77 °
Brace	40.56 ° (7.11)	20.89 ° (6.12)	25.15 ° (6.95)	-19.67 °	-15.41 °	4.26 °
Tape	41.07 ° (7.51)	21.26 ° (6.39)	29.37 ° (8.34)	-19.81 °	-11.70 °	8.11 °

SD = Standard Deviation

Diff. T1&T2 = Difference between Time 1 and Time 2

Diff. T1&T3 = Difference between Time 1 and Time 3

Diff. T2&T3 = Difference between Time 2 and Time 3

Figure 4.1 Joint Angles for Active Ankle Inversion Allowed by Each Condition Across Test Times.

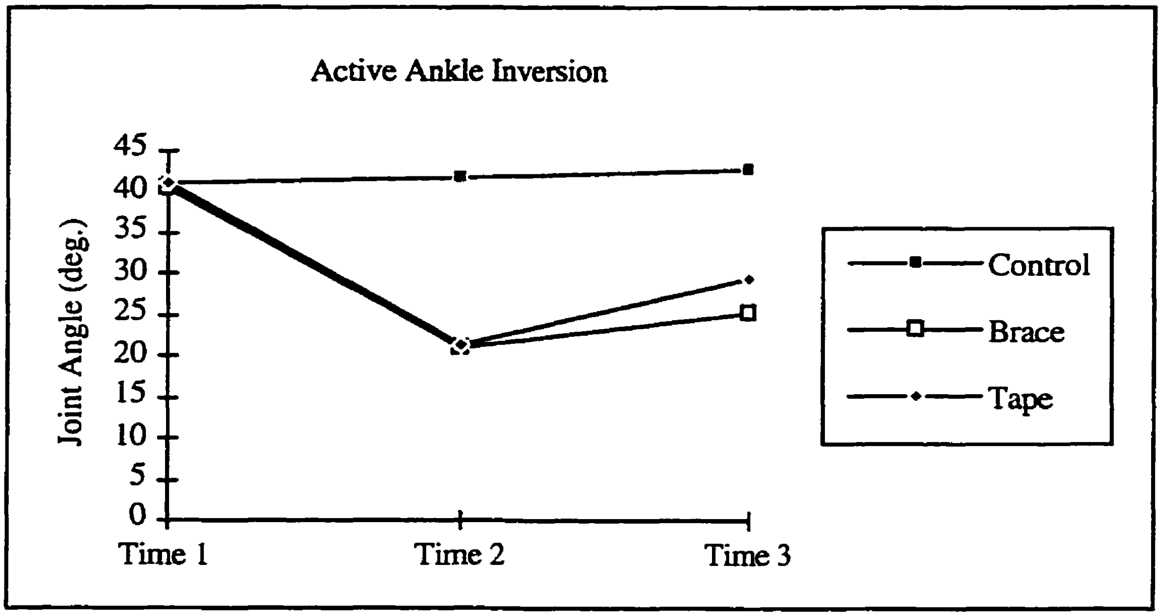


Table 4.2 shows that both the brace and the tape offered significantly ($p < .05$) greater restriction to active inversion than did the control, when comparing time 1 to time 2. There was no significant difference between the two supports themselves. The brace and the tape were both significantly ($p < .05$) more restrictive than the control between times 1 and 3, and times 2 and 3. In both of these latter cases though, the brace was found to be significantly ($p < .05$) better than the tape at restricting active inversion.

Arguably, the single most important comparison in this case may be that between times 2 and 3 since it is this comparison that shows how well the support stands up to the stresses of exercise.

Table 4.2 Post-Hoc Analysis of Active Ankle Inversion.

Active Inversion	Treatments	F Ratio
Time 1 vs. Time 2		
	Brace vs. Control	* 190.73
	Tape vs. Control	* 193.49
	Brace vs. Tape	0.01

Time 1 vs. Time 3		
	Brace vs. Control	* 135.34
	Tape vs. Control	* 82.99
	Brace vs. Tape	* 6.37
Time 2 vs. Time 3		
	Brace vs. Control	* 7.37
	Tape vs. Control	* 32.69
	Brace vs. Tape	* 9.02

* Indicates significance ($p < .05$).

4.3 Active Ankle Eversion

Table 4.3 shows the mean ranges of motion (for active eversion) across each of the 3 test times, and Figure 4.2 shows a graphic representation of the comparisons of the range of active eversion allowed by each treatment condition, across the 3 test times. Once again, there is a consistency demonstrated for each of the 3 test times in the control condition.

Table 4.3 Changes in Mean Joint Angles for Active Ankle Eversion for Each Condition Across Test Times.

Active Eversion	Time 1 (SD)	Time 2 (SD)	Time 3 (SD)	Diff. T2-T1	Diff. T3-T1	Diff. T3-T2
Control	14.93 ° (7.13)	16.48 ° (6.57)	16.22 ° (7.15)	1.55 °	1.29 °	-0.26 °
Brace	15.19 ° (7.45)	8.70 ° (5.32)	10.15 ° (6.06)	-6.49 °	-5.04 °	1.45 °
Tape	15.37 ° (6.92)	8.30 ° (6.13)	10.41 ° (6.20)	-7.07 °	-4.96 °	2.11 °

SD = Standard Deviation
Diff. T1&T2 = Difference between Time 1 and Time 2
Diff. T1&T3 = Difference between Time 1 and Time 3
Diff. T2&T3 = Difference between Time 2 and Time 3

Figure 4.2 Joint Angles for Active Ankle Eversion Allowed by Each Condition Across Test Times.

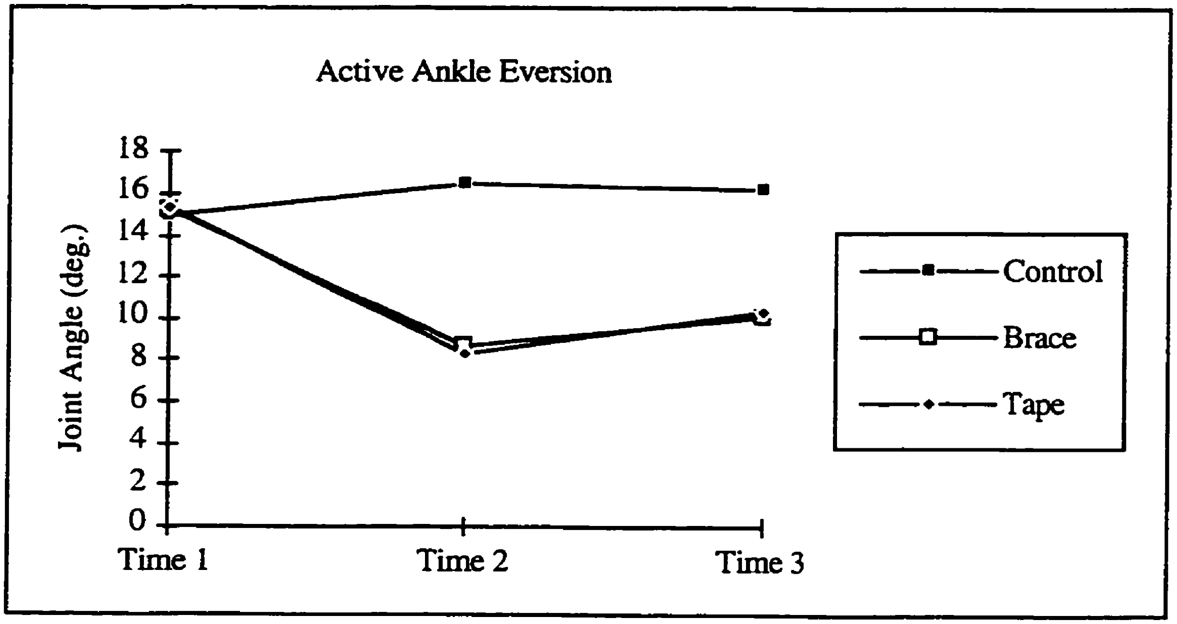


Table 4.4 indicates that when compared to the control, both the brace and the tape were significantly better ($p < .05$) at restricting active eversion between times 1 and 2, and between times 1 and 3. After exercise though, only the tape was significantly better ($p < .05$) than the control, at restricting active eversion. However, both the tape and the brace at time 3, were significantly better ($p < .05$) than the control condition.

Table 4.4 Post Hoc Analysis of Active Ankle Eversion.

Active Eversion	Treatments	F Ratio
Time 1 vs. Time 2		
	Brace vs. Control	* 66.34
	Tape vs. Control	* 76.49
	Brace vs. Tape	0.36
Time 1 vs. Time 3		
	Brace vs. Control	* 27.12
	Tape vs. Control	* 26.49
	Brace vs. Tape	0.00
Time 2 vs. Time 3		
	Brace vs. Control	2.81
	Tape vs. Control	* 5.44
	Brace vs. Tape	0.43

* Indicates significance ($p < .05$).

4.4 Active Ankle Plantar Flexion

Table 4.5 shows the mean ranges of motion (for active plantar flexion) across each of the 3 test times, and Figure 4.3 shows a graphic representation of the comparisons of the range of active eversion allowed by each of the control, tape, and brace groups, across the 3 test times.

Table 4.5 Changes in Mean Joint Angles for Active Ankle Plantar Flexion for Each Condition Across Test Times.

Active Plantar Flexion	**Time 1 (SD)**	**Time 2 (SD)**	**Time 3 (SD)**	**Diff. T2-T1**	**Diff. T3-T1**	**Diff. T3-T2**
Control	45.85 ° (4.33)	47.22 ° (3.95)	46.82 ° (3.86)	1.37 °	0.97 °	-0.40 °
Brace	45.74 ° (4.47)	42.78 ° (4.25)	42.74 ° (4.42)	-2.96 °	-3.00 °	-0.04 °
Tape	45.82 ° (5.02)	39.56 ° (4.65)	41.56 ° (4.46)	-6.26 °	-4.26 °	2.00 °

SD = Standard Deviation

Diff. T1&T2 = Difference between Time 1 and Time 2

Diff. T1&T3 = Difference between Time 1 and Time 3

Diff. T2&T3 = Difference between Time 2 and Time 3

Figure 4.3 Joint Angles for Active Ankle Plantar Flexion Allowed by Each Condition Across Test Times.

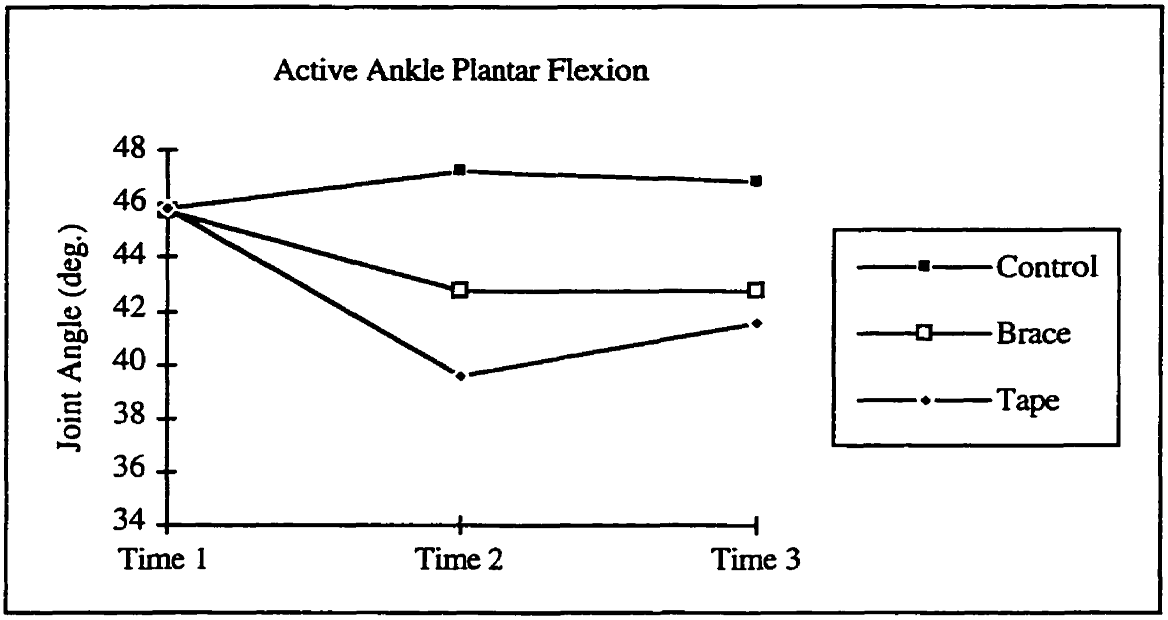


Table 4.6 indicates that between time 1 and 2, both the brace and the tape were significantly better ($p < .05$) at restricting active plantar flexion, than was the control. However, the tape significantly limited this motion more so than the brace ($p < .05$). There are some important ramifications of this and they will be discussed in the "Discussion" chapter. Both supports were significantly better ($p < .05$) than the control between times 1 and 3. No single support was found to be better than the other as far as active plantar flexion was concerned.

The effect of exercise (time 2 versus time 3) was to loosen the brace to the point where it no longer offered any significant restriction to plantar flexion, but the tape remained significantly more restrictive ($p < .05$) than either the brace or the control.

Table 4.6 Post Hoc Analysis of Active Ankle Plantar Flexion.

Active Plantar Flexion	Treatments	F Ratio
Time 1 vs. Time 2		
	Brace vs. Control	* 18.68
	Tape vs. Control	* 57.91
	Brace vs. Tape	* 10.81
Time 1 vs. Time 3		
	Brace vs. Control	* 19.05
	Tape vs. Control	* 33.08
	Brace vs. Tape	1.92
Time 2 vs. Time 3		
	Brace vs. Control	0.21
	Tape vs. Control	* 8.65
	Brace vs. Tape	* 6.19

* Indicates significance (p < .05).

4.5 Active Ankle Dorsiflexion

Table 4.7 shows the mean ranges of motion (for active ankle dorsiflexion) across each of the 3 test times, and Figure 4.4 shows a graphic representation of the comparisons of the range of active dorsiflexion allowed by each of the tape, the brace, and the control, across the 3 test times.

Table 4.7 Changes in Mean Joint Angles for Active Ankle Dorsiflexion for Each Condition Across Test Times.

Active Dorsiflexion	Time 1 (SD)	Time 2 (SD)	Time 3 (SD)	Diff. T2-T1	Diff. T3-T1	Diff. T3-T2
Control	21.56 ° (5.95)	20.67 ° (7.55)	19.67 ° (6.88)	-0.89 °	-1.89 °	-1.00 °
Brace	22.70 ° (6.32)	18.93 ° (7.35)	20.00 ° (7.15)	-3.77 °	-2.70 °	1.07 °
Tape	21.04 ° (7.81)	10.56 ° (5.68)	12.89 ° (7.53)	-10.48 °	-8.15 °	2.33 °

SD = Standard Deviation
Diff. T1&T2 = Difference between Time 1 and Time 2
Diff. T1&T3 = Difference between Time 1 and Time 3
Diff. T2&T3 = Difference between Time 2 and Time 3

Figure 4.4 Joint Angles for Active Ankle Dorsiflexion Allowed by Each Condition Across Test Times.

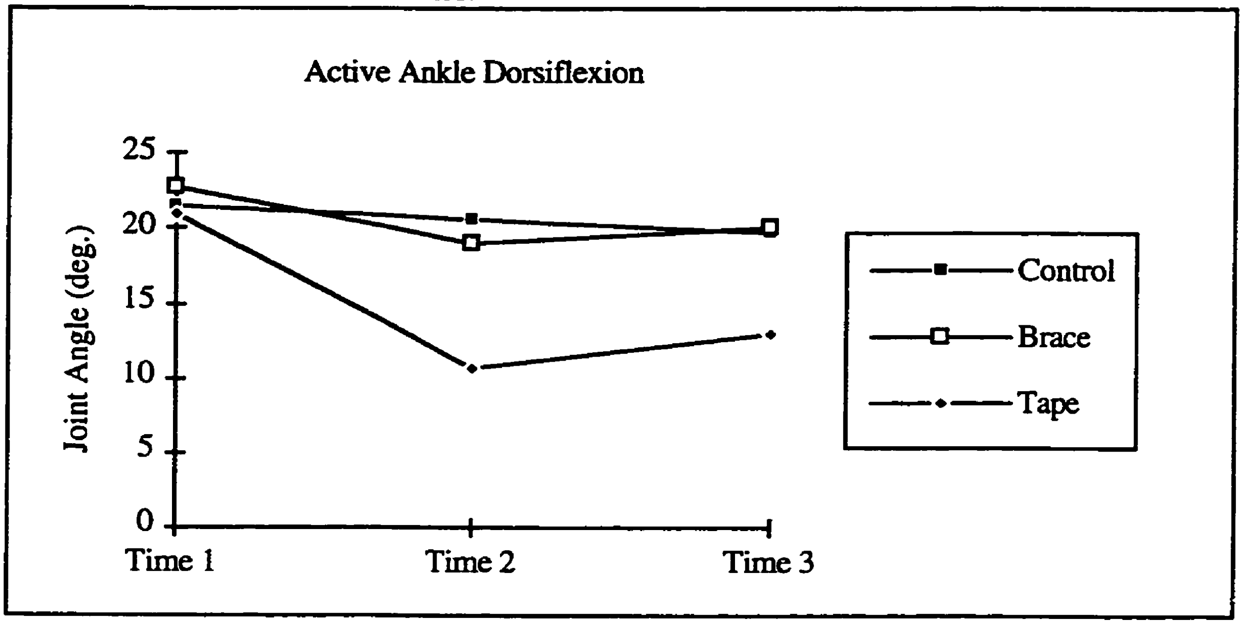


Table 4.8 shows that there is a significant ($p < .05$) difference in the amount of active dorsiflexion allowed by each condition (time 1 versus time 2), when compared to each of the other conditions. This was similar to what occurred in the active plantar flexion measures. When comparing time 1 and time 3, there was a significant difference ($p < .05$) between the tape and the control, as well as between the brace and the tape. After exercise, the decrease in support offered by both the tape and the brace were significantly greater than the control ($p < .05$). In other words, the exercise had a significant affect on the range of active ankle dorsiflexion in the supported conditions, but no affect on the control condition. Table 4.8 also indicates that the exercise had no greater affect on one support than the other when comparing time 2 versus time 3 measures.

Table 4.8 Post Hoc Analysis of Active Ankle Dorsiflexion.

Active Dorsiflexion	**Treatments**	**F Ratio**
Time 1 vs. Time 2		
	Brace vs. Control	* 4.48
	Tape vs. Control	* 49.38
	Brace vs. Tape	* 24.12
Time 1 vs. Time 3		
	Brace vs. Control	0.36
	Tape vs. Control	* 21.18
	Brace vs. Tape	* 16.03
Time 2 vs. Time 3		
	Brace vs. Control	* 4.05
	Tape vs. Control	* 10.47
	Brace vs. Tape	1.49

* Indicates significance ($p < .05$).

4.6 Passive Ankle Inversion

Table 4.9 and Figure 4.5 represent the mean ranges of passive inversion across each of the three test times. As was the case with the preceding ranges of motion, the control was very consistent (demonstrating reliability) across each of the test times. It is also noteworthy that the time 1 measurements were almost identical for each of the 3 treatment conditions. This is a strong indicator of the consistency of ROM measurements from day to day. In particular, it shows that the subject could be positioned, and the goniometer manipulated in much the same manner, on different test days.

Table 4.9 Changes in Mean Joint Angles for Passive Ankle Inversion for Each Condition Across Test Times.

Passive Inversion	Time 1 (SD)	Time 2 (SD)	Time 3 (SD)	Diff. T2-T1	Diff. T3-T1	Diff. T3-T2
Control	55.48 ° (5.30)	55.78 ° (5.43)	56.96 ° (5.77)	0.30 °	-1.48 °	1.18 °
Brace	56.30 ° (5.36)	34.85 ° (8.45)	39.26 ° (7.77)	-21.45 °	-17.04 °	4.41 °
Tape	56.78 ° (4.64)	36.07 ° (7.52)	45.37 ° (7.46)	-20.71 °	-11.41 °	9.30 °

SD = Standard Deviation
Diff. T1&T2 = Difference between Time 1 and Time 2
Diff. T1&T3 = Difference between Time 1 and Time 3
Diff. T2&T3 = Difference between Time 2 and Time 3

Figure 4.5 Joint Angles for Passive Ankle Inversion Allowed by Each Condition Across Test Times.

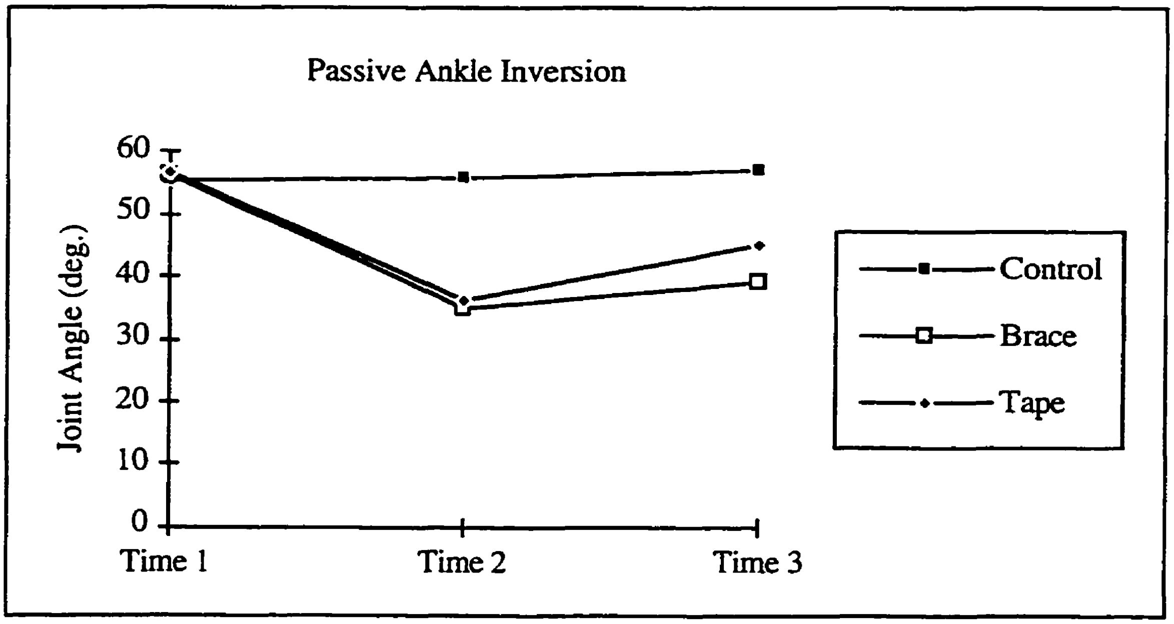


Table 4.10 once again shows a significant difference in passive ankle inversion, between the brace and control ($p < .05$), and the tape and control, when comparing time 1 and time 2. Tape and brace were no different between these 2 times. When comparing

how these supports changed between time 1 and time 3, the brace and the tape were both significantly more restrictive than was the control ($p < .05$), and the brace was significantly more restrictive than was the tape ($p < .05$). After exercise, the decrease in support offered by both the tape and the brace were significantly greater than the control ($p < .05$). In other words, the exercise had a significant affect on the range of passive ankle inversion in the supported conditions, but no affect on the control condition. This also indicates that the exercise affected (i.e., loosened) the tape more than it did the brace as far as passive ankle inversion was concerned ($p < .05$).

Table 4.10 Post Hoc Analysis of Passive Ankle Inversion.

Passive Inversion	Treatments	F Ratio
Time 1 vs. Time 2		
	Brace vs. Control	* 189.25
	Tape vs. Control	* 176.57
	Brace vs. Tape	0.22
Time 1 vs. Time 3		
	Brace vs. Control	* 154.97
	Tape vs. Control	* 75.07
	Brace vs. Tape	* 14.32
Time 2 vs. Time 3		
	Brace vs. Control	* 7.89
	Tape vs. Control	* 49.98
	Brace vs. Tape	* 18.16

* Indicates significance ($p < .05$).

4.7 Passive Ankle Eversion

Table 4.11 and Figure 4.6 represent the mean ranges of motion across each of the three test times. It is important to note both the consistency of the control group, as well as the similarity of time 1 range of motion measures for each of the 3 test conditions.

Table 4.11 Changes in Mean Joint Angles for Passive Ankle Eversion for Each Condition Across Test Times.

Passive Eversion	Time 1 (SD)	Time 2 (SD)	Time 3 (SD)	Diff. T2-T1	Diff. T3-T1	Diff. T3-T2
Control	28.78 ° (7.67)	28.52 ° (7.62)	28.82 ° (8.11)	-0.26 °	0.04 °	0.30 °
Brace	27.33 ° (8.78)	17.78 ° (7.09)	18.78 ° (5.17)	-9.55 °	-8.55 °	1.00 °
Tape	28.59 ° (7.46)	19.19 ° (6.87)	21.48 ° (7.30)	-9.40 °	-7.11 °	2.29 °

SD = Standard Deviation

Diff. T1&T2 = Difference between Time 1 and Time 2

Diff. T1&T3 = Difference between Time 1 and Time 3

Diff. T2&T3 = Difference between Time 2 and Time 3

Figure 4.6 Joint Angles for Passive Ankle Eversion Allowed by Each Condition Across Test Times.

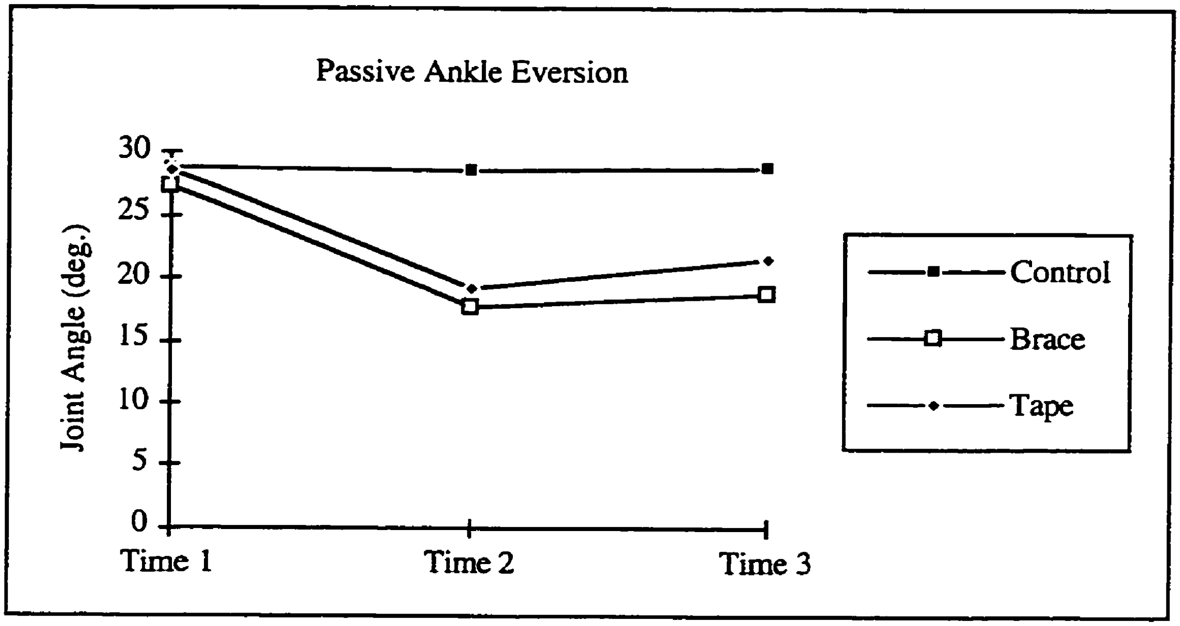


Table 4.12 shows that the only difference between time 1 and time 2 took place between each of the two supports, and the control group ($p < .05$). The same differences

were found between times 1 and 3. Interestingly, there were no differences between any of the 3 test conditions when time 2 and time 3 were compared. In other words, the amount of support did not change, due to exercise, in any of the test conditions.

Table 4.12 Post Hoc Analysis of Passive Ankle Eversion.

Passive Eversion	Treatments	F Ratio
Time 1 vs. Time 2		
	Brace vs. Control	* 40.55
	Tape vs. Control	* 39.27
	Brace vs. Tape	0.01
Time 1 vs. Time 3		
	Brace vs. Control	* 32.77
	Tape vs. Control	* 22.68
	Brace vs. Tape	0.93
Time 2 vs. Time 3		
	Brace vs. Control	0.30
	Tape vs. Control	2.38
	Brace vs. Tape	1.00

* Indicates significance ($p < .05$).

4.8 Passive Ankle Plantar Flexion

Table 4.13 shows the passive plantar flexion ROM means across all 3 test times. The initial restriction imposed by each support, and the effect that exercise had on said support can be seen in Figure 4.7.

Table 4.13 Changes in Mean Joint Angles for Passive Ankle Plantar Flexion for Each Condition Across Test Times.

Passive Plantar Flexion	Time 1 (SD)	Time 2 (SD)	Time 3 (SD)	Diff. T2-T1	Diff. T3-T1	Diff. T3-T2
Control	51.44 ° (4.84)	51.96 ° (3.30)	51.93 ° (3.45)	0.52 °	0.49 °	-0.03 °
Brace	51.26 ° (4.12)	46.56 ° (3.81)	48.04 ° (3.76)	-4.70 °	-3.22 °	1.48 °
Tape	51.63 ° (5.29)	45.33 ° (3.63)	47.48 ° (3.89)	-6.30 °	-4.15 °	2.15 °

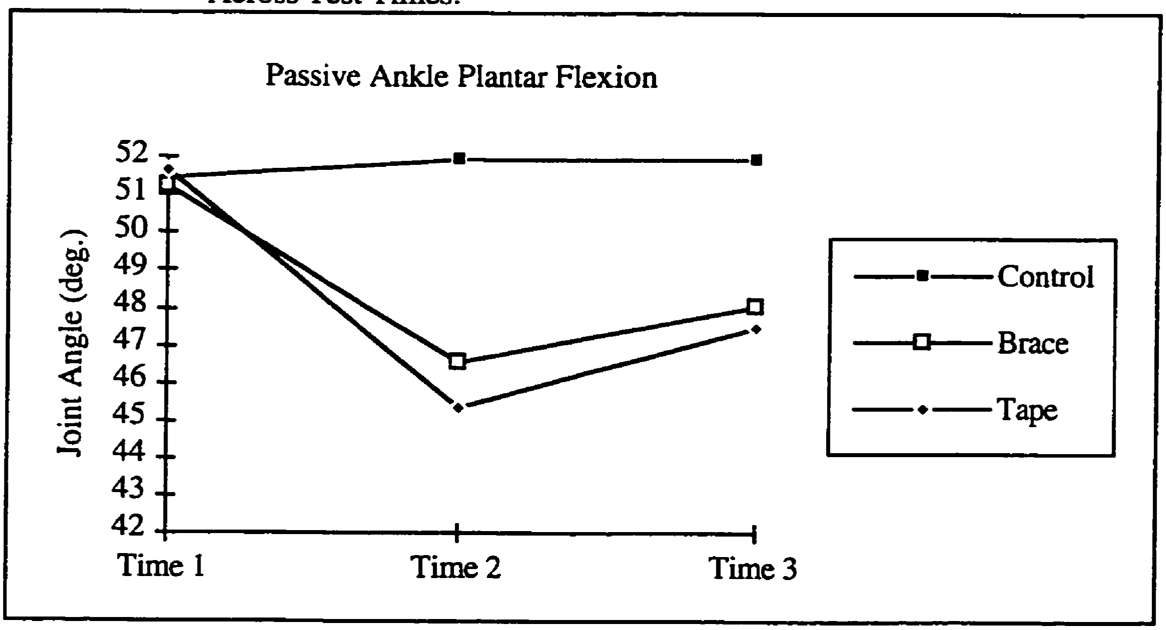
SD = Standard Deviation

Diff. T1&T2 = Difference between Time 1 and Time 2

Diff. T1&T3 = Difference between Time 1 and Time 3

Diff. T2&T3 = Difference between Time 2 and Time 3

Figure 4.7 Joint Angles for Passive Ankle Plantar Flexion Allowed by Each Condition Across Test Times.



In the case of passive plantar flexion (Table 4.14), both the tape and the brace were significantly more restrictive ($p < .05$) than the control, when times 1 and 2 were compared. The tape was significantly more restrictive than the brace ($p < .05$) across the same test times.

Across times 1 and 3, the tape and the brace both provided significant ($p < .05$) restriction, compared to the control group. There was no difference between the tape and the brace themselves.

Table 4.14 also shows the changes in passive ankle plantar flexion allowed between times 2 and 3. Both the tape and the brace conditions showed significant increases ($p < .05$) in ankle plantar flexion, following exercise. The same affect was not seen in the control condition.

Table 4.14 Post Hoc Analysis of Passive Ankle Plantar Flexion.

Passive Plantar Flexion	Treatments	F Ratio
Time 1 vs. Time 2		
	Brace vs. Control	* 62.16
	Tape vs. Control	* 105.85
	Brace vs. Tape	* 5.78
Time 1 vs. Time 3		
	Brace vs. Control	* 23.88
	Tape vs. Control	* 37.32
	Brace vs. Tape	1.49
Time 2 vs. Time 3		
	Brace vs. Control	* 4.41
	Tape vs. Control	* 9.12
	Brace vs. Tape	0.85

* Indicates significance ($p < .05$).

4.9 Passive Ankle Dorsiflexion

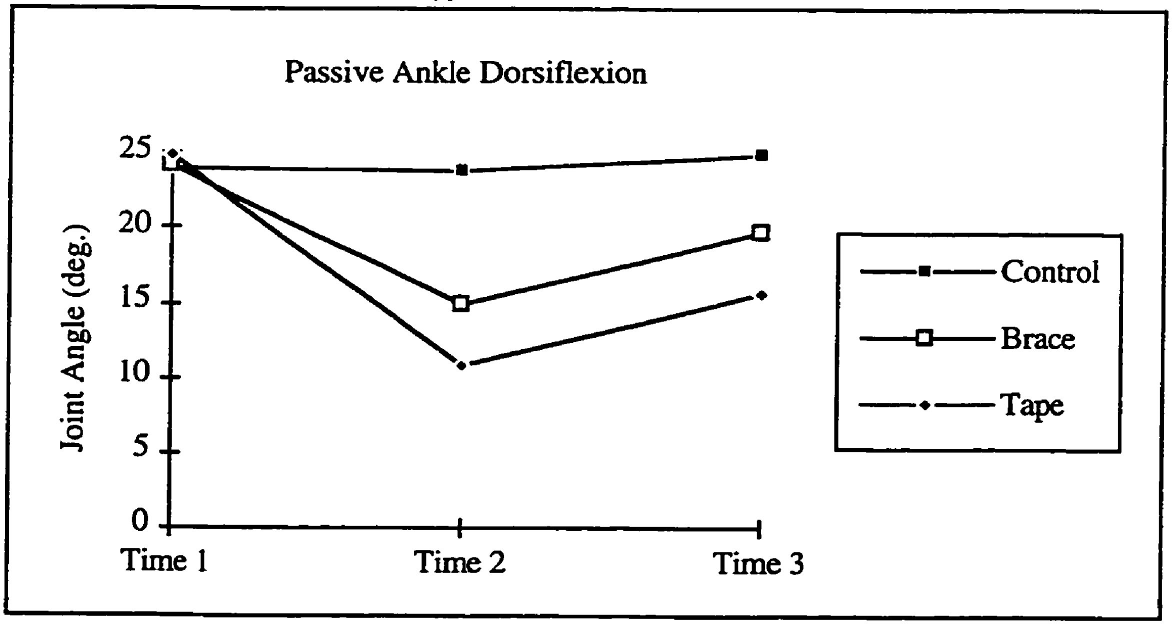
Table 4.15 shows the passive plantar flexion ROM means across all 3 test times. The initial restriction imposed by each support, and the effect that exercise had on said support can be seen in Figure 4.8.

Table 4.15 Changes in Mean Joint Angles for Passive Ankle Dorsiflexion for Each Condition Across Test Times.

Passive Dorsiflexion	Time 1 (SD)	Time 2 (SD)	Time 3 (SD)	Diff. T2-T1	Diff. T3-T1	Diff. T3-T2
Control	23.96 ° (9.15)	23.74 ° (10.33)	24.82 ° (10.55)	-0.22 °	0.86 °	1.08 °
Brace	24.22 ° (10.19)	15.00 ° (8.61)	19.63 ° (8.97)	-9.22 °	-4.59 °	4.63 °
Tape	24.93 ° (9.01)	10.85 ° (6.07)	15.59 ° (7.74)	-14.08 °	-9.34 °	4.74 °

SD = Standard Deviation
Diff. T1&T2 = Difference between Time 1 and Time 2
Diff. T1&T3 = Difference between Time 1 and Time 3
Diff. T2&T3 = Difference between Time 2 and Time 3

Figure 4.8 Joint Angles for Passive Ankle Dorsiflexion Allowed by Each Condition Across Test Times.



In the case of passive dorsiflexion (Table 4.16), both the tape and the brace were significantly more restrictive ($p < .05$) than the control, when times 1 and 2 were compared. The tape was significantly more restrictive than the brace ($p < .05$) across the same test times.

Between times 1 and 3, the tape and the brace both provided significant ($p < .05$) restriction, compared to the control group. The tape was significantly more restrictive ($p < .05$) than the brace across this same time.

Table 4.16 also shows the changes in passive ankle dorsiflexion allowed between times 2 and 3. Both the tape and the brace conditions showed significant increases ($p < .05$) in ankle dorsiflexion, following exercise. The same affect was not seen in the control condition.

Table 4.16 Post Hoc Analysis of Passive Ankle Dorsiflexion.

Passive Dorsiflexion	Treatments	F Ratio
Time 1 vs. Time 2		
	Brace vs. Control	* 26.40
	Tape vs. Control	* 62.53
	Brace vs. Tape	* 7.67
Time 1 vs. Time 3		
	Brace vs. Control	* 12.70
	Tape vs. Control	* 44.44
	Brace vs. Tape	* 9.63
Time 2 vs. Time 3		
	Brace vs. Control	* 6.06
	Tape vs. Control	* 6.45
	Brace vs. Tape	0.01

* Indicates significance ($p < .05$).

4.10 Perceived Comfort and Support

The perceived comfort and stability questionnaire was completed by each subject immediately following the post-exercise range of motion measures. The subject kept the support on while completing the questionnaire. Each statement required the subject to circle the response thought to most accurately reflect their perceived sense of comfort and stability. A Likert scale of 1 to 5 was used to indicate "strongly agree", "agree", "neutral", "disagree", and "strongly disagree", respectively, with the statement. Each subject's responses were recorded on an Excel 4.0 (Microsoft) spreadsheet for data analysis; with point values corresponding to each response (Appendix L). In other words, if a subject strongly agreed with a statement, a score of 1 was given. The lower the score, the greater the perceived comfort or stability. The following is a summary of their responses.

Table 4.17 Mean Scores for Each Perceived Comfort and Stability Statement, for Each Condition.

	Treatment Condition	
Statement	**Brace**	**Tape**
1. The support appears easy to apply.	1.5	2.5
2. The support felt comfortable prior to exercise.	1.9	2.3
3. The support felt comfortable during exercise.	1.9	2.8
4. The support felt comfortable after exercise.	2.1	2.8
5a. The support was uncomfortable for jogging.	2.0	2.3
5b. The support was uncomfortable for running.	2.0	2.4
5c. The support was uncomfortable for figure eights.	2.3	2.5
5d. The support was uncomfortable for stairs.	2.1	2.3
5e. The support was uncomfortable for vertical jumps.	2.0	2.1
5f. The support was uncomfortable for triple jumps.	2.1	2.0
6. My ankle felt stable with the support prior to exercise.	1.6	2.4
7. My ankle felt stable with the support during exercise.	1.6	1.4
8. My ankle felt just as stable with the support after exercise.	1.7	2.1

9a. The support was not adequately stable for jogging.	1.5	1.4
9b. The support was not adequately stable for running.	1.4	1.4
9c. The support was not adequately stable for figure eights.	1.7	1.4
9d. The support was not adequately stable for stairs.	1.4	1.4
9e. The support was not adequately stable for vertical jumps.	1.5	1.4
9f. The support was not adequately stable for triple jumps.	1.6	1.4
10. I would wear this support for high risk activities.	2.1	1.9
11. I would not wear this support for high risk activities.	2.0	1.6

Subject responses to these statements while performing the control condition were not included in Table 4.17 because they did not offer anything in the way of an analysis. In all cases, all subjects perceived the control condition to have offered greater comfort, and less support than either of the support conditions. Most of the above statements are obviously designed with the intention that the subjects would be applying them to one of the support conditions. It was deemed appropriate however, that they provide responses for the control condition to rule out the possibility that a subject with pain during a support condition, may have also had that same pain when performing the exercise without support.

Mean individual statement scores (as applied to each treatment condition) can be found in Table 4.17 The average total score for the control condition was 29 points, whereas the brace and tape conditions were 38 and 41 points respectively. At first this would appear to suggest that the control condition was the better of the three. However, when the statements related to comfort are separated from those related to stability, a different result is seen. The brace and tape conditions are clearly perceived to provide greater stability (one no better than the other), whereas the control condition is perceived to be more comfortable.

Table 4.18 shows the Wilcoxon signed rank values for each of the 11 statements of the Perceived Comfort and Stability Questionnaire. Only statements 1 and 3 showed a significant difference between the tape and brace groups ($p < .05$). Statement 1 indicated that the brace was easier to apply than the tape Statement 3 indicated that the brace was more comfortable during the overall exercise session.

Table 4.18 Wilcoxon Signed Rank Sum Scores for Each Perceived Comfort and Stability Statement, for all Subjects, for Each Test Condition.

Statement	DF	Mean X-Y	Paired t	Probability
1. The support appears easy to apply.	26	-1.000	-3.824	*0.001
2. The support felt comfortable prior to exercise.	26	-0.407	-1.655	0.208
3. The support felt comfortable during exercise.	26	-1.000	-3.824	*0.003
4. The support felt comfortable after exercise.	26	-0.667	-1.883	0.078
5a. The support was uncomfortable for jogging.	26	-0.222	-0.796	0.353
5b. The support was uncomfortable for running.	26	-0.407	-1.462	0.184
5c. The support was uncomfortable for figure eights.	26	-0.222	-0.782	0.568
5d. The support was uncomfortable for stairs.	26	-0.185	-0.633	0.546
5e. The support was uncomfortable for vertical jumps.	26	-0.111	-0.391	0.809
5f. The support was uncomfortable for triple jumps.	26	0.037	0.132	0.923
6. My ankle felt stable with the support prior to exercise.	26	0.222	2.280	0.099
7. My ankle felt stable with the support during exercise.	26	0.185	1.412	0.145
8. My ankle felt just as stable with the support after exercise.	26	-0.407	-2.021	0.202
9a. The support was not adequately stable for jogging.	26	0.111	0.827	0.747
9b. The support was not adequately stable for running.	26	-0.161	0.832	0.543
9c. The support was not adequately stable for figure eights.	26	0.222	1.185	0.646
9d. The support was not adequately stable for stairs.	26	0.037	0.273	0.543
9e. The support was not adequately stable for vertical jumps.	26	0.111	0.721	0.626
9f. The support was not adequately stable for triple jumps.	26	0.148	1.000	0.839
10. I would wear this support for high risk activities.	26	0.222	0.827	0.642
11. I would not wear this support for high risk activities.	26	0.259	1.045	0.415

* Indicates significance ($p < .05$).

Statements 1 and 3 were the only statements on the Perceived Comfort and Stability Questionnaire that were found to be statistically significant. The implications of these will be discussed below.

Statement 1 asked subjects to indicate whether or not they felt the support was easy to apply. Fourteen of the 27 subjects (52%) strongly agreed, and 13 (48%) agreed with the statement for the brace condition. For tape, the responses were more varied. Five subjects (18.5%) strongly agreed that the tape was easy to apply, 14 (52%) agreed, 1 was neutral, 4 (14.8%) disagreed, and 3 (11%) strongly disagreed with the statement. The average scores for the brace, and tape conditions were 1.5, and 2.5 respectively. This would suggest that the tape was far more difficult to apply.

The implications of this are important from a compliance point of view. Regardless of which support the quantitative data indicates may be more effective at reducing lateral ankle sprains, an athlete may not wear it because it is too difficult to apply. Or, they may require trained personnel to apply it for them. The support can only be effective if it is being worn by the athlete.

Statement 3 indicated that the support felt comfortable during exercise. In the brace group, 37% (n = 10) strongly agreed, 44% (n = 12) agreed, 15% (n = 4) were neutral, and 4% (n = 1) disagreed. The responses for the tape group were 11% (n = 3), 37% (n = 10), 15% (n = 4), 30% (n = 8), and 7% (n = 2) respectively.

The significant difference in responses to this statement have implications for compliance as well. Regardless of which support the quantitative data indicates may be more effective at reducing lateral ankle sprains, an athlete may not wear it because it is too uncomfortable prior to their commencing activity. This is particularly true when there is an alternative (such as a semirigid orthosis) that is perceived to be significantly more comfortable.

Chapter 5: Discussion

5.1 Introduction

Research on the efficacy of various types of prophylactic ankle protection is sometimes more confusing than clarifying. There are clearly a large number of studies that have been done; most of which have attempted to compare one or more semirigid supports to ankle taping. Unfortunately, most of these have focused on one support in particular (the Aircast Sport-Stirrup), with limited research devoted to any of the other supports that are currently available. This is particularly true of the Active Ankle, which has minimal independent research (due primarily to the fact that it is a newcomer on the market).

Another significant problem is that the studies that have been done using ankle taping as the ruler by which all other supports are compared, have not demonstrated any consistency in the manner in which the tape has been applied, nor by whom it has been applied. Bunch et al. (1985) showed that tape can be one-third less effective when applied by "inexperienced personnel". Such problems make it extremely difficult to look at comparisons between different studies.

Another concern has been the external validity of studies that focus on one particular sport or physical activity. Most of the previous research has focused on one specific sport / activity, or it has focused too much on one aspect of prophylactic support. In other words, there has always been a question as to whether or not results from an intramural basketball program, with few other external controls, can be generalized to other sports (Garrick and Requa, 1973). The same can be said of studies that look only at a university football program (Rovere et al., 1988). Such retrospective studies also bring into question the accuracy of external controls.

Chapter 4 shows the raw data and the subsequent statistical analysis but it does not provide any explanation as to why certain trends were seen. The following will discuss the results, what they mean, and what can be drawn from the data.

5.2 Subject Characteristics

None of the 27 subjects had previously worn any form of ankle support except for one who had some competitive experiences with ankle taping. This was fortunate in that it offered another form of control that had not been initially intended. There are two assumptions that can be made from this. One, that because there was no previous experience with ankle supports in an athletic setting (competitive or otherwise), one may expect that the perceived comfort would be very low. Clinically, athletes are encouraged to wear such supports over several practices so that they can adjust to them and get used to the restrictions that they provide. In other words, the subjects may have been unintentionally predisposed to low acceptance of the brace and tape conditions. Second, subjects may have been more acutely aware of the restrictions in range of motion, and therefore been likely to exaggerate the perceived support offered by each of the support conditions.

Seventeen of the 27 subjects were students in the Athletic Therapy Program at the University of Manitoba. This is an inherent subject bias (although in which direction remains unclear). For example, a subject who entered the study with a preconceived bias towards one method of support or another, may have performed in such a way as to bias her results in favor of the support that she preferred.

5.3 Quantitative Results

In total, 81 ROM measurements were taken with the subject wearing no external support other than a sock and shoe. The findings were encouraging in that the within subject ROM measures were virtually identical (Figure 3.1). This would suggest a strong researcher and equipment reliability. In other words, the accuracy of the results would be questionable if a subject had 20 degrees of inversion on test day 1, but 32 degrees of inversion the next day, and 16 degrees on day 3 of testing.

As was found in other studies (Bunch, et al., 1985; Capasso, 1989; Greene & Hillman, 1990; Gross, et al., 1987; Gross, et al., 1991; Hughes & Stetts, 1983; Delacerda, 1978; Malina, et al., 89.22; Morris & Musnicki, 1983), the ability of tape to restrict ROM prior to exercise was better (although not significantly), than was the ability of various other supports. This study also showed that both the tape and the Active Ankle semirigid orthosis were significantly more restrictive than the control group, regardless of when the ROM was measured.

Three separate time comparisons were made (time 1 versus time 2, time 2 versus time 3, and time 1 versus time 3). All 3 are important for various reasons. Any differences in ROM that occurred between time 1 and time 2 are related to the ability of the support to restrict certain movements, when compared to an unsupported ankle. A difference in ROM between times 2 and 3 would suggest that exercise caused some loosening of the support, thereby allowing greater ranges of motion in one or more directions. Any differences that occurred between times 1 and 3 held important ramifications from a practical standpoint. This "applied reality" has to be considered. If both supports showed a significant reduction in the ROM when compared to the unsupported condition, this would carry practical significance. But if the tape was shown to loosen after exercise, it may be deemed inadequate. However, even after loosening, it remained significantly more restrictive after exercise, than the unsupported condition. In other words, it may still be restrictive enough to protect against injury.

Something that has yet to be addressed is the delineation between statistical results and practical implications. Tables 4.1 and 4.7 both show changes across the control conditions (times 1 to 2 to 3) that are as small as 1.66 degrees and 1.89 degrees respectively. Yet these contribute to statistically significant results (as found in Tables 4.2 and 4.8). It could be strongly argued at this point that despite their statistical significance, these differences are not large enough to be of any practical value.

The real concern of course, is the ability of any support to offer the same restrictions after exercise as before. Such a support has yet to be invented but the closer one comes to achieving this ideal, the more effective it will be. There was no significant change in range of motion over time in the control group. This would appear to contradict what Myburgh, et al. (1984) refer to as a warm-up effect. That is that range of motion should increase with exercise simply because of the soft tissue stretch and physiologic tissue temperature increase that occurs. Whether or not such an effect occurs though, is somewhat irrelevant for this study because it would occur across all treatment conditions (assumingly to equal degrees).

There were 4 ROM measures that revealed significant differences between the brace and the tape between times 2 and 3 (i.e., after exercise). In the cases of active and passive inversion, the brace was found to be significantly more restrictive than was the tape ($p<.05$). In the cases of active plantar flexion and passive dorsiflexion, the tape was found to be significantly more restrictive than was the brace ($p<.05$). These findings are important from 2 perspectives.

First, some believe that most ankle injuries involve a combination of inversion and plantar flexion (Alves, et al., 1992; Greene & Roland, 1989; Lane, 1990; Lassiter, et al., 1989; Rarick, et al., 89.22), yet others believe that it is isolated inversion that causes most injuries to the ankle (Bunch, Bednarski, Holland, & Macinanti, 1985; Greene & Hillman, 1990; Greene & Wight, 1990; Miller & Hergenroeder, 1990; Paris & Sullivan, 1992; Tropp, 1986; Tropp, Askling, & Gillquist, 1985). Therefore, restricting one or both of these motions should reduce the likelihood of injury. While the brace is more effective at restricting inversion, the tape more effectively restricts active plantar flexion. Although plantar flexion does play a role in lateral ankle sprains, it is also a necessary movement for most sport activities, so limiting it may also inhibit performance. Tape was also more restrictive of passive dorsiflexion but this may also hinder athletic performance. The question that remains is whether the loss of plantar flexion with the tape is enough to reduce the likelihood of injury, without hindering performance.

The above exceptions aside, the changes in prophylactic support that occurred due to exercise were found not to be significantly different for the brace and tape groups. This is clearly different from that found in other studies that report break-downs of the tape anywhere from 10% (Myburgh, et al., 1984), and 37% (Greene & Hillman, 1990). One explanation for this may be that the only underwrap used in this study was to keep the heel and lace pads in place. In other words, the anchors were applied directly to the skin. Delacerda (1978) has shown that tape is significantly more restrictive when applied directly to the skin (although he does not indicate to what extent).

5.4 Perceived Comfort and Stability

Not surprisingly, there was a significant difference in the way in which subjects perceived their levels of comfort and stability for each of the 3 test conditions. All 27 subjects preferred the control condition in terms of their personal level of comfort. This is not in itself surprising since by definition, a support must be restrictive in order to achieve the desired effect. As discussed in Chapter 4, neither the brace nor the tape was found to be uncomfortable, it was a matter of the control condition being that much more comfortable. As discussed earlier though, the brace and tape may have been perceived as more uncomfortable simply because only one of the 27 subjects had any previous experience wearing ankle supports. Performing the exercise routine while wearing a support for the first time would surely create some sense of discomfort.

Both the brace and tape conditions were reported to offer greater perceived stability compared to the control condition. Again this is not surprising considering the fact that wearing a support during exercise was a new experience for all but one of the subjects. There was no significant difference in terms of a preference for one support over the other.

Both of these issues of perception are critical and unique to this study. An athlete who wears an ankle support (out of desire, need, or both) will be more likely to comply if he/she perceives that support to offer stability. Perhaps more important though, they must feel the support to be comfortable. If not, compliance will be low, and even if there is compliance, the support may pose a distraction to the point where it could affect performance.

Somewhat surprising was the fact that there was no significant difference between perceived comfort or perceived support across the various components of the exercise sessions. One would expect that subjects would perceive the brace and the tape to offer greater support during such exercises as the figure of eight pattern or the jumping. Similarly, because the figure of eights place greater stress on the ankle (laterally in particular), one would expect that subjects would perceive that exercise to be the most uncomfortable with the support on.

Chapter 6: Summary, Conclusions, and Recommendations

6.1 Summary

It was the purpose of this study to determine if any differences existed between a semirigid orthosis and tape, in terms of prophylactic support, and protection from ankle injury during activity. Twenty seven female subjects were recruited to participate in the study and were tested on 3 consecutive days. They were randomly assigned to one of 3 test orders which included control, semirigid orthosis, and tape conditions. Their active and passive ranges of ankle motion (inversion, eversion, plantar flexion, and dorsiflexion) will be measured 3 times per test session. Once prior to the application of any support and prior to exercise, once after the support had been applied but prior to exercise, and again after exercise. A hand-held scale was used to apply constant, passively applied torque. Pilot tests on other researchers, using variable overpressures, led to the belief that 89.2 N. and 124.9 N. were appropriate overpressures for the purposes of this study. These forces were also greater than those used in previous research. These torques were applied with no risk to the subject, and were intended to produce realistic stress on the ankle. Subjects were also asked to complete a questionnaire to assess their perceived comfort and stability of each of the treatment conditions.

The quantitative data was analyzed using a Systat program on an IBM computer. The qualitative data was inputted onto an Excel spreadsheet (4.0, Macintosh) for analyses. The findings were consistent with previous research in that both supports offered significantly better support than the control, in all 3 test times. Both supports loosened to significant degrees after exercise, in all cases except active ankle eversion and plantar flexion (only the tape loosened), and passive ankle eversion. With the exception of these movements, the tape and brace responded similarly after exercise.

Of course, there are obvious advantages to the brace, regardless of the efficacy of the tape. For instance, the tape requires a trained person with experience at taping in order to achieve the desired result. Such an individual also offers the advantage of being able to customize the support to achieve a greater number of effects (both injury, and sport specific). The brace on the other hand can be applied very quickly and with minimal instruction. It can also be retightened in the middle of a practice or a game if necessary.

6.2 Conclusions

In conclusion, this study found that:

1. Prior to exercise, a semirigid orthosis and prophylactic ankle tape both produced a significant reduction in ankle inversion and eversion, but not in plantar flexion or dorsiflexion. Following exercise, both demonstrated less restriction than before, but were both significantly more restrictive than the control.

2. The brace appears to loosen less than the tape after exercise. The exercise was found to affect the tape moreso than the brace in the cases of active ankle inversion, active ankle plantar flexion, and passive ankle inversion. These three motions are particularly critical in terms of the mechanism of injury for lateral ankle sprains.

3. There was a significant difference between the subjects' perceived comfort of the semirigid orthosis and the tape. The brace was reported to be more comfortable during the exercise session.

4. Both the semirigid orthosis and the tape provided significantly more perceived support than the control (across all subjects). There was no perceived difference between the brace and the tape; before, during, or after exercise.

5. The problem all along has been to find a way to truly test the mechanical limits of a support. Using a human subject in a situation where the support is tested to failure has obvious consequences. Therefore, applying these results to an environment where an athlete actually does get exposed to injury situations is questionable, and continues to pose a problem for researchers in this area.

6. Based on pilot testing of the Time 1 ROM measures, the method of positioning each subject in the goniometer, the application of passive forces, and the reading of ranges of motion, were all done reliably and consistently across all subjects. This was important in terms of developing a technique that allowed reproducible results. It also suggests that any difference(s) in ROM that were found, were due to a treatment effect, as opposed to such a factor as differences in subject positioning.

7. Based on the correlation coefficient testing of the pilot study for ankle tape application, this support technique was shown to be applicable in a consistent manner. This too suggests that any difference(s) in ROM that were found, were due to a treatment effect, as opposed to a factor such as differences in subject positioning.

6.3 Recommendations

1. Future studies may want to examine more semirigid orthoses at once. Although time consuming, it makes comparisons between braces more accurate.

Unfortunately, I do not believe that it is within the realm of possibility to standardize taping techniques. This means that true comparisons between studies that employ a taping component may never be possible.

2. A larger scale exercise component may be necessary. The exercise protocol used in this study was longer than that of most other studies, and more controlled. Although a variety of activities were used (to mimic those found in most sport environments), they were performed submaximally. This must be done to ensure consistency between subjects and between test days. However, it falls short of reproducing the stresses that would typically occur in a normal exercise situation.

3. Based on pilot studies, it appears that 11.6 Nm. is reasonable torque to be applied for testing passive inversion and eversion ankle ROM. However, it was the impression of both the researcher and most subjects, that 8.7 Nm. was too light for passive ankle plantar flexion and dorsiflexion.

4. One subjective finding pertains to the questionnaire for perceived comfort and stability. In future, the statements that were used should be more clearly written (some double negatives were confusing to some of the subjects, and had to be clarified at the time. A visual analogue scale may be more appropriate.

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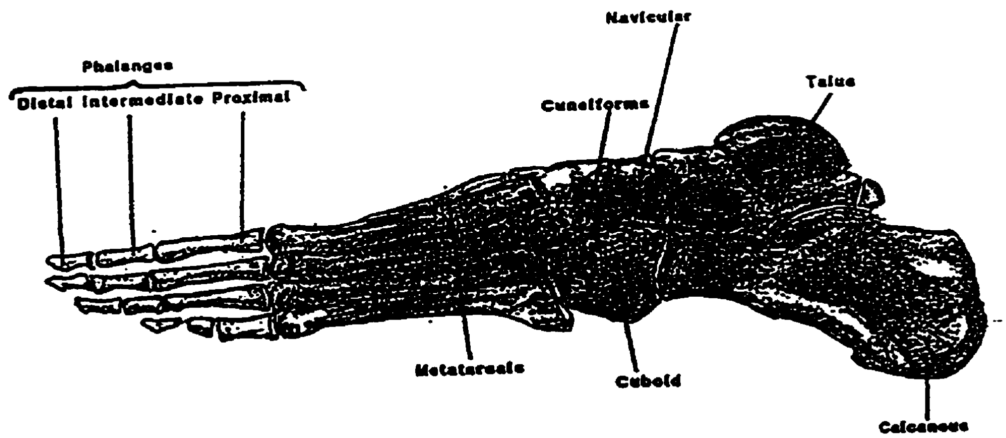
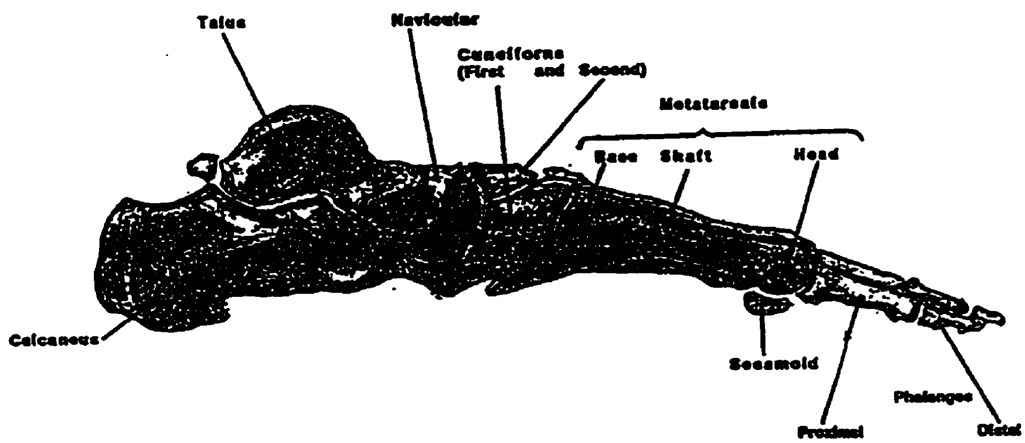
Appendix A

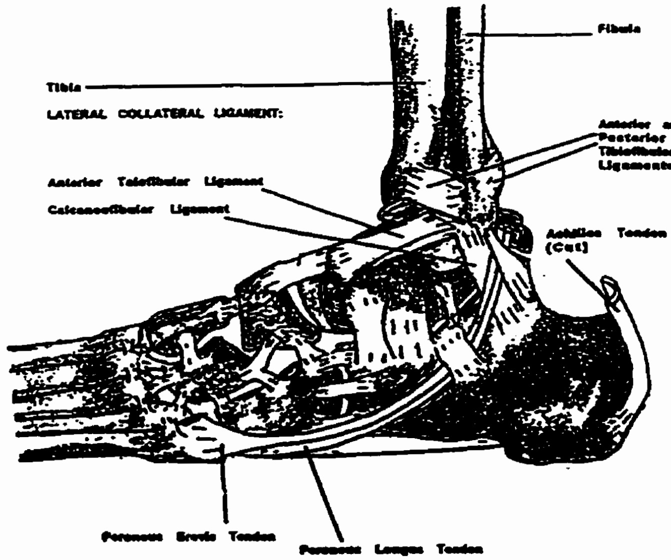
Anatomy of the Lower Leg



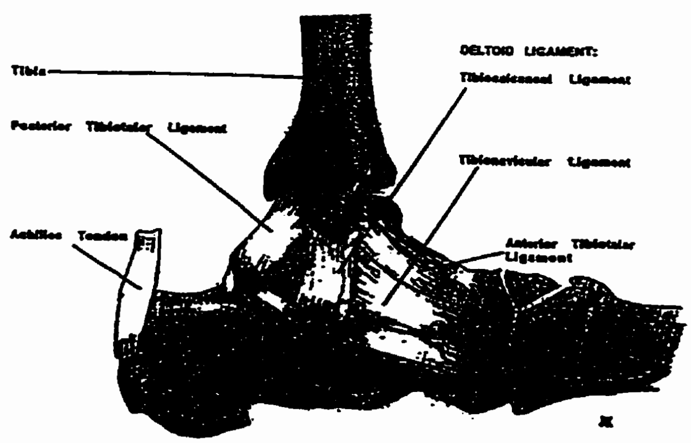
A. Lateral view of the bones of the left foot and ankle (Stewart, et al., 1993).



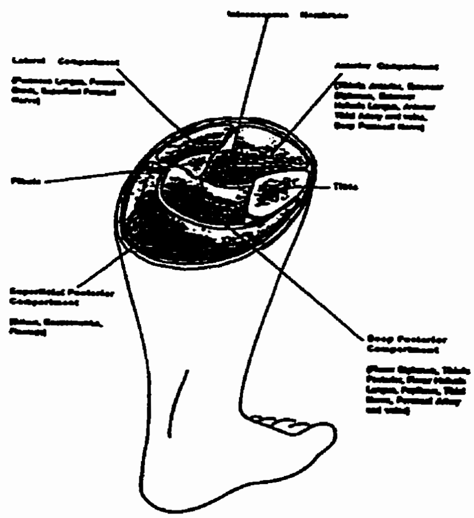
B. Medial view of the bones of the left foot and ankle (Stewart, et al., 1993).



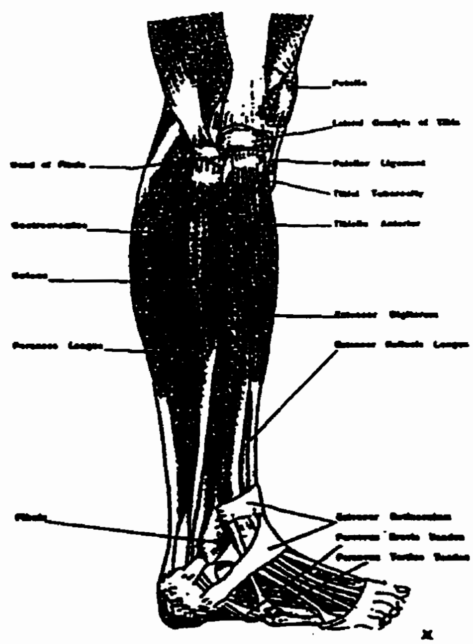
C. Lateral view of right ankle ligaments (Stewart, et al., 1993).



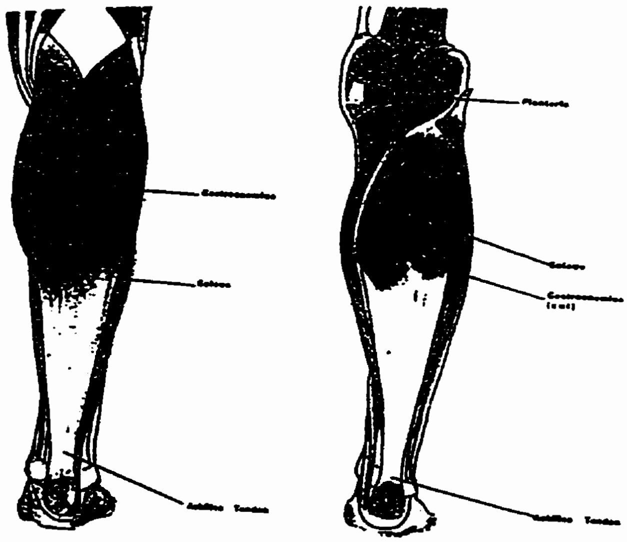
D. Medial view of right ankle ligaments (Stewart, et al., 1993).



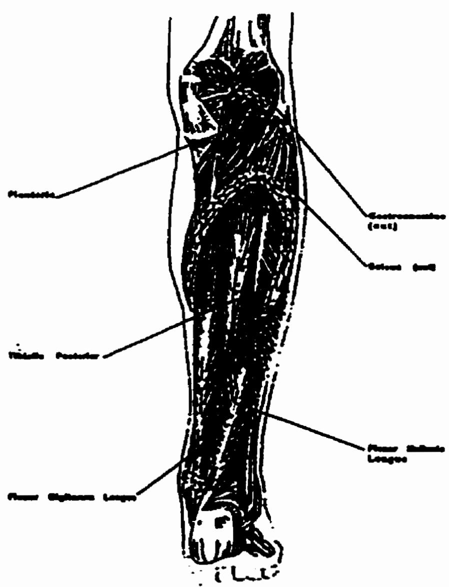
E. Muscular compartment of the left leg (Stewart, et al., 1993).



F. Lateral view of the muscles of the right leg (Stewart, et al., 1993).



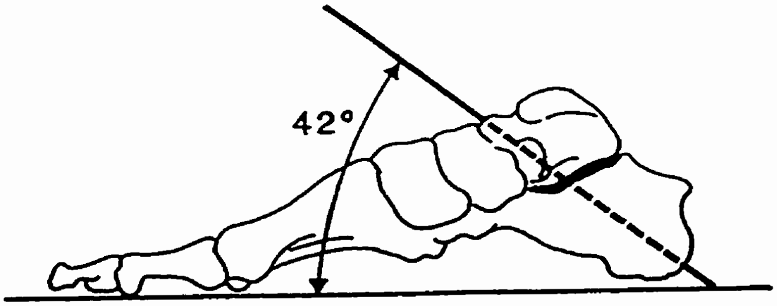
G. Superficial posterior compartment of the muscles of the right leg (Stewart, et al., 1993).



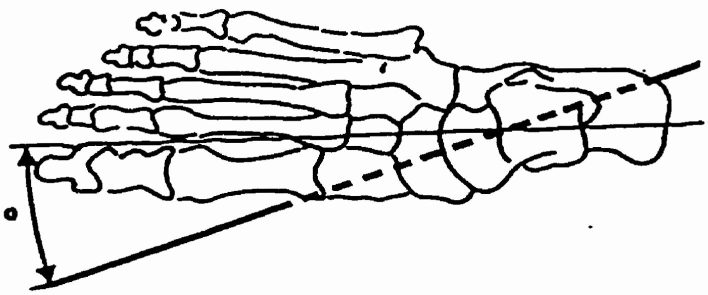
H. Deep posterior compartment of the muscles of the right leg (Stewart, et al., 1993).

Appendix B

Subtalar Axes of Rotation



A. Simplified axis of rotation at the subtalar joint (sagittal plane) (Sammarco, G.J., 1989)

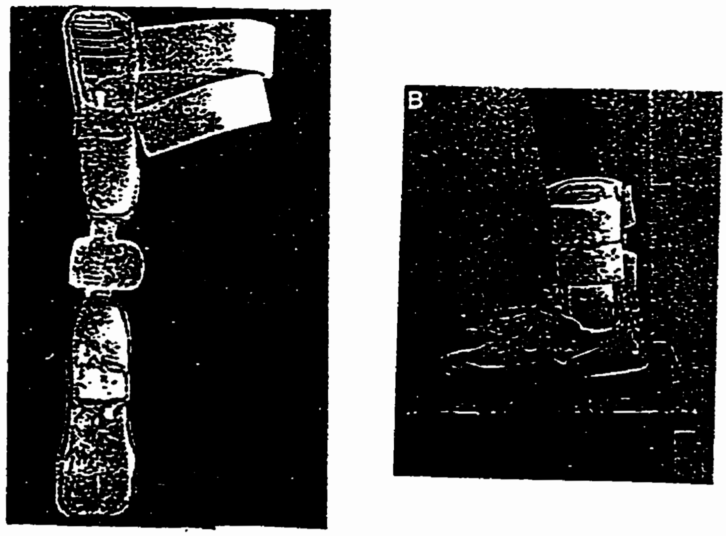


B. Simplified axis of rotation at the subtalar joint (transverse plane) (Sammarco, G.J., 1989).

Appendix C

Aircast Sport Stirrup and Active Ankle

Semirigid Orthosis



A. Aircast Sport-Stirrup ankle orthosis.

B. Active Ankle orthosis.

Appendix D

Ankle Taping Technique

Closed basketweave ankle taping technique (Stewart, et al., 1993).

Appendix E

Medical Screening Questionnaire

UNIVERSITY OF MANITOBA
FACULTY OF GRADUATE STUDIES

A COMPARATIVE ANALYSIS OF TWO PROPHYLACTIC ANKLE SUPPORTS

SUBJECT MEDICAL SCREENING QUESTIONNAIRE

The questions on this form are to be completed by the subject (with the help of a physician or therapist if necessary) in as much detail as possible. All information will be kept strictly confidential and used solely for the purposes of the study.

1) In the last 6 months, have you ever had an ankle injury (Y/N)? ____________________

2) If yes, was it your right or left ankle? ____

3) Was the injury to the inside or the outside of the ankle? _________________________

4) Did you require medical attention (Y/N)? ___________

5) If so, from whom and are you still receiving it?

____

____

6) Were/are you restricted in any way from any activity due to this injury (Y/N)? ________

7) Are you required to wear a specific brace or other method of support (e.g.. stabilizer, tape, etc.) and if so, which kind?

____

____

8) Does the injury bother you in any way now, and if so, how and when?

____

____

____

____

9) Additional comments or questions:

____

____

____

____

____

Appendix F

Subject Instructions and Informed Consent Form

UNIVERSITY OF MANITOBA
FACULTY OF GRADUATE STUDIES

A COMPARATIVE ANALYSIS OF TWO PROPHYLACTIC ANKLE SUPPORTS

SUBJECT INSTRUCTIONS & INFORMED CONSENT

The purpose of the study is to produce quantitative and qualitative information regarding the effectiveness of two different ankle prophylaxes in terms of active and passive ranges of motion prior to and following prescribed exercise. This research can provide valuable insights for athletes, coaches, and therapists in order to reduce the number and severity of ankle injuries that occur in sports. Currently there are many choices available to protect ankles from injury or reinjury. Unfortunately, there is no clear consensus as to which support is most effective. From the perspectives of both the players and the medical profession, there is an obvious need to determine the most cost-effective, and functional method of support.

Subjects will be volunteers from the Faculty of Physical Education and Recreation Studies at the University of Manitoba, or the University of Manitoba Athletic Therapy Centre. As a subject, you will have no injury to either ankle within the six months preceding the study and will have avoided strenuous exercise in the 24 hours preceding participation in the study (as declared on the attached medical questionnaire).

You will be randomly placed into one of three test conditions (tape, brace, no support) and the range of motion of your dominant ankle will be tested (you will be tested with each of these conditions on 3 separate days). You will then proceed with the following exercise program: jogging 2 warm-up laps (200 m. each), running 2 laps (200 m. each) at moderate intensity, 1 agility run, 4 flights of stairs, 5 vertical jumps, 3 triple jumps, 1 more agility run, and jogging a 2 lap (200 m. each) cool-down. You will perform all of these tasks in 15 minutes with each individual task being performed in a predetermined amount of time.

At the conclusion of the exercise you will be retested using the same protocol as before the exercise. You will also be asked to complete a brief questionnaire regarding the comfort and support provided by each of the test conditions (tape, brace, no support). The same procedure will be followed for each of the other two test conditions. This will complete your role in this study.

You are free to withdraw without penalty at any time. All of the information that is collected for the purposes of this study will be used for the study and in keeping with standard medical protocol, will be kept strictly confidential. Your name will remain anonymous at all times.

I, the undersigned, have read this form and understand the purpose of the study and my role in it. I am aware that I am free to ask questions at any time and that my participation in the study is completely voluntary. I am aware that I may withdraw without penalty at any time.

I ______________________________ have read and understood this form, and understand what is expected of me. I consent to participate in the above study.

____
print name of participant

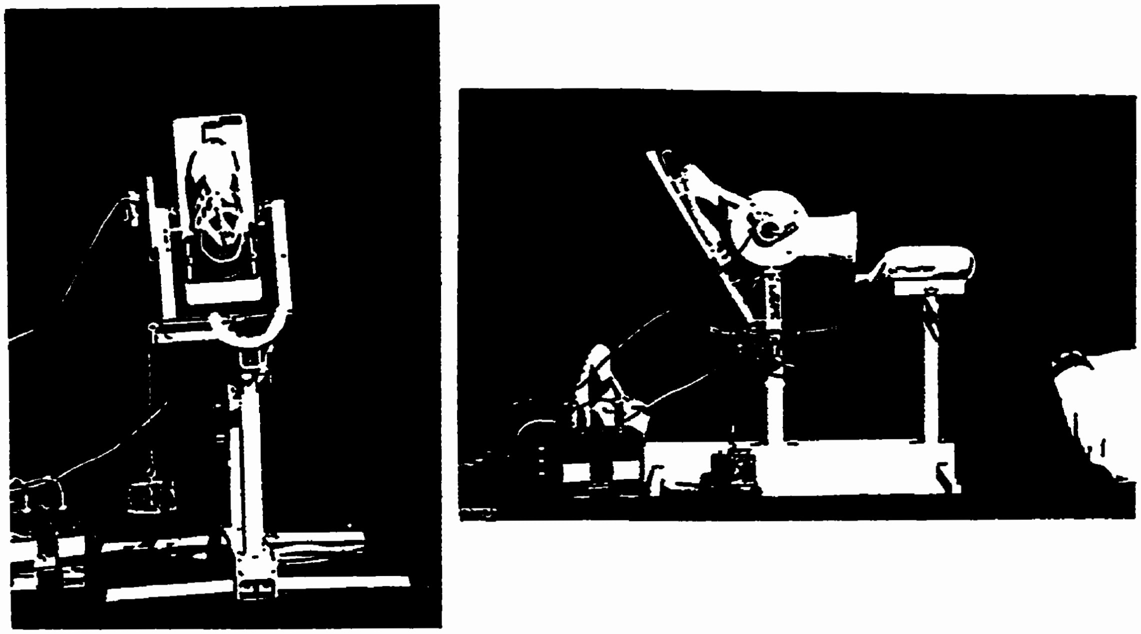
______________________________ ______________
signature of participant date

____
print name of witness

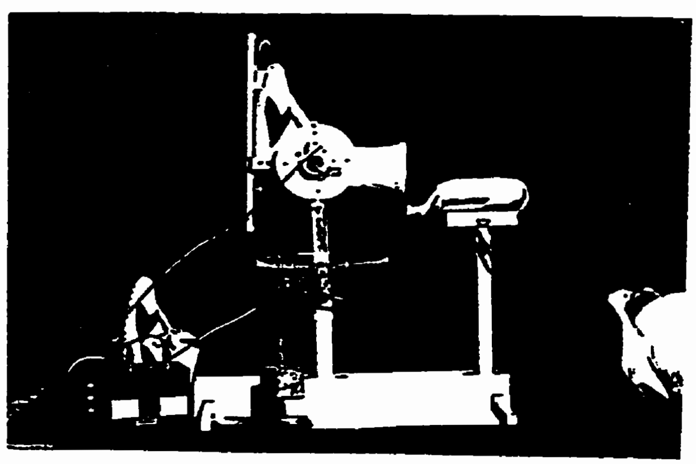
______________________________ ______________
signature of witness date

Appendix G

Subject Positioning for ROM Measures



A. Anterior and Lateral Views of the Ankle Range of Motion Goniometer.
A. Anterior and Lateral Views of the Ankle Range of Motion Goniometer.



B. Subject positioning for measurement of ankle range of motion

B. Subject positioning for measurement of ankle range of motion

Appendix H

Data Collection Sheets

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FACULTY OF PHYSICAL EDUCATION AND RECREATION STUDIES

A COMPARATIVE ANALYSIS OF TWO PROPHYLACTIC ANKLE SUPPORTS

PRE-EXERCISE DATA COLLECTION SHEET 1

Name: ______________________________ Phone No. ____________________

Support Used: _________________________ Time & Date of test: ____________

Pre-exercise Active Range of Motion:

Inversion _____________ degrees Eversion ___________ degrees

Plantar Flexion _________ degrees Dorsiflexion ________ degrees

Pre-exercise Passive Range of Motion:

Inversion _____________ degrees Eversion ___________ degrees

Plantar Flexion _________ degrees Dorsiflexion ________ degrees

UNIVERSITY OF MANITOBA
FACULTY OF PHYSICAL EDUCATION AND RECREATION STUDIES

A COMPARATIVE ANALYSIS OF TWO PROPHYLACTIC ANKLE SUPPORTS

PRE-EXERCISE DATA COLLECTION SHEET 2

Name: ______________________________ Phone No. ____________________

Support Used: _________________________ Time & Date of test: ____________

Post-application, Pre-exercise Active Range of Motion:

Inversion _____________ degrees Eversion ___________ degrees

Plantar Flexion _________ degrees Dorsiflexion _________ degrees

Post-application, Pre-exercise Passive Range of Motion:

Inversion _____________ degrees Eversion ___________ degrees

Plantar Flexion _________ degrees Dorsiflexion _________ degrees

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FACULTY OF PHYSICAL EDUCATION AND RECREATION STUDIES

A COMPARATIVE ANALYSIS OF TWO PROPHYLACTIC ANKLE SUPPORTS

POST-EXERCISE DATA COLLECTION SHEET

Name: ______________________________ Phone No. ____________________

Support Used: __________________________ Time & Date of test: ____________

Post-exercise Active Range of Motion:

Inversion _____________ degrees Eversion ____________ degrees

Plantar Flexion _________ degrees Dorsiflexion _________ degrees

Post-exercise Passive Range of Motion:

Inversion _____________ degrees Eversion ____________ degrees

Plantar Flexion _________ degrees Dorsiflexion _________ degrees

Appendix I

Perceived Comfort and Stability Questionnaire

UNIVERSITY OF MANITOBA
FACULTY OF PHYSICAL EDUCATION AND RECREATION STUDIES

A COMPARATIVE ANALYSIS OF TWO PROPHYLACTIC ANKLE SUPPORTS

PERCEIVED COMFORT & STABILITY QUESTIONNAIRE

The following questionnaire is designed to be completed immediately after you have completed the exercise protocol. Please answer all questions as honestly and completely as possible. All responses will be kept strictly confidential.

Name: ______________________________ Phone No. ______________

Support Used: ________________________ Date of test: ______________

	strongly agree	agree	neutral	disagree	strongly disagree
1) The support appears easy to apply.	1	2	3	4	5
2) The support felt comfortable prior to exercise.	1	2	3	4	5
3) The support felt comfortable during exercise.	1	2	3	4	5
4) The support felt comfortable after exercise.	1	2	3	4	5
5) Which exercise(s) was the support uncomfortable for? a) jogging	1	2	3	4	5
b) running	1	2	3	4	5
c) figure of eights	1	2	3	4	5
d) stairs	1	2	3	4	5
e) vertical jumps	1	2	3	4	5
f) triple jumps	1	2	3	4	5

If so, why? ____

____

6) My ankle felt stable with the support prior to the exercise.	1	2	3	4	5
7) My ankle felt stable with the support during the exercise.	1	2	3	4	5
8) My ankle felt just as stable with the support after the exercise.	1	2	3	4	5

9) Which exercise(s) did the support <u>not</u> provide adequate stability for?

a) jogging	1	2	3	4	5
b) running	1	2	3	4	5
c) figure of eights	1	2	3	4	5
d) stairs	1	2	3	4	5
e) vertical jumps	1	2	3	4	5
f) triple jumps	1	2	3	4	5

If not, why? ____

____

10) I would wear this support for activities where I was at risk for ankle injuries.	1	2	3	4	5
11) I would not wear this support for activities where I was at risk for ankle injuries.	1	2	3	4	5

Appendix J

Exercise Protocol

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A COMPARATIVE ANALYSIS OF TWO PROPHYLACTIC ANKLE SUPPORTS

EXERCISE PROTOCOL SHEET

ACTIVITY	TIME ALLOTTED (minutes)
walk and stairs (15/flight)	1.00
2 X 200 meter warm-up jog	2.00
stretch (hamstring, quadriceps)	1.00
2 X 200 meter run	1.50
active rest	1.00
figure of 8 course	1.50
active rest	1.00
5 X vertical jump	0.50
3 X triple jump	1.00
figure of 8 course	1.50
1 X 200 meter cool-down jog	2.00
walk and stairs (15/flight)	1.00
TOTAL	15.00

Appendix K

Raw Range of Motion Data

Table 1 Range of Motion Data for the Control Condition.

S	A inv T1	A ev T1	A pf T1	A df T1	P inv T1	P ev T1	P pf T1	P df T1	A inv T2	A ev T2	A pf T2	A df T2	P inv T2	P ev T2	P pf T2	P df T2	A inv T3	A ev T3	A pf T3	A df T3	P inv T3	P ev T3	P pf T3	P df T3
1C	38	15	40	17	57	27	52	14	36	16	44	17	60	26	52	15	39	20	46	16	66	27	53	14
2C	42	15	44	16	58	28	52	18	42	16	43	16	58	28	54	18	43	18	45	16	60	34	55	21
3C	52	16	53	20	62	38	58	24	49	17	53	19	60	38	58	24	49	18	53	18	62	35	58	26
4C	40	7	40	28	58	30	48	48	35	8	40	22	55	25	47	55	43	8	42	20	57	36	53	55
5C	44	8	40	20	59	20	48	24	45	9	40	19	59	19	49	24	40	9	40	21	60	23	48	28
6C	41	19	49	19	60	40	53	21	41	22	49	18	60	41	53	23	43	22	50	14	60	40	53	25
7C	45	15	44	25	55	26	54	22	47	21	49	20	55	29	54	21	47	13	45	19	57	26	50	14
8C	48	16	47	19	60	27	52	20	48	21	52	18	60	30	54	22	50	15	49	15	60	32	53	26
9C	33	6	34	36	45	12	42	40	33	8	36	36	46	20	41	39	35	8	36	33	49	15	43	44
10C	30	10	47	14	45	23	53	18	29	13	48	15	43	25	52	14	31	11	47	11	44	21	51	8
11C	36	15	47	22	48	27	51	23	40	17	48	22	52	26	54	20	39	18	48	20	44	29	55	24
12C	26	10	45	13	50	23	53	18	30	9	47	11	47	23	54	17	27	7	42	10	45	20	52	20
13C	48	14	45	14	56	38	50	12	48	16	49	13	58	34	53	12	47	15	48	18	58	29	52	14
14C	47	20	43	35	53	23	47	43	45	23	43	36	53	23	48	43	52	17	44	38	59	24	49	40
15C	43	21	51	21	62	39	53	26	43	19	51	19	63	28	54	19	42	17	50	14	62	42	56	20
16C	39	8	49	23	60	30	55	26	40	9	48	25	60	29	54	27	41	8	46	27	60	20	55	28
17C	45	14	45	24	59	27	52	18	49	16	47	26	59	25	51	30	53	12	46	25	60	22	51	30
18C	28	6	47	23	53	31	53	34	34	7	48	42	54	21	52	25	27	8	50	21	53	23	55	28
19C	40	9	45	12	49	15	48	20	41	11	48	13	50	15	49	18	46	12	49	9	55	16	53	15
20C	46	28	48	22	52	34	32	25	46	31	48	21	55	42	53	22	44	30	45	24	56	39	52	26
21C	37	13	47	20	48	19	49	10	37	11	47	19	47	17	50	12	33	13	46	17	52	16	48	12
22C	35	20	51	19	58	29	53	16	39	20	50	15	56	28	52	8	43	22	53	14	58	39	55	20
23C	34	11	42	24	54	29	50	28	35	20	48	28	58	44	52	30	37	17	49	24	58	38	54	35
24C	43	21	48	22	59	34	52	24	43	19	47	23	59	34	53	24	48	24	48	26	60	32	50	28
25C	47	6	50	30	64	35	52	33	54	11	50	28	65	30	50	36	60	14	46	28	65	30	50	33
26C	53	25	44	26	54	28	52	26	54	25	52	24	54	29	53	28	53	26	49	20	58	32	44	24
27C	45	35	53	18	60	45	55	15	46	30	50	13	60	40	57	15	38	36	52	13	60	38	54	12
SD	6.92	7.13	4.33	5.95	5.30	7.67	4.84	9.15	6.71	6.57	3.95	7.55	5.43	7.62	3.30	10.33	7.95	7.15	3.86	6.88	5.77	8.11	3.45	10.55

Key:
A = Active
P = Passive

inv = inversion
ev = eversion
pf = plantar flexion
df = dorsiflexion

T1 = time 1
T2 = time 2
T3 = time 3
SD = standard deviation

1C = Subject 1, control group
B = Brace group
T = Tape group

Table 2 Range of Motion Data for the Brace Condition.

S	A inv T1	A ev T1	A pf T1	A df T1	P inv T1	P ev T1	P pf T1	P df T1	A inv T2	A ev T2	A pf T2	A df T2	P inv T2	P ev T2	P pf T2	P df T2	A inv T3	A ev T3	A pf T3	A df T3	P inv T3	P ev T3	P pf T3	P df T3
1B	37	16	42	17	58	26	51	14	25	12	40	14	21	19	50	11	30	15	40	13	26	21	55	11
2B	42	16	44	16	59	30	53	20	25	16	44	15	32	20	49	16	30	17	46	18	40	22	52	18
3B	51	23	53	18	62	36	58	20	24	9	47	18	46	23	50	15	25	13	47	22	48	23	53	25
4B	36	8	38	29	57	19	44	42	16	7	34	24	30	12	40	31	20	8	34	16	32	15	42	34
5B	36	8	42	23	60	24	47	24	15	1	36	20	28	10	42	8	18	2	34	25	33	18	43	18
6B	41	22	47	23	59	35	52	25	25	12	45	21	34	24	49	15	23	13	43	17	40	21	49	22
7B	48	16	47	23	56	32	53	23	38	12	45	20	37	20	47	15	40	10	42	22	42	19	48	20
8B	49	12	48	24	60	26	54	24	25	7	48	20	35	13	45	18	35	10	49	13	44	17	51	19
9B	34	9	39	34	47	18	43	37	20	0	34	34	32	10	36	25	23	0	35	32	35	15	40	28
10B	33	9	47	15	50	24	52	15	25	8	44	12	33	19	48	14	31	11	45	13	36	20	48	11
11B	26	15	43	24	45	23	46	16	18	7	40	20	26	12	45	10	23	7	43	19	31	16	50	19
12B	28	8	45	17	50	25	53	23	8	8	40	11	28	16	47	12	10	8	42	11	35	18	49	16
13B	45	15	45	28	60	33	53	35	15	8	40	10	34	15	44	12	22	10	40	23	41	19	46	30
14B	52	20	44	38	58	22	48	46	29	10	42	33	40	7	44	26	34	13	43	38	43	15	45	36
15B	43	19	50	13	62	38	57	19	18	11	48	-1	43	25	53	4	23	10	46	4	46	27	53	15
16B	39	12	48	24	60	29	56	24	12	3	44	20	24	16	55	10	15	3	44	22	34	17	50	20
17B	42	10	42	29	58	21	49	36	21	8	43	25	33	14	48	24	21	11	42	26	30	22	46	26
18B	38	7	48	23	57	22	54	36	20	0	45	25	38	15	48	30	22	6	47	25	46	18	52	35
19B	41	11	42	11	53	14	48	12	21	3	42	8	35	10	45	6	23	2	40	9	30	9	45	10
20B	38	31	45	24	55	38	53	25	18	15	40	26	24	15	46	19	19	14	39	22	38	20	50	24
21B	33	12	47	23	44	16	49	14	17	8	42	15	22	10	45	12	17	12	44	17	26	12	46	10
22B	42	13	48	18	60	34	54	13	14	10	45	17	37	24	47	2	24	15	44	17	43	17	47	6
23B	31	12	43	28	52	23	52	38	20	11	45	22	37	14	47	30	25	10	42	25	43	15	49	25
24B	43	25	49	28	60	37	53	20	20	15	48	22	42	28	48	2	30	15	46	23	46	30	48	6
25B	51	14	50	24	60	51	50	32	20	7	43	24	55	25	45	24	29	7	46	28	58	17	46	29
26B	48	9	40	15	65	20	44	12	26	3	39	16	51	26	44	8	37	2	38	20	52	18	42	8
27B	48	38	59	24	53	42	58	9	29	24	52	20	44	38	50	6	30	30	53	20	42	34	52	9
SD	7.11	7.45	4.47	6.32	5.36	8.78	4.12	10.19	6.12	5.32	4.25	7.35	8.45	7.09	3.81	8.61	6.95	6.06	4.42	7.15	7.77	5.17	3.76	8.97

Key: A = Active
P = Passive

inv = inversion
ev = eversion
pf = plantar flexion
df = dorsiflexion

T1 = time 1
T2 = time 2
T3 = time 3
SD = standard deviation

1C = Subject 1, control group
B = Brace group
T = Tape group

Table 3 Range of Motion Data for the Tape Condition.

S	A inv T1	A ev T1	A pf T1	A df T1	P inv T1	P ev T1	P pf T1	P df T1	A inv T2	A ev T2	A pf T2	A df T2	P inv T2	P ev T2	P pf T2	P df T2	A inv T3	A ev T3	A pf T3	A df T3	P inv T3	P ev T3	P pf T3	P df T3
1T	36	15	41	15	60	26	52	14	18	10	40	15	26	21	51	15	25	15	41	18	37	24	54	16
2T	43	18	44	14	58	30	53	18	20	14	42	14	28	21	50	14	30	17	46	15	34	26	51	16
3T	51	19	52	20	62	34	56	22	19	2	41	6	50	27	52	10	33	15	45	13	57	31	53	22
4T	35	7	41	26	56	25	49	40	15	2	33	13	36	18	42	16	25	5	36	9	38	23	42	21
5T	38	8	38	23	60	18	45	23	15	0	35	10	33	15	42	15	25	4	35	14	42	18	42	20
6T	45	20	48	19	62	31	55	28	27	11	42	8	41	21	47	20	32	17	44	8	50	27	48	19
7T	45	17	42	18	56	26	52	18	29	9	45	13	29	17	46	13	44	11	43	11	47	25	47	12
8T	45	21	49	22	60	34	53	30	15	11	41	8	28	21	47	10	32	13	45	10	44	20	48	14
9T	34	7	36	34	46	19	42	34	15	0	32	20	21	9	36	23	30	0	35	25	41	13	42	29
10T	27	11	49	13	48	28	53	14	20	3	44	5	36	19	47	8	24	11	45	8	44	29	48	8
11T	37	14	46	17	50	25	51	15	25	7	41	9	30	11	43	5	26	11	42	15	36	14	44	10
12T	27	5	45	15	53	26	54	22	12	2	35	2	32	13	46	5	14	0	35	-4	32	12	45	5
13T	39	22	48	17	60	42	51	29	31	11	40	7	46	16	45	5	32	13	42	7	50	18	48	8
14T	51	16	44	46	60	22	46	46	18	11	33	15	32	14	40	8	42	7	37	33	49	12	41	39
15T	43	17	48	9	60	39	58	14	28	11	40	7	52	28	49	3	33	6	44	9	56	29	53	11
16T	44	8	49	20	61	23	54	26	15	0	39	2	43	15	47	5	24	3	43	7	53	19	49	9
17T	51	14	45	31	58	17	50	38	29	7	41	16	35	12	43	10	34	7	37	17	40	11	44	20
18T	31	12	47	26	60	30	52	32	15	2	28	20	40	29	40	24	22	2	44	19	45	20	50	25
19T	40	16	46	15	50	15	48	12	22	11	46	0	32	15	47	0	17	6	35	0	37	13	45	4
20T	40	28	46	24	55	36	52	30	19	19	34	3	40	24	44	9	26	16	37	10	45	19	46	10
21T	35	5	45	24	49	19	48	20	19	3	43	18	30	6	44	10	25	7	41	18	39	10	43	15
22T	44	27	49	15	60	38	34	18	27	24	44	12	32	22	45	5	31	22	44	12	52	27	49	10
23T	35	15	38	28	58	35	48	30	18	8	42	10	37	19	48	18	22	8	45	5	44	24	52	20
24T	45	20	45	28	60	35	52	35	27	17	38	20	43	20	45	15	32	11	39	22	57	27	46	10
25T	57	16	55	18	60	33	58	28	31	7	47	14	46	27	45	6	50	17	53	19	56	20	53	20
26T	50	9	42	17	58	27	48	22	33	8	40	11	40	20	43	13	43	22	45	14	55	30	47	16
27T	35	28	59	14	53	39	60	15	12	14	42	11	36	38	50	8	20	15	44	14	45	39	52	12
SD	7.51	6.62	5.02	7.81	4.64	7.46	5.29	9.01	6.39	6.13	4.65	5.68	7.52	6.87	3.63	6.07	8.34	6.20	4.46	7.53	7.46	7.30	3.89	7.74

Key:

A = Active	inv = inversion	T1 = time 1	1C = Subject 1, control group
P = Passive	ev = eversion	T2 = time 2	B = Brace group
	pf = plantar flexion	T3 = time 3	T = Tape group
	df = dorsiflexion	SD = standard deviation	

Table 4 Angles of Movement at Time 1 (Prior to the Application of Any Support, and Prior to the Exercise Session).

	Active Inversion	Active Eversion	Active Plantar Flexion	Active Dorsi-flexion	Passive Inversion	Passive Eversion	Passive Plantar Flexion	Passive Dorsi-flexion
Means	40.85	15.16	45.8	21.77	56.19	28.24	51.44	24.37
Control	40.93	14.93	45.85	21.56	55.48	28.78	51.44	23.96
Brace	40.56	15.19	45.74	22.7	56.3	27.33	51.26	24.22
Tape	41.07	15.37	45.82	21.04	56.78	28.59	51.63	24.93

Table 5 Angles of Movement at Time 2 (Following the Application of the Support (Except in the Control), but Prior to the Exercise Session).

	Active Inversion	Active Eversion	Active Plantar Flexion	Active Dorsi-Flexion	Passive Inversion	Passive Eversion	Passive Plantar Flexion	Passive Dorsi-Flexion
Means	27.99	11.16	43.19	16.72	42.24	21.83	47.95	16.53
Control	41.82	16.48	47.22	20.67	55.78	28.52	51.96	23.74
Brace	20.89	8.7	42.78	18.93	34.85	17.78	46.56	15
Tape	21.26	8.3	39.56	10.56	36.07	19.19	45.33	10.85

Table 6 Angles of Movement at Time 3 (Following Exercise).

	Active Inversion	Active Eversion	Active Plantar Flexion	Active Dorsi-Flexion	Passive Inversion	Passive Eversion	Passive Plantar Flexion	Passive Dorsi-Flexion
Means	32.37	12.26	43.7	17.52	47.2	23.03	49.15	20.01
Control	42.59	16.22	46.82	19.67	56.96	28.82	51.93	24.82
Brace	25.15	10.15	42.74	20	39.26	18.78	48.04	19.63
Tape	29.37	10.41	41.56	12.89	45.37	21.48	47.48	15.59

Appendix L

Raw Perceived Results Data

Perceived Comfort and Stability Raw Data Scores

S1	Point Value			S2	Point Value			S3	Point Value			S4	Point Value			S5	Point Value		
Statement	C	B	T	Statement	C	B	T	Statement	C	B	T	Statement	C	B	T	Statement	C	B	T
1	1	2	5	1	1	2	5	1	1	1	2	1	1	2	2	1	1	1	2
2	1	2	2	2	1	2	1	2	1	1	2	2	1	2	1	2	1	1	3
3	1	2	2	3	1	2	1	3	1	1	2	3	1	2	2	3	1	1	3
4	1	2	2	4	1	2	1	4	1	1	2	4	1	2	2	4	1	1	5
5a	1	2	3	5a	1	1	2	5a	1	1	2	5a	1	2	2	5a	1	1	2
5b	1	2	3	5b	1	1	2	5b	1	1	2	5b	1	2	4	5b	1	1	2
5c	1	4	4	5c	1	3	3	5c	1	1	2	5c	1	2	2	5c	1	1	2
5d	1	2	3	5d	1	3	2	5d	1	1	2	5d	1	2	2	5d	1	1	2
5e	1	3	3	5e	1	2	2	5e	1	1	2	5e	1	2	2	5e	1	1	2
5f	1	3	3	5f	1	3	2	5f	1	1	2	5f	1	2	2	5f	1	1	2
6	2	2	1	6	4	2	1	6	1	2	1	6	1	2	1	6	1	1	1
7	4	2	1	7	4	2	2	7	1	2	1	7	1	2	1	7	1	1	1
8	1	2	4	8	4	2	4	8	1	2	2	8	1	2	2	8	1	1	2
9a	4	1	2	9a	5	2	2	9a	1	2	2	9a	1	1	2	9a	1	1	1
9b	4	1	2	9b	5	1	2	9b	1	2	2	9b	1	1	2	9b	1	1	1
9c	5	2	1	9c	4	1	2	9c	1	2	2	9c	1	2	2	9c	1	1	1
9d	4	1	2	9d	5	1	2	9d	1	2	2	9d	1	1	2	9d	1	1	1
9e	4	1	2	9e	5	1	2	9e	1	2	2	9e	1	1	2	9e	1	1	1
9f	4	1	2	9f	5	2	2	9f	1	2	2	9f	1	1	2	9f	1	1	1
10	3	2	2	10	5	2	2	10	1	1	2	10	5	1	1	10	1	2	3
11	1	1	1	11	3	1	1	11	1	1	1	11	1	2	2	11	3	2	3
Total	46	40	50	Total	59	38	43	Total	21	30	39	Total	25	36	40	Total	23	23	41
avg C	29			avg 1C	1			avg 2C	1			avg 3C	1.1			avg 4C	1.1		
avg B	38			avg 1B	1.5			avg 2B	1.9			avg 3B	1.9			avg 4B	2.1		
avg T	41			avg 1T	2.5			avg 2T	2.3			avg 3T	2.8			avg 4T	2.8		
avg 11C	1.4			avg 12C	1.6			avg 13C	1.4			avg 14C	1.4			avg 15C	1.4		
avg 11B	1.6			avg 12B	1.6			avg 13B	1.7			avg 14B	1.5			avg 15B	1.4		
avg 11T	2.4			avg 12T	1.4			avg 13T	2.1			avg 14T	1.4			avg 15T	1.4		

Perceived Comfort and Stability Raw Data Scores

S6	Point Value			S7	Point Value			S8	Point Value			S9	Point Value			S10	Point Value		
Statement	C	B	T	Statement	C	B	T	Statement	C	B	T	Statement	C	B	T	Question	C	B	T
1	1	1	4	1	1	1	4	1	1	2	2	1	1	2	2	1	1	2	2
2	1	2	1	2	1	1	1	2	1	2	2	2	1	4	4	2	1	3	4
3	1	1	4	3	1	1	1	3	1	1	4	3	1	3	2	3	1	2	2
4	1	4	4	4	1	1	1	4	1	2	2	4	1	2	2	4	1	2	2
5a	1	1	4	5a	1	1	1	5a	1	1	4	5a	1	4	2	5	1	4	2
5b	1	1	4	5b	1	1	1	5b	1	1	4	5b	1	4	2	6	1	2	2
5c	1	1	4	5c	1	1	1	5c	1	1	2	5c	1	3	2	7	1	2	2
5d	1	1	4	5d	1	1	1	5d	1	1	2	5d	1	3	2	8	1	2	2
5e	1	1	4	5e	1	1	1	5e	1	1	4	5e	1	4	2	9	1	2	4
5f	1	1	4	5f	1	1	1	5f	1	1	4	5f	1	3	2	10	1	2	2
6	1	1	1	6	1	1	1	6	2	2	2	6	2	2	2	11	1	2	2
7	1	1	1	7	2	1	1	7	2	2	2	7	2	2	2	12	1	2	2
8	1	1	2	8	1	1	2	8	2	2	4	8	2	2	2	13	1	2	4
9a	1	1	1	9a	1	1	1	9a	1	1	2	9a	1	4	2	14	1	2	2
9b	1	1	1	9b	2	1	1	9b	1	1	2	9b	1	4	2	15	1	2	2
9c	1	1	2	9c	3	1	1	9c	1	1	2	9c	1	4	2	16	1	2	2
9d	1	1	1	9d	1	1	1	9d	1	1	2	9d	1	4	2	17	1	2	2
9e	1	1	1	9e	2	1	1	9e	1	1	2	9e	1	4	2	18	1	2	2
9f	1	1	1	9f	3	1	1	9f	1	1	2	9f	1	4	2	19	1	2	2
10	1	1	1	10	5	1	1	10	1	3	3	10	3	4	2	20	1	2	2
11	1	1	1	11	2	1	1	11	1	1	2	11	1	4	2	21	1	1	1
Total	21	25	50	Total	33	21	25	Total	24	29	55	Total	26	70	44	Total	21	44	47
avg 5C	1.1			avg 6C	1.1			avg 7C	1.2			avg 8C	1.1			avg 9C	1.1		
avg 5B	2			avg 6B	2			avg 7B	2.3			avg 8B	2.1			avg 9B	2		
avg 5T	2.3			avg 6T	2.4			avg 7T	2.5			avg 8T	2.3			avg 9T	2.1		
avg 16C	1.7			avg 17C	1.4			avg 18C	1.4			avg 19C	1.4			avg 20C	2.9		
avg 16B	1.7			avg 17B	1.4			avg 18B	1.5			avg 19B	1.6			avg 20B	2.1		
avg 16T	1.4			avg 17T	1.4			avg 18T	1.4			avg 19T	1.4			avg 20T	1.9		

Perceived Comfort and Stability Raw Data Scores

S11	Point Value			S12	Point Value			S13	Point Value			S14	Point Value			S15	Point Value		
Statement	C	B	T	Statement	C	B	T	Statement	C	B	T	Statement	C	B	T	Statement	C	B	T
1	1	2	2	1	1	1	1	1	1	2	1	1	1	1	3	1	1	1	2
2	1	2	2	2	1	2	2	2	1	2	4	2	1	1	4	2	1	1	1
3	1	2	2	3	1	1	2	3	1	3	4	3	2	3	4	3	1	2	5
4	1	4	2	4	1	1	4	4	1	2	4	4	2	4	3	4	1	4	4
5a	1	2	1	5a	1	1	1	5a	2	2	4	5a	2	4	4	5a	1	4	5
5b	1	2	1	5b	1	1	1	5b	2	4	4	5b	2	4	2	5b	1	4	5
5c	1	2	1	5c	1	1	1	5c	2	4	4	5c	2	4	2	5c	1	4	5
5d	1	4	1	5d	1	1	4	5d	2	2	4	5d	2	4	2	5d	1	4	4
5e	1	2	1	5e	1	1	1	5e	2	2	2	5e	2	4	2	5e	1	4	4
5f	1	2	1	5f	1	1	1	5f	2	2	2	5f	2	4	2	5f	1	4	4
6	1	2	1	6	1	2	1	6	2	2	2	6	2	2	2	6	1	1	1
7	1	2	1	7	1	2	1	7	2	2	2	7	2	2	2	7	1	1	1
8	1	2	1	8	1	3	1	8	2	2	2	8	2	2	2	8	1	1	1
9a	1	1	1	9a	1	1	1	9a	2	2	2	9a	2	3	2	9a	1	1	1
9b	1	1	1	9b	1	1	1	9b	2	2	2	9b	2	3	2	9b	1	1	1
9c	1	1	1	9c	1	1	1	9c	2	2	2	9c	2	3	2	9c	1	1	1
9d	1	1	1	9d	1	1	1	9d	2	2	2	9d	2	3	2	9d	1	1	1
9e	1	1	1	9e	1	1	1	9e	2	2	2	9e	2	3	2	9e	1	1	1
9f	1	1	1	9f	1	1	1	9f	2	2	2	9f	2	3	2	9f	1	1	1
10	5	5	1	10	1	2	1	10	2	2	3	10	2	2	4	10	1	1	2
11	1	5	1	11	1	2	1	11	1	1	1	11	2	2	4	11	1	1	1
Total	25	46	25	Total	21	28	29	Total	37	46	55	Total	40	61	54	Total	21	43	51
avg 10C	1.1																		
avg 10B	2.1																		
avg 10T	2																		
avg 21C	1.7																		
avg 21B	2																		
avg 21T	1.6																		

Perceived Comfort and Stability Raw Data Scores

S16	Point Value			S17	Point Value			S18	Point Value			S19	Point Value			S20	Point Value		
Statement	C	B	T	Statement	C	B	T	Statement	C	B	T	Statement	C	B	T	Statement	C	B	T
1	1	1	1	1	1	1	5	1	1	2	2	1	1	1	2	1	1	2	2
2	1	1	2	2	2	2	3	2	1	2	2	2	1	4	2	2	1	2	2
3	1	1	2	3	2	2	4	3	2	2	1	3	1	4	4	3	1	2	3
4	1	1	2	4	1	1	5	4	2	4	1	4	1	4	4	4	1	3	4
5a	1	1	1	5a	1	1	3	5a	1	2	1	5a	1	4	4	5a	1	3	1
5b	1	1	1	5b	1	1	3	5b	1	2	1	5b	1	4	4	5b	1	2	1
5c	1	1	2	5c	2	1	4	5c	2	4	1	5c	1	4	4	5c	2	1	3
5d	1	1	1	5d	1	1	4	5d	1	2	1	5d	1	4	4	5d	1	2	2
5e	1	1	1	5e	1	1	3	5e	1	2	1	5e	1	3	4	5e	1	2	2
5f	1	1	1	5f	1	1	3	5f	1	2	1	5f	1	4	4	5f	1	2	2
6	1	1	1	6	1	1	1	6	1	2	2	6	1	1	1	6	1	1	1
7	1	1	1	7	2	1	1	7	2	2	1	7	1	1	1	7	1	1	1
8	1	1	2	8	2	1	2	8	2	2	1	8	1	1	1	8	1	1	1
9a	1	1	1	9a	1	1	1	9a	1	1	1	9a	1	1	2	9a	1	2	1
9b	1	1	1	9b	1	1	1	9b	1	1	1	9b	1	1	2	9b	1	1	1
9c	1	1	1	9c	2	1	1	9c	1	1	1	9c	1	1	2	9c	2	1	2
9d	1	1	1	9d	1	1	1	9d	3	1	1	9d	1	1	2	9d	1	2	1
9e	1	1	1	9e	1	1	1	9e	1	1	1	9e	1	1	2	9e	1	2	1
9f	1	1	1	9f	1	1	1	9f	1	1	1	9f	1	1	2	9f	1	2	1
10	5	1	1	10	1	3	4	10	5	4	1	10	1	2	2	10	1	2	1
11	3	1	1	11	5	2	3	11	3	3	1	11	1	2	2	11	1	2	1
Total	27	21	26	Total	31	26	54	Total	34	43	24	Total	21	49	55	Total	23	38	34

Perceived Comfort and Stability Raw Data Scores

S21	Point Value			S22	Point Value			S23	Point Value			S24	Point Value			S25	Point Value		
Statement	C	B	T	Statement	C	B	T	Statement	C	B	T	Statement	C	B	T	Statement	C	B	T
1	1	1	1	1	1	2	2	1	1	1	4	1	1	2	4	1	1	2	2
2	1	2	1	2	1	1	5	2	1	4	4	2	1	2	3	2	1	2	2
3	1	3	2	3	1	1	3	3	1	2	5	3	1	2	4	3	1	2	2
4	2	2	1	4	1	1	2	4	1	2	5	4	1	2	1	4	1	2	2
5a	1	4	2	5a	1	1	1	5a	1	2	4	5a	1	2	1	5a	1	2	1
5b	1	4	2	5b	1	1	1	5b	1	2	4	5b	1	2	4	5b	1	2	1
5c	1	4	3	5c	1	4	2	5c	1	2	5	5c	1	4	4	5c	1	2	1
5d	1	4	3	5d	1	3	1	5d	1	2	4	5d	1	2	1	5d	1	2	2
5e	1	4	1	5e	1	1	1	5e	1	2	4	5e	1	3	1	5e	1	2	1
5f	1	4	1	5f	1	1	1	5f	1	2	4	5f	1	4	1	5f	1	2	1
6	1	2	1	6	1	1	1	6	2	1	2	6	1	2	2	6	2	2	2
7	3	2	1	7	1	1	2	7	2	2	2	7	1	2	2	7	2	2	1
8	2	2	1	8	1	1	2	8	2	2	2	8	1	2	2	8	2	2	2
9a	1	1	1	9a	2	1	1	9a	1	2	1	9a	1	1	1	9a	2	2	1
9b	1	1	1	9b	2	1	1	9b	1	2	1	9b	1	1	1	9b	2	2	1
9c	5	4	1	9c	2	1	1	9c	1	2	1	9c	1	1	1	9c	2	2	1
9d	1	1	1	9d	1	1	1	9d	1	2	1	9d	1	1	1	9d	2	2	1
9e	1	1	1	9e	2	1	1	9e	1	2	1	9e	1	1	1	9e	2	2	1
9f	1	1	1	9f	1	1	1	9f	1	2	1	9f	1	1	1	9f	2	2	1
10	3	4	1	10	5	1	2	10	4	1	2	10	1	2	2	10	5	2	1
11	1	4	1	11	5	1	1	11	2	1	2	11	1	2	2	11	1	2	1
Total	31	55	28	Total	33	27	33	Total	28	40	59	Total	21	41	40	Total	34	42	28

Perceived Comfort and Stability Raw Data Scores

S26	Point Value			S27	Point Value		
Statement	C	B	T	Statement	C	B	T
1	1	1	1	1	1	1	2
2	1	1	1	2	1	1	2
3	1	1	3	3	1	1	4
4	1	1	4	4	1	1	5
5a	1	1	2	5a	1	1	1
5b	1	1	3	5b	1	1	1
5c	1	1	1	5c	1	1	2
5d	1	1	1	5d	1	1	1
5e	1	1	1	5e	1	1	1
5f	1	1	1	5f	1	1	1
6	1	1	1	6	1	2	2
7	1	1	3	7	1	2	2
8	1	1	1	8	1	2	4
9a	1	1	1	9a	1	2	2
9b	1	1	1	9b	1	2	2
9c	1	1	1	9c	1	4	2
9d	1	1	1	9d	1	2	2
9e	1	1	1	9e	1	4	2
9f	1	1	1	9f	1	4	2
10	5	1	1	10	5	4	4
11	1	1	1	11	1	3	4
Total	25	21	31	Total	25	41	48

IMAGE EVALUATION TEST TARGET (QA-3)

150mm

6"

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