Using the Star Excursion Balance test as a predictor of lower extremity injury among high school basketball athletes

Brian D. Nelson

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Entitled

Using the Star Excursion Balance Test as a Predictor of Lower Extremity Injury Among

High School Basketball Athletes

by

Brian D. Nelson

Submitted to the Graduate Faculty as partial fulfillment of the requirements for the

Master of Science in Exercise Science Degree.

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May 2012
An Abstract of
Using the Star Excursion Balance Test as a Predictor of Lower Extremity Injury Among High School Basketball Athletes

by

Brian D. Nelson

Submitted to the Graduate Faculty as partial fulfillment of the requirements for the Master of Science in Exercise Science Degree

The University of Toledo

May 2012

Background: In the current literature, there is limited information to establish a reliable, cost-effective tool for preseason screening for predicting injury to the lower extremity with high success. The Star Excursion Balance Test (SEBT) has been employed for injury prediction of high school basketball players, but the reported outcomes did not fully consider normalizing procedures and mostly focused on injuries among female players. Purpose: To determine the usefulness of the SEBT as a predictor of lower extremity injury in high school basketball players and to identify a normalized cut-off score that would imply injury risk to individuals who scored below it. Design: Prospective cohort. Subjects: One hundred seventy (170) high school basketball athletes were recruited from Toledo, OH area high schools during both the 2009-2010 and 2011-2012 basketball seasons (age: 15.74 yrs± 1.11, height: 175.08 cm± 8.43, mass: 70.02 kg± 12.01) Methodology: All subjects were tested on the SEBT before their competitive basketball season began. Subjects were tested in three reach directions (anterior,
posteriormedial, and posteriorlateral) and the scores were normalized (to leg length) for each reach direction and compiled to generate a normalized composite score. Subjects were then followed throughout the course of their competitive season while all traumatic ankle and knee injuries were recorded by a Certified Athletic Trainer. Independent t-tests were used to determine statistical differences between groups. A receiver operator characteristic curve was used to obtain a cut-off score for each of the four SEBT measures that maximized sensitivity and specificity. From these calculations, likelihood ratios, odds ratios, and effect sizes were obtained. Statistical significance was set a priori at 0.05. **Results:** For the SEBT composite, there was no statistical significance between subjects who did and did not suffer a lower extremity injury (t=0.728, p=0.468). The ROC Cut-off score with the composite was 72.36% of leg length, associated with a sensitivity of 0.58, a specificity of 0.55, and an Odds Ratio (OR) of 1.7. For the anterior reach direction of the SEBT, there was no statistical significance between subjects who did and did not suffer a lower extremity injury (t=0.257, p=0.797). The ROC Cut-off score of 66.98% of leg length was associated with a sensitivity of 0.42, a specificity of 0.62, and an OR of 1.17. For the posteriormedial reach direction of the SEBT, there was no statistical significance between subjects who did and did not suffer a lower extremity injury (t=0.317, p=0.751). The ROC Cut-off score of 78.64% of leg length was associated with a sensitivity of 0.55, a specificity of 0.53, and an OR of 1.37. For the posteriorlateral reach direction of the SEBT, there was no statistical significance between subjects who did and did not suffer a lower extremity injury (t=0.053, p=0.958). The ROC Cut-off score of 67.45% of leg length was associated with a sensitivity of 0.42, a specificity of 0.60, and an OR of 1.08. **Conclusions:** In this study, the SEBT
demonstrated little ability to predict injury with any accuracy among high school basketball athletes as demonstrated by the data. This finding is in direct contrast with previous studies, suggesting the need for future studies perhaps with a larger sample size.
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Chapter One

Introduction

Recent research has investigated numerous screening and intervention protocols designed to prevent athletic injury to the lower extremity\textsuperscript{1-10}; however, accomplishing the prophylactic goal is something else entirely. In the field of athletic training, the ability to screen out and prescribe a prophylactic exercise intervention to individual athletes who are at an increased risk for injury would provide tremendous benefit to the athlete and potentially give an athletic team a significant advantage over the competition throughout the course of the season. If injuries do not occur due to the implementation of preventative exercise protocols, then time is not lost from competition, the athlete’s level of fitness does not decline, and the athlete remains in the game. However, before an exercise protocol can be established, a screening mechanism should be instituted prior to the beginning of a sports season in order to determine who needs such an intervention, and to what degree. This screening mechanism should not only be easily accessible, reliable, and valid, but should also have the ability to identify and predict imminent injury risk.
Acute lower extremity injuries in sport occur when the forces acting on a structure are greater than the body’s internal ability to overcome those forces\textsuperscript{11}. When traumatic injury occurs within a lower extremity structure, some of the immediate consequences include decreases in balance, range of motion of the affected area, and strength of the musculature surrounding the joint, in addition to other detrimental changes\textsuperscript{12}. These changes are not only present immediately after an injury is suffered, but bilateral deficits can be seen up to eighteen months post-injury\textsuperscript{13,14}. Therefore, when an individual returns to athletic competition, especially when adequate rehabilitation protocols have not been performed, he or she is at increased risk for further injury due to decreased performance of paramount lower extremity structures. The same increased risk for injury is present among those with bilateral deficits even before an injury has occurred. It has been established in the current literature that history of previous injury predisposes an individual to future injury\textsuperscript{15-18}. However, what has not been investigated fully is the problem of identifying an athlete as having an increased injury risk before they ever suffer an injurious event.

In the field of sports medicine, there are essentially two types of injuries: acute and chronic. Risk factors for chronic injuries are readily able to be identified and can be recognized days if not weeks before pain is experienced. Sports medicine professionals understand these risk factors, such as previous medical history of chronic injury, change of activity level, surface, footwear, and others\textsuperscript{12}. Also, chronic injury has been found to have a long onset period, allowing for the prevention of worsening symptoms even after the injury has begun to occur. The prevention of chronic injuries has already been
documented in textbooks; however, what is less understood is how clinicians can prevent acute injuries.

Most sports medicine clinicians understand that proper strength, range of motion, and conditioning level are important attributes for the potential prevention of acute injury. However, even the best conditioned, most flexible, and strongest professional athletes are injured from time to time. Some studies suggest this is simply because they are exposed to greater forces for a longer duration than their lesser skilled teammates. However, many others recognize the existence of a common link (ie. deficits in balance, proprioception, neuromuscular control, etc) among all lower extremity injury. The identification of that common risk factor link has been the focus of current literature for many years.

In general, risk factors are divided into two categories: intrinsic and extrinsic. Extrinsic risk factors are those outside the body and are difficult to control for, such as the speed and overall force of a hit an opposing player delivers in athletic situations, type of surface being played on, and suitability of athletic equipment. On the other hand, intrinsic risk factors for lower extremity injury can be controllable with the right knowledge. Intrinsic risk factors are those inside the body such as anthropometric data like height, weight, and BMI, along with measurements such as flexibility, strength, balance, and neuromuscular control. Current literature is riddled with interventions designed to improve these measures of intrinsic risk factors. However, what has been less researched is the means by which an intrinsic risk factor is detected either when compared to others or compared bilaterally (side to side deficit).
Simple measures of anthropometric data are easy to obtain, but they do not necessarily provide adequate information for the development of effective injury prediction models. Static balance deficits have been observed to be associated with increased ankle injury risk\textsuperscript{18,23}, but often these assessments may require expensive equipment and experienced personnel, also they may not equate with dynamic movements seen in athletic participation. In a study by McGuine et al\textsuperscript{23} it was found that high school athletes who have higher levels of postural sway during a single-limb balance testing on a force plate have increased incidence of ankle sprains. They have therefore concluded that decreased levels of static balance in athletes lead to a higher risk of injury to the lower extremity. This study demonstrates to clinicians that deficits in static balance can be used to predict injury risk. The problem with this study is that it is difficult to reproduce due to high associated costs (force plate) and it is simply a static measure of postural control, not a dynamic movement.

The Star Excursion Balance Test (SEBT) is a reliable and valid test of dynamic postural control, or ones ability to balance their center of gravity over their base of support while performing some dynamic movement task\textsuperscript{25,26}. The SEBT is a very portable, easy to use, and objective test that has been shown to be sensitive to changes in dynamic postural control as caused by chronic ankle instability or other factors\textsuperscript{26-29}.

In 2006, Plisky et al\textsuperscript{29} used the SEBT to predict lower extremity injury in high school basketball players. This study tested 235 athletes on the SEBT before the season began and then followed and tracked injuries and exposure data as the season progressed. They found that a bilateral anterior reach deficit of over 4 cm created an injury risk 2.5 times more than those without a deficit\textsuperscript{29}. Also observed was that females who could not
achieve a composite score of 94% of their leg length were 6.5 times more likely to suffer an injury to the lower extremity. Further, the authors suggested that the SEBT should be incorporated into pre-participation physicals in order to screen out those most likely to sustain an injury. Prophylactic interventions can then be undertaken to prevent injury from occurring. With this study, Plisky et al established the predictive value of the SEBT; however, they failed to establish a composite cut-off score for male high school basketball players and they failed to account for contact vs. non-contact injury. The SEBT may be a reliable measure of lower extremity injury risk (although this result has not been confirmed by multiple studies), but it’s injury prediction capabilities are most likely limited to non-contact injuries caused by intrinsic risk factors, as opposed to contact injuries derived from extrinsic risk factors.

1.1 Statement of Problem

There is limited information in the current scientific literature establishing a reliable, cost-effective preseason screening tool for predicting injury to the lower extremity with high success. The SEBT has been employed for injury prediction of high school basketball players, but the reported outcomes did not fully consider normalizing procedures and mostly focused on injuries among female players.

1.2 Statement of Purpose

Therefore, the purpose of this study is to determine the effectiveness of the SEBT as a predictor of lower extremity injury in high school basketball players and to identify a
SEBT normalized cut-off score that would imply injury risk to individuals who scored below it.

1.3 Significance of the Study

The outcomes of this study are significant as it may support or refute the SEBT as a reliable and accurate predictor of lower extremity injury among high school basketball athletes. Predicting injury is important not only for the short-term or within a single season, but also in the long-term. Many individuals who suffer an acute lower extremity injury report continuing symptoms, diminished physical activity, and a lower quality of life as compared with healthy individuals. By preventing injury among young high school athletes, clinicians can prevent a lifetime of inactivity, obesity, and pain.

1.4 Hypotheses

H1: High school basketball athletes who experience an acute lower extremity injury to the ankle or knee during the competition season will demonstrate lower normalized reach distances on the SEBT during pre-season assessments compared with the athletes who do not experience a lower extremity injury.

H2: There will be a predictive normalized score on the SEBT that will produce sensitivity and specificity scores above 0.70 for the prediction of athletes with or without lower extremity injuries in high school basketball players.
H3: The normalized SEBT scores during the pre-season of those that suffer ankle injuries during the regular season participation will be lower than those that suffer knee injuries and the non-injured group.

H4: The normalized SEBT scores during the pre-season of those that suffer non-contact lower extremity injuries throughout the regular season participation will be lower than athletes that suffer contact injuries and the non-injured group.
Chapter Two

Literature Review

2.1 Introduction

Lower extremity injuries are very prevalent in modern sport at all levels. While injuries can range drastically in severity, the simple ankle sprain is one of the most common and most devastating injuries in athletics, accounting for fifteen percent of all injuries in organized sport and accounting for healthcare costs of up to two billion dollars annually\textsuperscript{13,18,31-33}. In a classic study of injury incidence performed by Gomez et al\textsuperscript{34}, it was found that as much as thirty eight percent of all male high school basketball players will suffer an ankle sprain of some kind during any given season. Also, it has been reported that once an athlete suffers an ankle sprain, the risk of recurrence is as high as seventy and eighty percent\textsuperscript{13,35}. The primary reason behind the high recurrence rate is the fact that the ankle has been found to have reflexive proprioception deficits after a traumatic ligamentous injury\textsuperscript{13}. Proprioception, or the sense of body position in space, is needed to maintain dynamic postural control and stability during sport situations. A ligamentous injury then reduces proprioception, which in turn leads to an increased risk for more injury, and the cycle continues.
Considering these abnormally high injury and recurrence rates to the lower extremity in sport situations, it is easy to understand why many athletes and athletic trainers spend extraordinary amounts of money, time, and other resources in order to prevent ankle sprains and other lower extremity injuries. While these injuries may not be life threatening, individuals who suffer an ankle sprain or another lower extremity ligamentous injury commonly report continuing symptoms, diminished physical activity, and a lower quality of life as compared with healthy individuals as chronic pain can lead to osteoarthritis in the ankle in up to twenty percent of these cases\textsuperscript{30,36}. Athletic trainers and other rehabilitative specialists are taught early on to prevent injury by establishing adequate strength, range of motion, and muscular endurance within a targeted body segment. Also, traditional prophylactic bracing mechanisms have been proven as effective in the prevention of acute ligamentous injury\textsuperscript{31}. However, recent research suggests that balance training to improve neuromuscular mechanisms can not only reduce the risk of injury in the lower extremity, but can also reduce the severity of injuries that still occur\textsuperscript{2,5,7-10,30,37,38}. Still other research has identified that dynamic stability ultimately comes from the core musculature of the body; only by targeting and strengthening the core (hip) musculature can a clinician observe an increase in dynamic postural control and an associated decrease in injury incidence to the lower extremity\textsuperscript{3,4}. The optimal strategy to be used in order to prevent acute injuries from occurring in the lower extremity is most likely a combination of each of these proven methods, however, a “gold standard” of lower extremity injury prevention protocols is yet to be established.

In the past, dynamic postural control, or the ability to maintain balance under some dynamic force, has typically been measured through the use of a force plate\textsuperscript{39}. A
force plate measures an individual's Center of Pressure (COP) and can track the movement, or excursion of this COP to determine dynamic stability and postural control. Other devices such as the NeuroCom Balance System (NeuroCom Inc- Clackamas, OR) and the Kinesthetic Ability Trainer (SportKAT LLC- Vista, CA) can also objectify balance ability while adding a dynamic component. While these devices have their merit in the laboratory, their lack of portability and excessive associated cost make them next to obsolete in the field, especially in the levels of sport where funds are limited (i.e. high schools). Therefore, other low-cost and efficient tests have been designed in recent years to determine balance and/or stability of an individual. For example, the Balance Error Scoring System is a simple objective test of static postural control which essentially tabulates the number of corrections an individual makes from a given single limb stance and uses this data to make determinations about postural control. Other tests are even simpler in design only involving the basic measure of time maintained in a single limb stance, for example. Each of these low-cost objective tests are appropriate in the measure of static balance but do not objectively measure dynamic stability and dynamic postural control which is needed in most all sport situations.

In a study by McGuine et al, it was found that higher levels of postural sway and therefore decreased levels of stability in high school athletes as measured on a force plate led to an increase in the incidence of ankle sprains. Therefore, decreased levels of proprioception and dynamic postural control in athletes lead to a higher risk of injury to the lower extremity. Moreover, the direct correlation between decreased balance ability and increased risk for injury appears to be more prevalent in men than in women. To further understand this statement, one must be aware of not only the definition of terms
such as „proprioception” and „dynamic postural control”, but should also be aware of the definition of the injury itself. The ankle sprain was defined within this study to be, “trauma that disrupts the structures of the ankle that occurs during a team-sponsored practice or competition session, and causes the athlete to miss the rest of practice or competition or miss the next scheduled team practice or competition.” Going further, the authors then classified these ankle sprains in terms of severity by the number of days the athlete missed due to the injury. While no correlation was reported between increased levels of postural sway and increased severity of injury, decreased balance ability was directly correlated to injury incidence (p=.001).

McGuine et al. also noted in the study that they were not the first to attempt to identify a link between balance and injury incidence. In an initial study, Tropp et al. found that soccer players with poor balance ability had four times the number of ankle injuries than players with normal balance as measured by a static force plate trial. Knowing that decreased levels of balance and dynamic postural control increase the risk for injury incidence in high school athletes, clinicians directly involved with athletes at this level should begin to screen out those most at risk for lower extremity injury by employing a low-cost, simple to perform, efficient, yet effective test.

2.2 The Star Excursion Balance Test

The Star Excursion Balance Test (SEBT) was first introduced by Gray in 1995. Essentially, this test is a series of eight unilateral balance tests designed to objectively determine dynamic postural control through low-cost and efficient means. In terms of materials needed, this test requires nothing more than athletic tape applied over a flat
surface. The tape should be positioned so that there are precisely eight straight rays all originating from one central point on the floor placed at even intervals of 45 degrees from each other. The evaluator can then use this set-up to determine the dynamic postural control of any given individual. Simply instruct the individual to stand with a single leg base of support over the central point. Then, after randomly selecting a direction, ask the athlete being tested to reach with the contralateral leg and make a light touch with his or her toes as far out on the tape as possible, then the athlete should return to an upright position. The evaluator should mark this point of touch on the tape and measure the distance to collect objective data; repeat these steps for the other seven directions. At no point during the reach should the individual being tested lose balance over the stance leg or reach out to gather himself/herself in any capacity; if balance is lost, the trial must be discarded and repeated\textsuperscript{39}. Typically, three trials are performed in each direction (after the completion of four practice trials) so that a mean value can be calculated\textsuperscript{39}. The greater the reach distance, the greater dynamic stability an individual has. While a cut-off score for adequate dynamic postural control in terms of distance reached has not yet been determined for the SEBT, we can still use the test to analyze individual improvements in dynamic stability and for comparison across populations with great accuracy\textsuperscript{25}.

In a study by Hertel et al\textsuperscript{25} the SEBT was examined in terms of its intertester and intratester reliability. The authors of this study took sixteen healthy subjects and had each of them perform the SEBT in all eight directions multiple times (once for each evaluator or tester) over the course of two days. The results of this simple study showed that while intratester variance was less than intertester variance, overall, the SEBT has proven itself to be very reliable and valid from tester to tester and from day to day
(Intratester ICC .78-.96, Intertester ICC .35-.93)\textsuperscript{25}. The reliability of this test is primarily due to the simple nature of its design. With limited training and practice, an individual can accurately use the SEBT to objectively measure dynamic stability and balance. Therefore, the SEBT can be identified as a simple yet effective test with minimal set-up or associated costs that can be performed with limited knowledge and skill. In short, the SEBT is an ideal objective measure of dynamic stability for the high school setting and can be used as a measurement tool to identify decreased dynamic postural control and thereby prevent lower extremity injury through preventative interventions.

Other studies have been performed in recent years which have aimed to improve upon the existing SEBT. Gribble and Hertel\textsuperscript{27} published a study in 2003 which suggested that measures on the SEBT should be normalized to leg length in order to create a more accurate comparison among subjects of different heights. Before this study was performed, men were consistently found to perform better on the SEBT than women\textsuperscript{27}. After further analysis, it was found that neither hip flexion nor dorsiflexion range of motion influenced the results of the test as much as leg length\textsuperscript{39}. Therefore, normalizing SEBT reach distances to leg length can create a more accurate depiction of dynamic postural control.

The SEBT has also been noted to have a significant learning effect\textsuperscript{25}. As more trials are completed, the subject becomes more aware of how to achieve further reach distances. Therefore, in 2009 Robinson and Gribble\textsuperscript{42} suggested that four practice trials are allotted to each subject per reach direction on the SEBT in order to allow the learning to take place. Four practice trials per reach direction is a reduction from the original six trials previously suggested, however, four trials has nonetheless been proven to counter
the learning effect on the SEBT and allow for accurate measures of dynamic postural control.

In 2006, Hertel et al\textsuperscript{43} produced a study which analyzed the Star Excursion Balance Test and designed an experiment which aimed to reduce the number of reach directions from the traditional eight without compromising the integrity of the test in its assessment of dynamic postural control. Other studies found that hip and knee flexion accounted for 62\% to 95\% of the variance between normalized reach distances and from this data determined that the eight reaches of the SEBT created measurement redundancy\textsuperscript{44}. This research ultimately led to the conclusion that the eight reach directions of the SEBT could be reduced to three: Anterior, Posteriorlateral, and Posterioirmedial\textsuperscript{43}. A recent study by Earl and Hertel\textsuperscript{45} found that each of these three directions has a different muscular activation pattern, proving that the revised version of the SEBT allows for more efficient testing sessions without any reduction in the effectiveness of the test in determining dynamic postural control. Also contained in this study is the suggestion of further uses for the SEBT beyond a screening tool. Earl and Hertel recommend the use of the posterior directions of the SEBT in early rehabilitation of ACL injuries, progressing towards the more eccentrically demanding (on the quadriceps and hamstrings) lateral and anterior directions\textsuperscript{45}. The SEBT is useful and effective in many respects, but how can it be adapted to the clinical setting?

A recent study performed by Pollock et al\textsuperscript{28} attempted to use the Star Excursion Balance Test with only three reach directions to predict lower extremity injury in high school football players. This prospective cohort study tested each of the 97 participants on the SEBT (three directions) before the season began and then monitored these athletes
throughout the season and recorded all lower extremity injuries to the knee or ankle. The results of this study were somewhat surprising as there existed significant differences (p<.05) in normalized reach distances for both the anterior and composite scores from the injured to the uninjured group. These results demonstrate that high school football players who suffered a traumatic knee or ankle injury during the season presented with decreased dynamic postural control before the season began. The implications of these findings are monumental as clinicians may now view the Star Excursion Balance Test as a predictive tool and a gauge of determining which athletes need preseason postural control interventions in order to prevent injury. However, the research is still in need of a cut-off score for the SEBT. In other words, the current literature has yet to determine a level at which we can say with great confidence that an individual is at high risk for an ankle sprain. Future research should look to identify a cut-off score (normalized to leg-length) so that clinicians can accurately use the SEBT to predict and thereby prevent lower extremity injury.

A 2006 study by Plisky et al used the SEBT to predict injury in high school basketball players. This study tested 235 athletes on the SEBT before the season began and then followed and tracked injury/exposure data as the season progressed. They determined that a bilateral anterior reach deficit of over 4 cm created an injury risk 2.5 times more than those without a deficit. Also observed was that girls who could not achieve a composite score of 94% of their leg length were 6.5 times more likely to suffer an injury to the lower extremity. Plisky goes on to suggest that the SEBT should be incorporated into pre-participation physicals in order to screen out those most likely to sustain an injury. Prophylactic interventions can then be undertaken to prevent injury.
from occurring. This study suggests that future studies should examine which anatomical and biomechanical factors most influence the SEBT reach distance\(^2^9\). In all, Plisky et al present a well-performed cohort study which establishes the predictive value of the SEBT yet fails to fully consider normalizing procedures.

The SEBT is not only reliable and valid as a screening tool, but it has also proven itself as sensitive in nature for detecting changes in dynamic postural control. Likewise, the SEBT has been proven to accurately reflect levels of fatigue, chronic ankle instability (CAI), as well as anterior cruciate ligament reconstruction\(^3\). Many studies have used the SEBT to first screen subjects and then attempt to improve their dynamic balance through an intervention\(^3-5,7,37\). This is because the SEBT is able to reflect improvements in dynamic stability through increased reach distances. A recent study by Gribble et al\(^4^6\) found that CAI influenced hip and knee sagittal plane movement during the SEBT, and this movement was worsened with fatigue. This research further proves the sensitivity of the SEBT to detect the slightest changes in dynamic postural control.

A clinician using the SEBT should be aware of any and all influences on dynamic stability. Subjects being tested should never wear shoes or joint supports of any kind on the lower extremity due to their external effect on internal stability. Also, clinicians should realize the time of day influences on balance control. Gribble et al\(^4^7\) found that dynamic postural control is performed better in the morning than in the evening or the afternoon. While this does not mean athletes cannot be screened with the SEBT in the afternoon, it simply implies that testing should be consistent across all variables and across all subjects.
The Star Excursion Balance Test is not the only low-cost and effective test of dynamic postural control available to clinicians today. Traditional measures of balance ability include a timed single limb stance on an unstable surface with eyes closed as well as the Flamingo Balance Test which consists of counting the number of attempts it takes to complete a one minute stance on a narrow beam with the eyes open\textsuperscript{40}. The Functional Movement Screen is another widely used tool as it is essentially a series of seven tests that assess dynamic stability through bilateral strength and range of motion\textsuperscript{48}. A study by Webster et al, determined that the Functional Movement Screen (FMS) is not bias towards sex or level of athletic ability and therefore can be used as an adequate assessor of dynamic postural control with all athletes\textsuperscript{48}.

Other dynamic tests of postural control include the Single Leg Functional Squat and the Balance Error Scoring System. The functional squat is a measurable exercise in which the participant performs a single leg squat on a level surface facing a wall. The participant places the foot as far away from the wall as possible and then squats down to where the weight bearing knee is just capable of making contact with the wall. The distance from the wall to the toes of the stance foot is then measured for objective dynamic stability data. Also, the Balance Error Scoring System is a simple test of functional stability that involves counting the number of corrections or errors during a given stance and assigning a point value to them\textsuperscript{26}. This objective data can then be used for comparison across time or samples of a population. Regardless of the test used, the clinician must be sure to use correct testing technique, make careful objective measurements, and above all, be consistent across subjects and sample populations.
2.3 Dynamic Postural Control

Having an understanding of how dynamic postural control can be assessed, it then becomes necessary to understand how dynamic postural control is attained and its importance within athletics. To begin, postural control has been generally defined as the ability to control the body's position in space for purposes of stability and/or orientation\(^35\). Another way to consider the term is simply the ability to achieve a state of equilibrium by maintaining the body’s center of gravity over the body’s base of support\(^40\). Many factors play a role in dynamic postural control, from the central motor cortex and subsequent efferent muscular contractions to afferent stimuli from the peripheral nervous system. Generally, the terms „dynamic postural control”, „balance”, and „stability” are all synonymous terms and should not be thought of as separate entities.

A few factors have been individually identified that directly either enhance or degrade dynamic postural control. A study by Nakagawa and Hoffman\(^49\) in 2004 demonstrated that subjects with “recurrent ankle sprains,” known by some as „chronic ankle instability”, had a significantly greater excursion of the Center of Pressure (COP) in both static and dynamic tests performed over a force plate. This research was aimed at evaluating the postural control of nineteen individuals with chronic ankle instability compared to that of nineteen aged-matched controls. The conclusion of the authors was simply that a history of repeated ankle sprains leads to decreased dynamic postural control as shown by the tests\(^49\).

The first study ever to examine the phenomenon that would later become known as chronic ankle instability (CAI) and its effects on dynamic postural control was one published by Freeman et al in 1965\(^14\). In this paper, it was hypothesized for the first time
that balance was negatively affected by ligamentous injury to the ankle and that balance
and coordination training could decrease associated proprioceptive deficits\textsuperscript{14}. However,
over the past half century since this study was published, research has failed to either
confirm or refute this hypothesis beyond reasonable doubt\textsuperscript{30}. Balance training as well as
core stability interventions have been designed to not only improve dynamic postural
control, but also prevent injury. Some have shown promising results, while others have
failed to prove the efficacy of such interventions.

Forty-five years after the Freeman study, Gribble et al\textsuperscript{50} published a paper
outlining the effects of both gender and fatigue on postural control. This study used
sixteen healthy subjects and had each perform the Star Excursion Balance Test before
and after four different fatigue protocols\textsuperscript{50}. Fatigue was not surprisingly found to have a
detrimental effect on dynamic stability as reach distances decreased across the board in
all three directions used. However, this study found that women were able to reach
further than men when reach distance was normalized to leg length while women also
displayed a greater degree of maximal knee flexion\textsuperscript{50}. These differences were even more
pronounced when fatigued as dynamic postural control has many variable factors that
determine the stability of an individual.

Realizing the strong effect that both fatigue and CAI have on dynamic postural
control, Gribble et al attempted to link these factors in a 2004 study\textsuperscript{51}. The authors
analyzed fourteen individuals with unilateral CAI and compared their performance on the
Star Excursion Balance Test to sixteen healthy controls. The conclusions in this study
were very similar to the studies previously mentioned as both CAI and fatigue were
found to negatively disrupt dynamic postural control. However, the authors noted more
specifically that dynamic postural control was disrupted by the reduction of “sagittal plane joint angles proximal to the ankle.” In other words, CAI caused a reduction in hip and knee flexion of the involved limb which was reflected in reach distances on the SEBT. Going further, Gribble and Hertel published another study which fatigued the primary movers of the hip and then the primary movers of the ankle in a crossover study. The purpose of this study was to determine which region of the body primarily determines postural control. The results found that fatigue of the primary movers of the hip (through isokinetics) created statistically significant excursion of COP in the frontal and sagittal planes pre to post-fatigue as measured by a force plate. Meanwhile, ankle fatigue did not have any significant effect on COP excursion. It seems as if primary hip musculature is the largest determinant of postural control, at least in static standing.

With this information now in hand, the question can be raised. How can clinicians improve the dynamic stability of individuals with CAI as demonstrated by functional screens like the SEBT? Moreover, how can clinicians increase the dynamic postural control of healthy individuals in order to prevent injuries from ever occurring in the lower extremity?

The answer to these questions is quite complex as there are many ways of approaching this issue through interventions. Contrary to the results of the Gribble and Hertel study, some interventions focus on strengthening the ankle and lower leg as some believe that this is where stability ultimately comes from. Other interventions focus more on the hip and core musculature of the body, known as proximal rehabilitation. Still, others represent a combination or holistic approach to rehabilitation for the improved dynamic postural control of individuals with chronic ankle instability. These
approaches tend to involve exercises of all types in order to achieve the goal of improved dynamic stability. The theories behind the two different types of interventions ultimately stem from the two different types of dynamic postural control found within the body.

Typically, the body employs an ankle strategy to maintain stability which largely involves the peroneal muscles assisting in balance. However, after an injury is sustained to the ankle or lower leg, it has been noted that peroneal function declines and the body therefore must turn elsewhere for dynamic postural control. The body then looks up the kinetic chain to employ a hip strategy in order to maintain stability. Often seen in elderly patients as well as younger individuals with CAI pathology, this strategy relies primarily on the strength of the gluteus medius musculature to correct posture and keep an individual balanced. Recent studies have identified that gluteus medius musculature is weak after an individual suffers an ankle sprain, however, it is unclear whether this was present before the sprain occurred and if it may have contributed to the injury itself.

Regardless of what type of intervention is used to improve dynamic stability, it is imperative that it be effective and ultimately efficient, because when improvements in dynamic stability are achieved, the risk for lower extremity injury will decrease.

2.4 The Effect of Balance Training Interventions on Dynamic Postural Control

The task of balancing, or maintaining one’s center of gravity over a given base of support, may seem simple; however, in reality, it involves a “high degree of coordination among the various components of the neuromuscular system.” A higher degree of balance ability translates to improved dynamic postural control which in turn promotes a decreased risk for injury. Therefore, exercises and interventions designed to improve
balance ability are essential not only for the injured population wishing to avoid recurrence, but also for the healthy population seeking to prevent injury altogether.

Most balance training interventions focus on maintaining a single leg stance under a number of different conditions designed to challenge recovery from a perturbation and overall dynamic postural control. These types of exercises are believed to enhance the input to the central nervous system which alters the efferent neural response “in a manner that improves neuromuscular control of joints throughout the kinetic chain.” 8,36 This improved postural control as a result of balance training has been hypothesized to significantly decrease injury rates in all populations by as much as 75%. 8 However, there does appear to be a certain number of acute ankle sprains that are inevitable. In other words, no matter how long or intense a balance training intervention is, there is a certain „baseline‘ injury rate that will always be in place36. It is the job of the athletic trainer and/or coach to prevent the injuries that can be prevented within any given athletic team via intervention and bracing methods.

The optimal balance training intervention should focus on the performance of single leg activities on an unstable surface with eyes open and closed, multi-component plyometric training, and biomechanical awareness training for ten to twenty minutes daily for three to seven weeks8,36. However, this type of intervention is not always feasible due to time constraints or compliance issues; therefore, the search for a “gold standard” balance training intervention must continue30,38. The ideal balance training intervention would use activities that need no equipment to perform for five to ten minutes three to five days per week for less than four weeks. If this type of intervention could be designed and proven to be effective in the prevention of acute injury, then it would be
employed by athletes everywhere. The “clinical bottom line” according to a 2008 McLeod study is that there is moderate evidence to support the use of a supervised balance training program in order to prevent acute injury, however, this program must be optimized to be not only effective, but efficient as well.

McKeon et al. published an article in 2008 which was entitled, “Balance Training Improves Function and Postural Control in Those with Chronic Ankle Instability.” This study placed thirty-one adults with self-reported chronic ankle instability into either an experimental group or a control group. The experimental group was put through a four week balance training intervention that emphasized dynamic stability primarily in a single limb stance. Primary outcome measures included self-reported function, the Foot and Ankle Disability Index (FADI), dynamic postural control as measured by the SEBT, and static postural control measured by Time to Boundary Analysis (TTB). After four weeks of training, the subjects were found to have improved dynamic stability by measures of the SEBT, FADI, and self-reported function.

Other similar studies have been able to create these same results as well as extend them to long-term scenarios. For example, a study by Elis and Rosenbaum reported that their six week balance training program allowed for a sixty percent reduction in episodes of “giving way” up to one year after the intervention was over. Therefore, with the realization of how powerful these interventions can be and their effect on the athlete not only in the short-term, but in the long run as well, a clinician should be aware of what these exercises are and how to implement them.

McKeon et al. hypothesized that individuals with self-reported chronic ankle instability that underwent a four week supervised balance training program would see
significant improvements in dynamic postural control. The four week intervention took place three times per week for twenty minutes per session. Therefore, total time spent on improving postural control throughout the intervention was only four hours per individual. The intervention itself involved the use of exercises designed to challenge an individuals’ single-leg stance and recovery from a perturbation. Overall, only five groupings of activities were used in progressive sequence: (1) hop to stabilization, (2) hop to stabilization and reach, (3) hop to stabilization box drill, (4) progressive single limb stance, and (5) progressive single limb stance with eyes closed. This program was designed to improve single limb balance and dynamic postural control, and that is exactly what it achieved. After the intervention, subjects in the experimental group had improved their dynamic postural control by measure of the Star Excursion Balance Test, self-reported function, time to boundary analysis, and other measures.

Minimal amounts of balance training have proven effective in improving dynamic stability in those with CAI. However, the long term effects of this program were not determined in the study and were suggested as avenues for further research. Can the improved stability as a result of this balance training intervention lead to decreased injury rates because of increased proprioception? The answer can only be found with a more prolonged study that utilizes screening mechanisms, an intervention, and a prospective analysis after the completion of a certain amount of time/exposures.

Another intervention study examined the effects of a balance training program as it relates to injury incidence among high school athletes written by McGuine and Keene and published in 2006 in the American Journal of Sports Medicine. This very large study used 765 healthy subjects and randomly assigned them to either an experimental group or
a control group. The purpose of this study was to design a simple balance training program that would reduce the number of lower extremity injuries suffered by the high school athletic population. The authors of this study reported the estimated direct healthcare and indirect associated costs with ankle sprains among high school soccer and basketball players, a sum well over one billion dollars annually, directly expressing the need for such a program to exist that would prevent these injuries.

Projecting an ankle sprain rate of fifteen percent from the outset, McGuine and Keene randomized twenty seven athletic teams from area high schools into the intervention group and twenty eight teams into the control group. This method of randomization (by team) is not considered optimal, however, it is necessary to randomize in this fashion in order to “limit contamination” between groups and to maintain compliance. The intervention was quite involved as it consisted of five phases of four primary exercises: (1) single leg stance with eyes open then closed, (2) single leg functional sport activities, (3) balance board activities, double leg then single leg, eyes open then closed, and (4) functional sport activities on the balance board.

The results of this study were quite fascinating. Not only did ankle injury incidence decrease significantly in the intervention group as compared to the control group (1.13 vs. 1.87 injuries per 1000 exposures, p<0.05; exposure= one subject and one practice or event), but also those who were injured in the intervention group were able to return to play faster than their control group counterparts (2.3 days faster). These results suggest that a simple balance training program taking no more than thirty minutes per week during the season could reduce ankle sprain incidence by 38%. One interesting note to make on this study was that an increased risk for ankle sprain was
found for those who had a history of ankle sprains (2.14 Relative Risk) and those who used ankle supports. This balance training program was able to reduce the risk of lower extremity injury in healthy subjects with no history of injury, but could not seem to reduce the risk for those subjects with previously compromised joint integrity of the ankle. Further research into the effects this type of program has on other lower extremity injuries, such as ligamentous knee injuries, was suggested in the conclusion. Balance training has proven itself as beneficial for the reduction of injury incidence and severity in the ankle; however, researchers must still be on the hunt for more beneficial ways of reducing lower extremity injury through intervention protocols.

A third notable intervention study was published in 2009 by McLeod et al. This study, not unlike the others, set out to determine if balance improvements would be present in female high school basketball players after the completion of a six week neuromuscular training program. The intervention itself focused on the inclusion of four key components: (1) plyometrics, (2) functional strengthening, (3) single leg balance activities, and (4) stability ball exercises. As with the other interventions previously mentioned, McLeod et al found that their training program improved scores on the Balance Error Scoring System (BESS) and on SEBT reach distances. This study, along with the other two (McKeon et al, and McGuine et al), prove that traditional balance training interventions can improve the dynamic stability and balance over a short-term program of six weeks or less. It has also been noted that balance improvements are still seen up to one year after the completion of the intervention as this improved balance can lead to a reduced risk of injury.
A systematic review published in 2010 by Webster and Gribble\textsuperscript{35} reviewed all functional interventions for subjects with chronic ankle instability; McKeon et al was one of the six studies found in the literature review. The systematic review produced a few interesting results; first, all studies that were reviewed used a wobble board or a similar device in their intervention. Also, each article found improvements in postural control, either by self-reported means or a functional test of dynamic postural control\textsuperscript{35}. Therefore, all studies currently in the literature have shown that balance training improves postural control in interventions ranging in length from four to six weeks in those with chronic ankle instability\textsuperscript{35}. But what of athletes without CAI; can a balance training intervention effectively prevent injury in already healthy individuals?

The answer to this question remains largely undetermined as there is high-level evidence supporting each side of the equation. McGuine and Keene clearly demonstrate that their season-long balance training intervention prevented injury incidence by as much as 38\% in healthy individuals\textsuperscript{37}. Other studies prove that balance training on uninjured individuals is beneficial even in terms of decreased inversion/eversion of the rearfoot when walking\textsuperscript{6}. However, still other evidence refutes this claim. For example, a study by Soderman et al\textsuperscript{9} examined the effects of a season-long balance board training program in female soccer players. The program included only five exercises completed one leg at a time for three sets of fifteen seconds each. The program was to be performed at home as each athlete was given their own balance board and told to complete the exercises each day for the first thirty days, and then three times per week for the remainder of the six month season. The results of this intervention study were quite unexpected as no significant differences were reported between the intervention and
control groups in terms of number or severity of injuries to the lower extremity\textsuperscript{9}. Even after the intervention group was divided between those who performed the intervention as prescribed and those who did not, still no differences were seen in terms of injury prevention\textsuperscript{9}.

Soderman et al\textsuperscript{9} note that this finding is in direct contradiction with the work of Caraffa et al\textsuperscript{54} and Wedderkopp et al\textsuperscript{55}. The Caraffa study reported a significant decrease in the incidence of ACL injuries after a balance board intervention in male soccer players\textsuperscript{54}. Also, Wedderkopp et al found that female handball players whom underwent an balance board training intervention saw a significant reduction in traumatic injuries to the lower extremity\textsuperscript{55}. In comparison, all three of these balance board interventions were very similar in intensity and duration, however, subtle differences do exist that may account for the disparity in the results. For example, Wedderkopp et al used a standardized warm-up protocol before the balance board training was completed each day\textsuperscript{55}. This may suggest that the warm-up protocol has an effect on injury prevention, but this is unlikely. The fact remains that similar high-quality studies found very different results in terms of injury prevention through a balance board training program.

A systematic review by Zech et al\textsuperscript{10} published in 2010 in the Journal of Athletic Training reviewed all studies in the current literature that used a balance training intervention to improve neuromuscular control or for purposes of performance enhancement. The authors begin the review with the suggestion that performance enhancement, rehabilitation, and injury prevention are all effects of improved neuromuscular control seen as a result of balance training interventions. In fact, balance exercises are commonly denoted as the causal factor for neuromuscular adaptations in
terms of proprioception or spinal reflex activity. For an individual with decreased reflex activity or proprioception, balance training can and will help restore neuromuscular control\textsuperscript{5,35,37}. However, the effect of balance training on uninjured individuals remains a topic of much discussion. Therefore, this systematic review by Zech et al\textsuperscript{10} set out to examine all studies that performed a balance training intervention on healthy individuals.

Twenty studies were found that met the inclusion and exclusion criteria for the systematic review. While each of the studies found consisted of various exercise interventions, intervention duration, frequency, and intensity, the review was able to determine many things regarding what the current literature has to say about balance training interventions. In terms of functional performance, the review found that both static postural sway and dynamic stability improved with balance training, more so in non-athletes than in the athletic population (most likely because the baseline was lower)\textsuperscript{10}. However, this is not to be extrapolated to performance measures such as strength, speed, and jump height, as the review found that strength training was more influential on these measures than balance training alone\textsuperscript{10}. The longer interventions, showed better results in terms of static and dynamic postural control (typically between 6 and 12 weeks)\textsuperscript{10}. In order to adequately improve measures of static and dynamic stability, Zech et al determined that a minimum duration of six weeks is necessary for an intervention length\textsuperscript{10,30}.

A study by Bahr et al\textsuperscript{1} showed a 49\% reduction in the risk for ankle sprain in volleyball players during the second year of a balance training program as compared to a 21\% reduction during the first year. Studies like these show that the longer the intervention goes on, the more positive the results tend to be. However, these findings
are largely speculative as other studies such as Hamman et al\textsuperscript{56} found that there was no difference in static stability between two similar groups when one performed five consecutive days of balance training and the other performed a five week balance intervention consisting of exercises one day per week. So while the current literature may not be able to determine the optimal duration, frequency, or intensity of a balance training intervention, Zech et al\textsuperscript{10} did conclude that balance training is effective in improving static and dynamic stability.

Another systematic review by Hrysomallis\textsuperscript{40} published in 2007 found nine prospective balance intervention studies. Of those, five found that poor balance ability were significantly related to ankle injury incidence, however, the overall heterogeneity of the studies led to the conclusion that more studies of high quality are necessary in order to determine the true effect of balance training interventions. The review suggested that new balance training intervention studies examine balance ability both before and after the intervention along with measurements of other abilities such as landing, cutting, sprinting, and jumping\textsuperscript{39}. In conclusion, Hrysomallis suggested that balance training as a single intervention may not be as effective as when it is part of a multi-faceted intervention\textsuperscript{40}. Nonetheless, balance training does appear to increase stability and decrease injury risk. The mechanism by which injuries are prevented through balance training is unknown as an injury can only occur when, “the load applied to a structure exceeds its capacity to sustain it.” \textsuperscript{40} Therefore, in order to prevent injury, one must either reduce the load or improve the structure’s ability to sustain the load. Since the former is rarely possible in sport situations, the latter must be undertaken. Balance training has
been found to enhance active joint stability by causing a co-contraction of agonist and antagonist muscles within the ankle joint.

On a more practical note, when should a clinician implement a balance training program? We have already seen that the time of day plays a significant role in dynamic postural control as it generally decreases as the day goes on\textsuperscript{47}. However, in terms of when to perform a balance program with a team, certain research suggests that it is of no importance. Performing balance training interventions before or after a practice or workout session does not influence performance nor effectiveness of the program\textsuperscript{57}. Balance training has proven itself as effective in improving dynamic postural control, even though when the intervention is performed is as varied as how it is performed. However, one thing is certain; balance training programs restore dynamic stability and ultimately can help to prevent injury.

2.5 The Effect of Proximal Joint and Core Strength Training on Dynamic Postural Control

Balance training has proven itself as beneficial for reducing injury rates as well as injury severity in the lower extremity. However, other interventions exist in the current literature which suggests that balance is derived primarily from hip and core musculature thus eliminating the need for balance training while still observing the results of a decreased injury rate and decreased injury severity\textsuperscript{3,4}. Current research has displayed that core strength is an essential component for balance as well as for effective athletic movements in both the upper and lower extremity\textsuperscript{58}. Known as proximal rehabilitation,
many research studies have examined these claims in recent years. Among them: Kahle & Gribble\textsuperscript{3} and Leavey et al\textsuperscript{4}.

While many have suggested that core strength is necessary for dynamic postural control, Kahle and Gribble\textsuperscript{3} may have been the first to investigate the claim. Using the Star Excursion Balance Test as an outcome measure, the authors recruited thirty healthy, college-aged individuals and randomly assigned them to either an intervention group which was to receive a proximal core strengthening intervention three times per week for six weeks, or a control group, which refrained from any core strengthening exercises during the same six week span\textsuperscript{3}. SEBT post-intervention measures showed that the intervention group could achieve significantly further reach distances as compared to their pre-intervention measures while the control group displayed no significant change in their scores. The authors suggest that while balance training may be warranted after an injury occurs as a rehabilitation tool, core strengthening should be considered by all clinicians as a preventative tool\textsuperscript{3}. It has been said that „an ounce of prevention is worth a pound of cure”\textsuperscript{5}; if this statement is true, then all clinicians should look to identify and implement core strengthening exercises with their athletes regardless of level.

If the study by Kahle and Gribble\textsuperscript{3} has one flaw, it is the fact that the authors used an extraordinary amount of exercises for their intervention group. The intervention included ten exercises encompassing everything from abdominal crunches to bridges to stability ball exercises. While this is an excellent and holistic approach to core stability, the problem with this intervention is that it is largely impractical. The amount of time that these exercises would take to complete is more than what an average high school athlete is willing to give simply for the purpose of prevention of injury. Clinicians and
researchers must look for more efficient intervention designs in order to assure compliance while not degrading effectiveness.

Another example of a core strengthening intervention being used to improve dynamic postural control was published in 2010 by Leavey et al. Using the Star Excursion Balance Test to assess subjects both pre and post intervention, Leavey et al used a multi-directional approach to core strengthening. The authors utilized sixty healthy subjects and randomized them into four different groups: (1) control group, (2) PT group, (3) GMST group, and a (4) COMBO group. The control group was given no exercises to complete while the COMBO group was given both the exercises of the PT group and the GMST group.

The PT, or proprioception training group, was given eleven progressive exercises focused specifically on increasing proprioception through weight bearing static or dynamic balance activities. Variations of double and single limb support, eyes open and eyes closed, as well as performing the exercises on fixed and unstable surfaces were utilized in this intervention. The GMST, or the gluteus medius strength training group, was given only six exercises to be performed at a progressive rate throughout the six week intervention. The exercises chosen to be performed in this group included: (1) side-lying hip abduction, (2) walking with weight in opposite hand, (3) gorilla walking, (4) body weight activities, (5) single leg squat, and (6) lateral step down exercises. The primary goal of this study was to determine if the exercises given would increase strength in the gluteus medius and result in improved dynamic stability. Their results were not surprising as it was reported that the COMBO group saw the most improvement in dynamic stability as demonstrated by the SEBT. This makes logical sense as the
COMBO group participated in the most exercises. While the GMST group saw a greater increase in SEBT reach distances than the PT group, both groups demonstrated significant improvements over baseline scores\(^4\). However, no significant differences existed in gluteus medius strength between groups post-intervention\(^4\). This implies that core strengthening exercises should supplement typical proprioception training exercises post-injury because it will ultimately maximize dynamic postural control.

Like any study, the research by Leavey et al\(^4\) was not without its problems. First, similar to the Kahle and Gribble\(^3\) study, the design of the intervention presented was largely impractical, requiring seventeen exercises be performed three to four times per week for six weeks\(^4\). Also, this study used healthy subjects yet made implications for injured persons. In the conclusion, the authors’ state that gluteus medius strengthening should be incorporated into proprioception training following an ankle injury\(^4\), however, further research is necessary in order to substantiate the claim.

Research in the area of dynamic postural control remains heterogeneous in nature. While studies previously mentioned have established a clear connection between balance ability and/or core strength to injury incidence, other studies have found that these factors play no significant role in injury. A 2010 study by Reimer and Wikstrom\(^59\) compared the effects of fatigue on the hip musculature and the ankle musculature as measured by postural control. This study concluded that both areas of musculature contribute equally to postural control in a single limbed stance because neither contributed significantly toward postural control reduction when fatigued\(^59\). A two-year study by McHugh et al\(^18\) first measured the balance ability, injury history, and core strength of 169 high school athletes and then analyzed the acute ankle sprain injuries that occurred within the sample.
The results of this study were the antithesis of many others as the authors found that balance ability, hip abduction, and hip flexion strength were not significant factors in injury incidence among acute ankle sprains\textsuperscript{18}. Not surprisingly, the largest risk factor for injury in the study was a history of previous ankle sprains. If a similar study was performed using only healthy subjects, a different result may be seen, and this could drive the literature of dynamic postural control and injury prevention toward a more homogenous outcome.

2.6 Ankle Injury Epidemiology

As the current literature is yet to determine the most optimal preventative intervention for lower extremity injury, clinicians should be aware of which individuals are most at risk. Having already established that diminished postural control\textsuperscript{15}, history of previous injury\textsuperscript{49}, and being in a state of fatigue\textsuperscript{46} all place an individual at a higher risk for injury, clinicians should also understand global risk factors.

In 2007, the Journal of Athletic Training published an entire issue (Volume 42, Issue 3) dedicated to identifying injury epidemiology in modern sport. Within this issue, Nelson et al\textsuperscript{60} performed a study which analyzed ankle injuries among high school athletes. In one of the most comprehensive epidemiology studies ever performed, Nelson et al included 425 schools across United States as a part of the study. Each school had a certified athletic trainer on-site whom reported injury and exposure data on a weekly basis using the Reporting Information Online (RIO) System (Columbus Children’s Research Institute, Columbus, OH). This study logged more than 1.73 million athlete-exposures and with that found over nine hundred ankle injuries\textsuperscript{60}. These numbers
correlated to an overall ankle injury rate of 5.23 per 10,000 exposures. Ankle injuries made up 22.6% of all sport-related injuries within the study, making it the most commonly injured joint of the body within the athletic setting. The study then went on to break down ankle injury by sport, sex, height, weight, and BMI while considering factors like the type of athletic maneuver the injury occurred in and where on the field of play the injury occurred. In the end, this excellent study identified a few important global risk factors. Nelson et al discovered that ankle injuries occurred more frequently in sports that involved both running and jumping with the highest injury to exposure rates occurring in football, soccer, and basketball respectively. This implies that ankle injuries occur during dynamic tasks, but why do some athletes suffer an ankle sprain while others do not as they compete side by side?

Overall, there are two main categories of risk factors: intrinsic and extrinsic. Extrinsic risk factors are those which are outside the body and therefore are risk factors that the individual has little to no control over. Examples of extrinsic risk factors in athletics include the type of sport being played, the sport surface, protective equipment, weather, and many more. Extrinsic risk factors can be minimized by controlling what is able to be controlled, such as playing indoors on a flat surface, having the best protective equipment available, etc. However, the elimination of extrinsic risk factors cannot be accomplished without proper funds which are usually difficult to attain in the lower levels of sport. A two year cohort study by Kofotolis and Kellis found that female basketball players who did not wear external ankle supports, and those who played the center position, were at increased risk for ankle sprain. This study is among the best in the current literature that identifies two extrinsic risk factors as the primary culprit for
ankle injury. Overall, extrinsic risk factors are difficult to control, however, wearing an ankle support or changing one’s position on the field of play could most likely be accomplished with minimal difficulty.

A systematic review of ankle sprain prevention in sport performed by Thacker et al. determined that any athlete who sustains an ankle sprain should complete a rehabilitative program to improve proprioception, range of motion, and strength, and should wear a prophylactic support on the ankle during dynamic activities for six months post-injury. This systematic review analyzed many methods of ankle sprain injury prevention in the current literature. Shoe type, taping, bracing, and training level were all analyzed as potential ankle injury preventers. In the end, training level was determined to be the most important preventative factor, while ankle bracing was also shown to decrease injury incidence. This study analyzed both intrinsic and extrinsic risk factors and determined that both were of importance for injury prevention.

Intrinsic risk factors are very controllable with the right knowledge and vary from individual to individual. A number of intrinsic risk factors that place a healthy individual at an increased risk for injury to the lower extremity have already been discussed in this review, however, the most common of these variables include: decreased strength, decreased postural control, decreased proprioception, decreased muscle reaction time, ligamentous laxity, and mal-alignment of body structures.

2.7 Intrinsic Risk Factors

In a pioneering study in this field, Clark et al. was able to identify a link between ligamentous laxity and acute ligamentous injury in 1971. Clark et al. measured the
ligamentous and muscular laxity of 462 high school football players and followed them prospectively throughout the season. This study was among the first to determine that there exists no link between ligamentous laxity and injury incidence or severity, even though a previous study had seen this result in professional football players just one year prior.

In 2005, a study by Willems et al. set out to determine the most influential intrinsic risk factors in women. The authors recruited 159 physically active college-aged females without a history of injury to the lower extremity to be a part of the study. Also, the subjects could not use a prophylactic support of any kind during the period of their physical education. Before the study began, a series of tests were administered to the subjects including measurements of: anthropometric data, proprioception, muscular strength, lower limb alignment, static and dynamic postural control, and muscle reaction time. They reported that decreased proprioception as measured by passive joint position sense, decreased postural control, and increased range of motion of toe extension and dorsiflexion strength are the leading intrinsic contributors to inversion sprains among physically active females. In a similar methodological study, Willems et al. identified running speed, cardio-respiratory endurance, balance, dorsiflexion strength and ROM, and muscular reaction time as risk factors for inversion ankle sprain in physically active males. The results of both of these studies showed no significant effect of any anthropometric data on ankle injury incidence; however, this result has been contradicted by other studies.

Many studies have attempted to identify a link between injury incidence and anthropometric data. Repeated analyses reveal no significant link between any variables
however, Waterman et al\textsuperscript{32} found that increased height, weight, and BMI in men resulted in an increased incidence of ankle sprain (p<0.001). Still other studies found no significant relationship between anthropometric data and injury incidence, but noted injury incidence as “tending” to be higher in those with increased BMI (p>0.05)\textsuperscript{18}. While the current literature does not seem to completely agree on the relationship between anthropometric data and injury incidence, other intrinsic risk factors are universally accepted.

One of the original risk factor studies for ankle injury was performed by Ekstrand and Gillquist\textsuperscript{64}. This study used 124 soccer athletes and examined health history and anthropometric data before the season began. Then, the authors followed these athletes throughout the season while recording exposure and injury data. A previous history of ankle sprains was found to be the number one contributor for increased lateral ankle ligament sprain risk\textsuperscript{64}. Ekstrand and Gilquist were among the first to identify previous ankle sprains as a risk factor for new ankle sprains, a hypothesis that has been confirmed by many studies since \textsuperscript{15-17,34}. Hiller et al\textsuperscript{17} took this finding one step further, identifying that dancers with a history of ankle sprain had an increased risk for sprain on the contralateral ankle. While this statement is yet to be confirmed by other studies, it should represent the fact that intrinsic risk factors are holistic in nature and are not specific to one side or one joint of the body.

It is well known that females are at a greater risk for suffering an acute rupture of their anterior cruciate ligament in the knee\textsuperscript{15,40,54}, however, does this mean that females automatically are at a higher relative risk for injury to the ligaments of the lateral ankle as compared with their male counterparts? Beynnon et al\textsuperscript{15} suggests that we cannot make
this conclusion from the current literature. Some studies have found a significant

difference between the sexes in terms of ankle sprain relative risk. For example, Hosea et

al\textsuperscript{65} reported a 25\% increase in relative risk for females over males in ankle sprain

incidence among basketball players. However, for every study which found a difference

in ankle sprain risk between the sexes, Beynnon et al\textsuperscript{15} reports that there have been others
to refute it. Moreover, the current literature cannot support any type of anthropometric

measurement as significant in determining risk factors for ankle sprains\textsuperscript{15}. However,
what can be adequately determined is that risk factors are difficult to generalize for entire

populations. Beynnon et al\textsuperscript{15} identified no global risk factors that were consistent among
the literature (other than history of ankle sprains) including postural sway, joint laxity,
and muscular strength.

This is not to say that there are no global intrinsic risk factors for ankle sprains,
rather, the literature has simply not identified them yet with high certainty. Verhagen et
al\textsuperscript{66} suggests that an athletes behavior is the key risk factor for injury in sport and that risk

factors for injury are psychological as opposed to physiological. However, others may
recognize that injury is not fabricated by psychological mechanisms, but occurs
physiologically through incredible sustained forces. Therefore, there must be any

number of intrinsic risk factors that result in an increased risk for injury. Many risk

factors already identified in this review include decreased postural stability/balance\textsuperscript{24},
decreased lower extremity range of motion\textsuperscript{19}, decreased strength\textsuperscript{24}, and possible increased

BMI\textsuperscript{32}. A study by Hadzic et al\textsuperscript{22} determined that decreased dorsiflexion range of motion
along with increased plantar flexion strength increased the relative risk of sustaining an

ankle sprain by 22\% among female volleyball players. This study, as with many others,
used correlation analyses to determine the interaction effect of two or more variables on each other. In terms of intrinsic risk factors, clinicians and researchers should accept the fact that more than one variable determines injury risk. In short, injury risk is determined by the combination of all the researched positive risk factors, from decreased proprioception and balance to decreased range of motion and increased ligamentous laxity.

2.8 Conclusion and Knowledge Gap

Both intrinsic and extrinsic risk factors play a role in lower extremity injury. From decreased strength and balance to external forces and playing surface, each identified risk factor alters dynamic postural control. Therefore, tests like the SEBT can be used to identify and screen out those at increased risk for injury both effectively and efficiently. The SEBT can be used as a predictive screening tool because it has proven itself over and over in the current literature. Once an athlete is determined as having an increased risk for injury, a combination of balance and core strength training may be implemented in order to prevent injury from occurring. These interventions alter the intrinsic risk factors while other mechanisms, such as bracing and shoe type, should be considered to control as much as possible for extrinsic risk factors. However, it should be noted that no test of intrinsic dynamic postural control can predict injury of an extrinsic/contact mechanism. Tests like the SEBT can only be useful in the prediction of non-contact/intrinsic risk factor injuries.

Within the current literature, there remain areas of limited knowledge in the field of dynamic postural control. First, it should be noted that the use of dynamic stability
screening devices such as the Star Excursion Balance Test has made significant leaps in recent years, however, a composite cut-off score that can determine with high certainty an individuals’ risk for a lower extremity injury is yet to be determined. This score could allow clinicians to use the SEBT to not only compare and monitor an individual’s improvements in dynamic stability over time, but would also allow for the SEBT to be used as a mandatory pre-season screening tool in order to predict and ultimately prevent injury. Secondly, interventions to improve dynamic postural control fail to consider the effect of their program on injury incidence. There is not yet conclusive evidence that a lack of dynamic postural control can lead to an increased risk for injury\textsuperscript{23,35}. Therefore, the ultimate goal of this research is to develop injury prediction models that are not only effective, but can be efficiently distributed with high sensitivity and specificity. Future research must focus on finding the intervention that reduces the injury rate, whether that is a balance training intervention, proximal/core strengthening intervention, or some combination of both.

With the high prevalence of lower extremity injuries seen in modern sport, clinicians must look to implement preventative strategies through interventions by using screening mechanisms like the SEBT. The resultant intervention to be used must be effective, efficient, promote compliance, and most importantly, it must prevent injury.
Chapter Three

Methods

3.1 Subjects and Study Design

One hundred seventy (170) high school basketball players were recruited from five Toledo, OH area high schools during both the 2009-2010 and 2011-2012 basketball seasons for this multi-year prospective cohort study. This study analyzed the anthropometric and SEBT data from preseason baseline measurements prior to the competitive high school basketball season, comparing individuals who sustained a lower extremity injury during the season to non-injured individuals.

Preseason anthropometric data was taken from each subject including height, weight, age, and BMI. Also, before beginning the competitive season, all subjects were tested using the Star Excursion Balance Test (SEBT). Each subject was tested in three directions on the SEBT, the anterior, posteriormedial, and posteriorlateral\textsuperscript{44,45}. To be included in the study, subjects must have been medically cleared to play the sport of basketball for their competitive season; this was the only inclusion or exclusion criterion. All subjects received, read, and signed a University Institutional Review Board approved
informed consent form before the data collection began. Subjects’ parents/guardians also read and signed the informed consent form if the subject was under eighteen years of age.

When subjects were approved to enter the study, baseline anthropometric and SEBT data were collected before the competitive season began. Measurements were recorded by a team of Certified Athletic Trainers (ATC’s) as to control for extreme variance in intertester reliability. Throughout the season, injury and exposure data were collected by an ATC. One exposure was operationally defined as one practice/event per subject. A lower extremity injury was operationally defined as any acute disruption in homeostasis to the lower extremity that causes and athlete to miss one or more team practices or events. A contact injury was operationally defined as injury resulting from contact with another player whereas non-contact injury was operationally defined as an injury occurring with no outside influence.

3.2 Instrumentation and Protocol

The method for collecting SEBT dynamic postural control trials followed previously published procedures: The subject’s leg length was first recorded by measuring from the inferior portion of the anterior superior iliac spine to the inferior portion of the ipsilateral medial maleolus with a standard tape measure on both limbs. This measurement was taken so to normalize SEBT scores to leg length. After leg length had been measured, subjects completed four practice reach trials in each direction before three actual trials were collected; this process was then repeated for both legs. Each SEBT trial consisted of the subject standing in a single limb base of support over the center of the SEBT testing grid. The distal head of the first phalanx of the plant foot was
positioned at the starting line in the center of the grid for the completion of the anterior direction. Similarly, the most posterior part of the heel was positioned at the starting line for the completion of the posteriormedial and posteirollateral reach directions.

After the subject was properly positioned, the individual performed four practice trials followed by three recorded trials in each of the three SEBT directions for both limbs. The order of testing limbs and directions was randomized. The subject reached with the contralateral limb as far away on the line as possible, made a light touch with the toes, and then returned to a position of double limbed stance. If balance was lost at any time during the trial as demonstrated by the subject bearing weight on the reach leg, lifting the heel of the stance leg, falling over, or otherwise losing control of single limbed posture, the trial was discarded and retried. Trials were measured for distance (cm), normalized to leg length (trial reach distance/leg length), and multiplied by one hundred to obtain a percentage score. The three right and left limb scores were averaged for each direction and used for analysis. Also, composite scores were created by adding together the means of the three reaching direction performances and dividing by three.

3.3 Statistical Analysis

This study has four dependent variables (normalized reaching distance in three directions: anterior, posteriormedial, posteriorlateral, and composite score). For each dependent variable, an independent t-test was performed to determine if a statistical difference was present between injured and non-injured athletes (Hypothesis #1). Separate one-way ANOVA models were to be used to determine if there was a statistical difference in each of the SEBT scores between different injury classification groups.
(ankle, knee, non-injured) (Hypothesis #3) and different mechanisms of injury (contact, non-contact, or non-injured). For all of these tests, statistical significance was set a priori at $p<0.05$. SPSS 17.0 (IBM, Inc.; Chicago, IL) was used to perform the statistical analyses.

To determine the magnitude of the differences in means, effect sizes were produced using Cohen’s $d$, between groups, utilizing the pooled standard deviations, along with the 95% confidence interval around the effect size point measures. (Cohen’s $d$ effect size calculation= \[\frac{\text{Non-injured mean-Injured mean}}{\text{Injured Standard Deviation}}\])

The interpretation of Cohen’s $d$ is: small $<0.3$; moderate $0.3-0.8$; large $>0.8$.

In order to determine a cutoff score for the SEBT that maximizes sensitivity and specificity of injury prediction (Hypothesis #2), a receiver operator characteristic (ROC) curve was used. This curve maximizes true positives and controls for false positives by identifying the uppermost left point on the graph. After a cutoff score was determined for each direction of the SEBT and the composite score, a $2\times2$ contingency table was used to determine which subjects in the injured/non-injured groups scored above or below the cutoff point. This curve determined the efficacy of the cutoff score and enabled the calculation of odds ratios, likelihood ratios, sensitivity, and specificity of the SEBT as follows:

$Sensitivity = \frac{\text{True Positives}}{\text{True Positive} + \text{False Negatives}}$

$Specificity = \frac{\text{True Negatives}}{\text{True Negatives} + \text{False Positives}}$

$+ \text{Likelihood Ratio} = \frac{Sensitivity}{1-\text{Specificity}}$

$-\text{Likelihood Ratio} = \frac{1-Sensitivity}{\text{Specificity}}$

$Odds Ratio = \frac{Sensitivity}{\text{Specificity}}$
Subject demographics are reported in Table 1 which includes gender breakdown, number of injured subjects, age, height, and mass from the data collected representing six high school basketball programs. For the composite of the Star Excursion Balance Test, there was no statistical significance between participants who did and did not suffer a lower extremity injury during the competitive season (t=0.728, p=0.468) (Table 2). From the ROC analysis, a score of 72.36% of leg length was associated with sensitivity of 0.58, specificity of 0.55, odds ratio (OR) of 1.7, and an effect size (ES) of 0.14 (Table 3 and 4).

For the anterior reach direction of the SEBT, there was no statistical significance between participants who did and did not suffer a lower extremity injury during the competitive season (t=0.257, p=0.797) (Table 2). From the ROC analysis, a score of 66.98% was associated with sensitivity of 0.42, specificity of 0.62, an OR of 1.17, and an ES of 0.05 (Tables 3 and 5).

For the posterior-medial reach direction of the SEBT, there was no statistical significance between participants who did and did not suffer a lower extremity injury during the competitive season (t=0.317, p=0.751) (Table 2). From the ROC analysis, a
score of 78.64% was associated with sensitivity of 0.55, specificity of 0.53, an OR of 1.37, and an ES of 0.06 (Tables 3 and 6).

For the posteriorlateral reach direction of the SEBT, there was no statistical significance between participants who did and did not suffer a lower extremity injury during the competitive season (t=0.053, p=0.958) (Table 2). From the ROC analysis, a score of 67.45% was associated with sensitivity of 0.42, specificity of 0.60, an OR of 1.08, and an ES of 0.01 (Tables 3 and 7).

Our Hypotheses #3 and 4 could not be tested due to insufficient cases of knee injuries (Hypothesis #3) and contact injuries (Hypothesis #4).
Table 4.1 - Demographics

<table>
<thead>
<tr>
<th></th>
<th>Male</th>
<th>Female</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>Number (N=)</td>
<td>106</td>
<td>64</td>
<td>170</td>
</tr>
<tr>
<td>Age±SD (years)</td>
<td>15.87±1.13</td>
<td>15.73±1.06</td>
<td>15.8±1.1</td>
</tr>
<tr>
<td>Height±SD (cm)</td>
<td>182.6±9.11</td>
<td>168.02±7</td>
<td>175.31±8.06</td>
</tr>
<tr>
<td>Mass±SD (kg)</td>
<td>77.13±13.16</td>
<td>63.15±10.49</td>
<td>70.14±11.83</td>
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</table>

Table 4.2 - Group Comparison of SEBT Scores

<table>
<thead>
<tr>
<th>Group</th>
<th>N=</th>
<th>Mean±SD (% leg length)</th>
<th>t</th>
<th>p</th>
<th>ES (95% CI)</th>
</tr>
</thead>
<tbody>
<tr>
<td>SEBT_Comp</td>
<td></td>
<td></td>
<td>0.728</td>
<td>0.468</td>
<td>0.14 (-.25, .53)</td>
</tr>
<tr>
<td>Injured</td>
<td>31</td>
<td>71.74±8.21%</td>
<td></td>
<td></td>
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</tr>
<tr>
<td>Non-Injured</td>
<td>139</td>
<td>72.81±7.3%</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>SEBT_Ant</td>
<td></td>
<td></td>
<td>0.257</td>
<td>0.797</td>
<td>0.05 (-.34, .44)</td>
</tr>
<tr>
<td>Injured</td>
<td>31</td>
<td>68.27±7.33%</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Non-Injured</td>
<td>139</td>
<td>68.61±6.48%</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>SEBT_PM</td>
<td></td>
<td></td>
<td>0.317</td>
<td>0.751</td>
<td>0.06 (-.33, .45)</td>
</tr>
<tr>
<td>Injured</td>
<td>31</td>
<td>78.6±10.22%</td>
<td></td>
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</tr>
<tr>
<td>Non-Injured</td>
<td>139</td>
<td>79.22±9.88%</td>
<td></td>
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<tr>
<td>SEBT_PL</td>
<td></td>
<td></td>
<td>0.053</td>
<td>0.958</td>
<td>0.01 (-.38, .40)</td>
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<tr>
<td>Injured</td>
<td>31</td>
<td>70.49±8.56%</td>
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<tr>
<td>Non-Injured</td>
<td>139</td>
<td>70.58±9.37%</td>
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</table>

Table 4.3 - ROC Cut-off, Sensitivity, Specificity, and Odds Ratios

<table>
<thead>
<tr>
<th>Reach Direction</th>
<th>ROC Cut-off Score</th>
<th>Sensitivity</th>
<th>Specificity</th>
<th>Odds Ratio</th>
</tr>
</thead>
<tbody>
<tr>
<td>SEBT_Comp</td>
<td>72.36%</td>
<td>0.58</td>
<td>0.55</td>
<td>1.7</td>
</tr>
<tr>
<td>SEBT_Ant</td>
<td>66.98%</td>
<td>0.42</td>
<td>0.62</td>
<td>1.17</td>
</tr>
<tr>
<td>SEBT_PM</td>
<td>78.64%</td>
<td>0.55</td>
<td>0.53</td>
<td>1.37</td>
</tr>
<tr>
<td>SEBT_PL</td>
<td>67.45%</td>
<td>0.42</td>
<td>0.6</td>
<td>1.08</td>
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</table>

Table 4.4- 2x2 Contingency for SEBT Composite Score

<table>
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<tr>
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<th>Injured</th>
<th>Non-Injured</th>
</tr>
</thead>
<tbody>
<tr>
<td>SEBT_Comp</td>
<td>Test (+)</td>
<td>18</td>
</tr>
<tr>
<td></td>
<td>Test (-)</td>
<td>13</td>
</tr>
</tbody>
</table>
Table 4.5- 2x2 Contingency for SEBT Anterior Reach Direction

<table>
<thead>
<tr>
<th></th>
<th>Injured</th>
<th>Non-Injured</th>
</tr>
</thead>
<tbody>
<tr>
<td>SEBT_Ant Test (+)</td>
<td>13</td>
<td>53</td>
</tr>
<tr>
<td>SEBT_Ant Test (-)</td>
<td>18</td>
<td>86</td>
</tr>
</tbody>
</table>

Table 4.6- 2x2 Contingency for SEBT Posteromedial Reach Direction

<table>
<thead>
<tr>
<th></th>
<th>Injured</th>
<th>Non-Injured</th>
</tr>
</thead>
<tbody>
<tr>
<td>SEBT_PM Test (+)</td>
<td>17</td>
<td>65</td>
</tr>
<tr>
<td>SEBT_PM Test (-)</td>
<td>14</td>
<td>74</td>
</tr>
</tbody>
</table>

Table 4.7- 2x2 Contingency for SEBT Posteriorlateral Reach Direction

<table>
<thead>
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<th>Non-Injured</th>
</tr>
</thead>
<tbody>
<tr>
<td>SEBT_PL Test (+)</td>
<td>13</td>
<td>56</td>
</tr>
<tr>
<td>SEBT_PL Test (-)</td>
<td>18</td>
<td>83</td>
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</table>
Chapter Five

Discussion

The purpose of this study was to determine the ability of the Star Excursion Balance Test as a predictor of lower extremity injury in high school basketball players and to identify a SEBT normalized cut-off score that would imply injury risk to individuals that scored below it. The problem in the current literature is that there is limited information to establish a reliable, cost-effective tool for preseason screening for predicting injury to the lower extremity with high success. The SEBT has been employed for injury prediction of high school basketball players, but the reported outcomes did not fully consider normalizing procedures and mostly focused on injuries among female players\textsuperscript{29}.

This study included four hypotheses. First, we hypothesized that high school basketball athletes who experience an acute lower extremity injury to the ankle or knee during the competition season will demonstrate shorter normalized reach distances on the SEBT during pre-season assessments compared with the athletes who do not experience a lower extremity injury. This hypothesis was correct as each of the three SEBT reach direction normalized scores along with the normalized composite score were lower in the
injured group compared to the non-injured group (Table 2). However, when an
independent t-test was run for each of these score sets, no statistical significance was
found. Therefore, the null hypothesis must be accepted as statistical significance was not
achieved (Table 2). Also, effect size calculation revealed very weak effect sizes (0.01 to
0.13), and odds ratio assessment saw a maximum score of 1.7 (SEBT_Comp) (Tables 2
& 3). This implies that there was no practical significance to the findings either as low
odds ratios and weak effect sizes would support weak clinical application.

The second hypothesis was that there would be a predictive normalized score on
the SEBT that would produce sensitivity and specificity scores above 0.70 for the
prediction of athletes with or without lower extremity injuries in high school basketball
players. This simply was not met due to very low sensitivity and specificity scores for all
SEBT variables (Table 3). The third hypothesis of this study stated that the normalized
SEBT scores of those that suffer ankle injuries during the competitive basketball season
will be lower than those that suffer knee injuries and the non-injured group. However,
even with a moderate sample size of six high school basketball programs, there were so
few knee injuries (two knee injuries out of 31 total injuries) recorded that this hypothesis
could not be tested adequately. In the future, a larger sample size may allow for more
ankle and knee injuries to be recorded and values to be calculated to address this
hypothesis.

The fourth hypothesis stated that the normalized SEBT scores of those that suffer
non-contact lower extremity injuries throughout the regular season participation will be
lower than athletes that suffer contact injuries and the non-injured group. However, even
with a moderate sample size of six high school basketball programs, there were so few
contact injuries recorded (one contact injury out of 31 total injuries) that this hypothesis
could not be tested adequately. As a larger sample size is developed, it is possible that
more contact injuries may be recorded, which may lead to the ability to test this
hypothesis.

We did not find any statistical significance; however, it is possible, but not likely,
that a Type II Error occurred. By pooling data collected this year with data collected in
the previous year, we feel our sample size was adequate to address our primary
hypotheses. Our data imply very limited usefulness of the Star Excursion Balance Test
as a predictor of lower extremity injuries among high school basketball athletes. This
conclusion can be drawn exclusively from the calculated odds ratios, which are the
culminating calculation for this study. The highest odds ratio observed was 1.7 for the
SEBT composite score. This number denotes the likelihood of injury for a subject
scoring below the ROC cut-off score compared to a subject whom scored above it.
However, this odds ratio of 1.7 is weak, implying that the SEBT has very limited
predictive capabilities of lower extremity injury among high school basketball athletes as
no individual SEBT score appears to have drastically more predictive capabilities than
the others. Other observed data support this conclusion including very weak effect sizes
and non-statistically significant p-values. Therefore, the SEBT had a very limited
predictive capability of lower extremity injury among high school basketball players.

Our finding conflicts with the only published paper by Plisky et al.\textsuperscript{29}, which found
positive and significant prediction of lower extremity injury risk with the Star Excursion
Balance Test among high school basketball athletes. They determined that a bilateral
anterior reach deficit of over 4 cm created an injury risk 2.5 times more than those
without a deficit\textsuperscript{29}. Also observed was that girls who could not achieve a composite score of 94% of their leg length were 6.5 times more likely to suffer an injury to the lower extremity\textsuperscript{29}. The results of the current study do not compare with the results of Plisky et al because we did not consider bilateral deficit measurement, just as Plisky et al did not consider SEBT normalizing procedures for the bilateral measurement. Also, the current study combines male and female athletes and does not fully consider the effect of gender on SEBT scores and its overall injury prediction capabilities. It is possible that if we analyze only female data, our results may move closer to that of Plisky et al; however, this limitation does not address the issue of predicting lower extremity injuries among male high school basketball athletes.

Finally, the Plisky et al SEBT composite cut-off score of 94% of leg length is much higher than observed in our study\textsuperscript{29}. The predictive composite cut-off score in our data was 72.4% of leg length. In examining our raw data scores, none of our participants, male or female, could achieve more than 91% of leg length, and only 25 participants performed more than 80% of leg length. In the experience of the faculty advisor with testing over one thousand participants in the last ten years with the SEBT, our data set is consistent with the performance of the population, meaning that normalized performances rarely exceed 90% of leg length. This raises some potential questions about the data that were collected and the interpretation in the Plisky et al\textsuperscript{29} study. Perhaps the predictive strength in high school basketball players is not as high as reported in that study.

Other studies such as the those performed by McGuine et al\textsuperscript{23} and Tropp et al\textsuperscript{41}, found that higher levels of postural sway and therefore decreased levels of stability in
high school athletes as measured on a force plate led to an increase in the incidence of ankle sprains\textsuperscript{23}. They concluded that decreased levels of neuromuscular control in athletes leads to a higher risk of injury to the lower extremity\textsuperscript{23}. Going further, studies such as Hertel et al\textsuperscript{25} and Gribble and Hertel\textsuperscript{27} have established the SEBT as a valid and reliable assessment of dynamic postural control. Therefore, if lower levels of dynamic postural control have been determined to be an injury predictor, and the SEBT can accurately measure dynamic postural control, it is surprising that our data did not support our hypotheses.

It is possible that certain limitations may have influenced our outcomes. First, baseline SEBT measurements were completed by a team of assessors rather than a single tester. While this increases testing efficiency, it may have allowed for variances in inter-rater reliability. It should be noted that each ATC that performed data collection had prior experience and training on the SEBT and was well-qualified to collect data. Also, Hertel et al.\textsuperscript{25} identified that both the intra and inter-rater reliability of the SEBT are high (ICC=0.93), therefore, any variance found in this study due to inter-rater reliability can be considered negligible. Additionally, a recent investigation by the primary investigator shows that inter-rater reliability of the SEBT conducted by multiple evaluators at two separate testing sites was strong, with ICC values ranging from 0.89-0.94\textsuperscript{68}. We followed procedures that have been suggested to create a consistent and reliable test, including appropriate practice trials\textsuperscript{42} and leg length normalization\textsuperscript{27}.

Other limitations of this study took place after preseason baseline data collection. While subjects were not permitted to wear shoes or any type of support on the ankle or knee while performing the assessment, injuries recorded took place during basketball
activities which allow and encourage the use of these devices within the sport. Therefore, subjects with known chronic ankle instability may have used prophylactic bracing and by doing so may not have suffered a traumatic lower extremity injury. In short, prophylactic taping and bracing may have limited the number of subjects within the injured group. Prophylactic braces are said to prevent injury by increasing the amount of afferent sensory and proprioceptive feedback from a limb. With athletes wearing prophylactic devices within this study, the true intrinsic neuromuscular control capabilities may have been improved by an extrinsic device.

The sport of basketball itself may have also had a significant effect on the results of the current study. The sport is played on a level and flat surface, unlike field sports, which may allow for the prevention of injuries caused by the playing surface. Also, the sport of basketball utilizes only five players at a time as opposed to other sports which utilize up to 11. Typically, the best athletes (with the highest levels of dynamic neuromuscular control) take the court at any given time. Therefore, those with the lower scores on the SEBT representing those with lower dynamic postural control were not given the opportunities for injury to occur because they were safe on the sideline. This limitation assumes that better basketball athletes have higher levels of dynamic postural control; however, it is worth consideration. Future studies should take into account starters versus non-starters and game versus practice injuries in an attempt to account for this limitation.

Finally, the role of fatigue in injury should be noted here. The level of fatigue or amount of physical activity completed before the injurious event was not recorded in this study. It is possible that fatigue played a causal role in the non-contact joint injuries.
Gribble et al\textsuperscript{50,51} identified that fatigue can diminish levels of postural control by altering proximal joint kinematics. Therefore, future research should be completed to determine the role of fatigue on both SEBT baseline measures and injury rates. These studies may consider accounting for when an injury occurs, either in practice (first hour, second hour, etc) or during a game (first quarter, fourth quarter, etc).

From the data presented in the current study, we can conclude that the SEBT has limited injury prediction capabilities among high school basketball athletes. This is in direct contrast to the findings of Plisky et al\textsuperscript{29}. Therefore, future studies should be performed that include larger sample sizes in order to determine the true nature of the SEBT in injury prediction. Also, future studies should attempt to control for the limitations seen in the current study including gender comparison, bilateral deficit analysis, and the examination of the role of fatigue in SEBT scores and injury rates. Finally, with more testing to increase the sample size, if a injury predictive normalized score for the SEBT can be established for any or all of the SEBT reach directions, prophylactic interventions should be implemented among the “at risk” population. Future studies should investigate which prophylactic intervention is most effective and efficient at reducing lower extremity injury rates in order to one day see the SEBT be used not only as an injury predictor, but as a tool for injury prevention.
References


