

A Thesis
entitled
Functional Movement Screening as a Predictor of Injury in High School Basketball
Athletes

by

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

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Objective: To determine if there is a significant difference in FMSTM scores between athletes that were injured and athletes that were not injured during the high school basketball season. A cut-off score that maximizes specificity and sensitivity of the FMSTM will also be determined. **Design, Setting, and Data Source:** Testing and data collection was performed at local Toledo area high schools. The testing included the girls' and boys' junior varsity and varsity teams with the ages of the athletes ranging from 14-18 years old. Before testing, each subject completed a questionnaire providing demographics such as age, gender, previous/current injuries, brace/tape use, and participation in conditioning programs. The data collected was separated into three groups: all subjects, subjects with previous history of lower extremity injury, and subjects without previous history of lower extremity injury. To determine if there is a significant difference in FMSTM scores between athletes that were injured and athletes that were not injured during the high school basketball season, a dependent t-test was performed on each group with significance set at the $P < .05$ level. To determine cut-off scores, a

receiver-operator characteristic (ROC) curve was used for each group to plot sensitivity (true positives) versus 1-specificity (false positives) for the screening test. A 2x2 contingency table was produced to dichotomize the athletes that suffered an injury and those who did not as well as those who were above or below the cut-off score. From the table, odds ratios, likelihood ratios, sensitivity and specificity were calculated. To estimate the amount of influence an athlete's FMSTM score has on the probability of suffering an injury, post-test odds and probability were calculated. **Results:** A total of 82 athletes that completed the 2009-2010 basketball season who participated in the pre-season FMSTM screening met our inclusion criteria. Of the 82 subjects, 20 of them suffered an injury that caused them to be removed from participation during the season. For subjects without a previous history of lower extremity injury, a t-test revealed a significant difference between the means scores of those injured (14.2 ± 1.8) and those who were not injured (15.6 ± 2.0) ($t = 2.2$; $df = 52$; $p = .034$). Analysis of the ROC curve showed that a cut-off score of 14.5 maximized the sensitivity and specificity of this group's data. The odds ratio for this group showed that athletes are almost 6 times more likely to get injured during the season if they score 14 or below on the FMSTM. The post-test probability for subjects with no previous history of lower extremity injury was calculated to be 34%, an increase of 19% from pre-test probability. **Conclusion:** This study demonstrated that high school basketball athletes who do not have previous history of injury and score a 14 or below on the FMSTM have a higher chance of suffering an injury over the period of the high school basketball season. However, the FMSTM did not have the ability to predict injury to high school basketball athletes with prior history of lower extremity injury. Clinicians should consider implementing the FMSTM to screen

for first time lower extremity injury as a low cost, reliable tool when used by trained individuals.

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Chapter 1

1.1 Introduction

Basketball was the most popular sport in the United States during the 2007 -2008 academic year, with 552,935 boys and 449,450 girls participating at the high school level.¹ Previously reported injury rates (case rate/100 players) in high school basketball were 28.3 for boys and 28.7 for girls .¹⁵ This equates to roughly 156,000 injuries for boys and 130,000 injuries for girls throughout the high school basketball season. The most common injuries reported in boys and girls high school basketball were sprains with girls' basketball injuries showing to be more severe, resulting in more surgeries and time loss due to injury.¹⁶ To help limit the amount of injuries that occur during the season, pre-participation screenings are performed during the pre-season. However, there has been limited research on the ability of pre-participation screening exams to predict whether an athlete is at risk of possible injury during the regular season.

Today's pre-participation screening exams typically consist of a medical exam followed by performance tests such as sit-ups, push-ups, endurance runs, sprints, and agility activities.² These performance tests often provide objective data that fails to evaluate the efficiency of an athlete's physical abilities.³ Cook et al³ reports that in these pre-participation screening exams, little consideration is given to functional movement deficits, which may predispose the athlete to injury. Recently, implementation of the Star

Excursion Balance Test (SEBT) into the pre-participation screening exam has been reported to be a reliable and predictive measure of lower extremity injuries in high school basketball players.¹³ However, the SEBT only assesses lower extremity injury, therefore to evaluate the functional movement of both the lower and upper body, Cook et al³ devised an evaluation tool called the Functional Movement ScreenTM (FMS).

The FMSTM is a combination of seven tests that assess multiple domains of function including balance, strength, and flexibility, through fundamental movement patterns. The purpose of each test is to place the athlete in a position where muscle weaknesses and imbalances are noticeable in the event the athlete does not have the required stability and mobility to correctly perform the task. It is suggested that muscle weakness and imbalance may cause the athlete to develop compensatory movement patterns, which results in poor biomechanics and an increased risk of injury.³ Each test was designed around the kinetic link model that portrays the body as a linked system of independent segments. Neuromuscular control is an integral part of the kinetic link model, in which each body segment needs to function properly in order for the athlete to perform the seven tests with efficient movements. Lingering deficits from previous injuries the athlete has suffered also may be assessed with the FMSTM. If the athlete did not get the medical attention needed for the previous injuries, he/she could have developed poor movement patterns because of compensation due to altered proprioceptive input, mobility, and stability.³ Whether the poor movement pattern is due to muscle weakness and imbalances or previous injury, the FMSTM is designed to help the clinician identify the problem. The clinician will then be able to devise and implement

interventions to eliminate the deficiency of the athlete and possibly prevent future injuries.

Minick et al¹¹ has performed research to determine the interrater reliability of the FMSTM. Minick et al¹¹ used a total of 4 raters, 2 expert and 2 novice raters, each independently score the FMSTM of 40 subjects (23 female, 17 male). An expert rater was defined as an individual who was instrumental in the development of the FMSTM with over 10 years of experience with the testing tool. Novice raters were defined as having taken the standardized introductory training course and have used the FMSTM less than a year. Minick et al¹¹ compared the scores of the 2 experts as well as the scores of the 2 novice raters. Also evaluated were the scores comparing paired experts and novice raters. During the study, the level of agreement was calculated between each pair of raters for each test.

Minick et al¹¹ calculated a weighted Kappa statistic for each of the 7 tests between the 2 pairs of raters. The Kappa statistic is a statistical analysis tool that measures “true” agreement beyond which is expected by chance.¹¹ The Kappa value is a ratio of the proportion of times that the raters agree, corrected for chance agreement, to the maximum proportion of times that the raters could agree.

The kappa values of both individual right and left sides and the final score for each of the 7 tests were analyzed. Results showed that the novice raters demonstrated excellent agreement on 6 of the 17 scores, substantial agreement on 8 of the 17 scores, and moderate agreement on 3 of the 17 scores. There was more variance in the scoring of the expert raters, as they showed excellent agreement on 4 of the 17 scores, substantial

agreement on 9 of the 17 scores, and moderate agreement on 4 of the 17 scores.¹¹ Minick et al then compared the average scores of the paired novice and expert raters. The results showed excellent agreement on 14 of the 17 scores and substantial agreement on 3 of the 17 scores. With their results, Minick et al indicates that the FMSTM has a high interrater reliability and can confidently be applied by trained individuals when the standard procedure is used.¹¹

Previous research by Kiesel et al⁹ has shown that a score of 14 or less on the FMSTM was successful in predicting serious injury among professional football players (specificity = 0.91, sensitivity = 0.54), who participate in a high contact sport with a very high risk of injury. Injury definition used by Kiesel et al⁹ was membership on the injured reserve and time loss from play of three weeks. The purpose of our study is to determine if the FMSTM can be used as a pre-screening tool to identify if an athlete is at risk of injury prior to the start of the season. We will be examining participants in a sport with a lower risk of contact (basketball) to minimize the contact injuries that are a part of sport, but are not typically a product of inefficient or altered neuromuscular control. Therefore, the injuries that occur during the basketball season may be attributed more to muscle imbalances and weaknesses or previous injury compensations, which will help determine the effectiveness of the predictive capabilities of the FMSTM.

1.2 Statement of the Problem

Information on the ability of pre-participation screening tools to identify injury risk in basketball players is limited. While the FMSTM appears to have some usefulness

among professional football players, its application to high school male and female basketball players is unknown.

1.3 Statement of the Purpose

The primary purpose of the study will be to determine if there is a significant difference in FMSTM scores between athletes that were injured and athletes that were not injured during the high school basketball season. The secondary purpose is to determine the cut-off score of the FMSTM that maximizes specificity and sensitivity.

1.4 Hypotheses

H₁: Preseason data on the FMSTM will show a significant difference between injured basketball athletes that do and do not suffer a lower extremity injury during the competition season.

H₂: A cut -off score between 14 and 15 will maximize sensitivity and specificity on the FMSTM.

1.5 Limitations

A significant limitation for this study would be having the athletes return parent consent forms, a requirement due to most of the athletes being under the age of 18 years old. During the season, some athletes choose to wear ankle braces or get ankles taped in order to prevent injury. Other limitations included exclusion from this study due to vestibular dysfunction, lower extremity injury, concussion within the past three months, or refusal to perform the FMSTM.

Chapter 2

Literature Review

2.1 Knee Anatomy

The knee, a modified hinge joint, consists of two joints: the tibiofemoral joint and the patellofemoral joint. Tremendous forces are placed on the knee joint, which relies on the tibia, femur, patella, ligaments, the capsule, and musculature to provide stability within the joint. While providing stability and control under loaded conditions, the knee joint also must allow for flexion and rotation.

2.1.1 Tibiofemoral Joint

The tibiofemoral is the largest joint within the body, consisting of 2 condyloid articulations between the tibia and the femur.⁵ These articulations are composed of the medial and lateral condyles of the femur, the longest and strongest bone in the body, articulating with the corresponding tibial plateaus. This modified hinge joint is capable of freedom of motion in two planes: (1) flexion and extension and (2) internal and external rotation.²² The hyaline cartilage covered medial and lateral condyles are convex in shape and are separated by the intercondylar notch. The lateral condyle is smaller than the medial condyle, contributing to the valgus and anteroposterior alignment of the knee.⁵

The shapes of the femoral condyles allow the medial femur to rotate on the tibia and also allows for limited anteroposterior translation of the medial femur.

2.1.2 Collateral Ligaments

There are two collateral ligaments that help stabilize the tibiofemoral joint: the medial collateral ligament (MCL) and the lateral collateral ligament (LCL). The MCL, which is the primary medial stabilizer of the knee, is formed by two layers: the deep layer and the superficial layer. The MCL originates from a broad band on the medial femoral condyle inferior to the adductor tubercle and travels medially along the joint line, attaching to the medial tibial plateau. The deep layer of the MCL is separated from the superficial layer by a bursa and attaches to the medial meniscus. The MCL functions mainly to protect the knee against valgus forces, but also contributes to the knee as a restraint against external rotation of the tibia and anterior translation of the tibia on the femur.²² Both layers of the MCL are taut when the knee is in complete extension. As the knee is being flexed, the tension is transferred from the anterior fibers being in midrange and to the posterior fibers in complete flexion.

The LCL attaches to the lateral femoral condyle and inserts proximally on the fibular head. The LCL functions to protect the knee against varus forces when the knee is between full extension and 30 degrees of flexion.²² The LCL also helps with controlling the internal and external rotation of the tibia on the femur.

2.1.3 Cruciate Ligaments

The cruciate ligaments, consisting of the anterior cruciate ligament and the posterior cruciate ligament, are intraarticular, but are not within the synovial capsule.

Originating from the anteromedial intercondylar eminence of the tibia, the ACL runs posteriorly, inserting medially on the lateral femoral condyle. The ACL acts to stabilize the knee against anterior translation, internal rotation, and external rotation of the tibia on the femur and hyperextension of the tibiofemoral joint. Consisting of the anteromedial bundle and posterolateral bundle, a juxtaposition of the ACL attachments occur as the knee moves from extension to flexion.²² In full extension, the posterolateral bundle is taut, while in full flexion, the anteromedial bundle is taut.

Attaching on the posterior side of the tibia, the PCL runs superiorly in an anterior direction to attach laterally on the femur's medial condyle. The PCL is considered to be the primary stabilizer of the knee because it is stronger and wider than the ACL.²² The PCL is composed of 3 segments: the anterolateral, posteromedial, and the meniscofemoral segments. Together, these segments are the primary restraint against posterior displacement of the tibia on the femur while also serving as a restraint against external tibial rotation.²² During the knee's range of motion, the anterolateral bundle is the primary restraint of posterior tibial displacement between 40 and 120 degrees of flexion. When the knee is flexed beyond 120 degrees, the anterolateral and posteromedial bundles both become taut.

2.1.4 Arcuate Ligament Complex and Tibiofibular Syndesmosis

Also providing stability to the knee joint is the arcuate ligament complex and the proximal tibiofibular syndesmosis. The arcuate ligament complex provides support to the posterolateral joint capsule. Made up of the arcuate ligament, LCL, oblique popliteal ligament, popliteus tendon, and the lateral head of the gastrocnemius, the arcuate

ligament complex helps the cruciate ligaments in controlling posterolateral rotatory instability. The articulation between the fibular head and indentation on the proximal tibia makes the proximal tibiofibular syndesmosis more stable than the distal tibiofibular syndesmosis.²² This joint is stabilized by the superior anterior and posterior tibiofibular ligaments and the interosseous membrane.

2.1.5 Meniscus

Between the articulation of the femur and tibia is the meniscus, which helps make the articulation more anatomically congruent. This fibrocartilaginous structure is divided into the medial and lateral menisci and helps to: (1) deepen the articulation and disperse the load over a greater percentage of the joint surface, (2) improve lubrication for the articulating surfaces, (3) provide shock absorption, (4) and increase the stability of the joint.²² The menisci are wedge shape and their outer borders are thicker than their inner rims, making the knee more stable when bearing weight than when it is not. Each meniscus is divided into thirds: anterior, middle, and posterior. The anterior and posterior horns of the menisci are the portions of the menisci that are most frequently torn. The outer rims have a narrow vascular zone, which supplies blood to the meniscus in that zone. The inner portions of the menisci are avascular, making the healing of tears more difficult. The avascular zones of the menisci rely on the delivery of nutrients from the synovial fluid, instead of from blood supply like the vascular zones. The medial meniscus, shaped like a C, is wider posteriorly than anteriorly, while the lateral meniscus is shaped more like a circle. The menisci are attached to the tibia via the coronary ligament and are connected to each other via the transverse ligament. Anteriorly, the menisci are attached to the patellar tendon by the patelomeniscal ligaments. The lateral

meniscus attaches to the lateral side of the medial femoral condyle via the meniscomfemoral ligaments, the ligament of Wrisberg and the ligament of Humphrey.²² The lateral meniscus is also attached to the popliteus muscle by the joint capsule and the coronary ligament.

2.1.6 Joint Capsule

Surrounding the knee joint is a fibrous joint capsule. The capsule runs superior to the femoral condyles along the medial and lateral sides of the knee joint and attaches distal to the tibial plateau on the anterior portion of the knee. On the posterior side of the knee, the capsule attaches above the joint line on the posterior side of the femoral condyles and inferiorly to posterior tibial condyle.²² The capsule is reinforced by surrounding structures to add strength to the capsule. Medially and laterally, the capsule is reinforced by the medial collateral ligament (MCL), patellofemoral ligament, and retinaculum. The oblique popliteal ligament and arcuate ligaments reinforce the capsule posteriorly, while the patellar tendon reinforces the capsule on the anterior side. Lining the articular portions of this fibrous joint capsule is a synovial capsule, which surrounds the articular condyles of the femur and tibia.²² The synovial capsule inserts along the femur's intercondylar notch and the tibia's intercondylar eminences on the posterior side of the articulation, which excludes the cruciate ligaments from the synovial membrane.²²

2.1.7 Patellofemoral Joint

The largest sesamoid bone in the body, the patella, lies within the patellar tendon and articulates with the femoral trochlea. The main function of the patella is to increase the mechanical advantage of the extensor muscles by changing the angle of pull to

increase the distance away from the axis of rotation. This mechanical advantage results in reducing the amount of force required by the quadriceps to extend the knee by 15% to 30% through the knee's range of motion.⁷ The stability of the patella within the trochlea's groove relies on bony, ligamentous, and musculature restraints.

The articular surface of the patella is made up of 3 hyaline cartilage covered facets. The medial and lateral facets each have superior, middle, and inferior articular subdivisions, while the odd facet is not further subdivided. The patella tracks within the femoral trochlear groove during the movements of flexion and extension of the knee. Medial tracking of the patella occurs within the femoral trochlear groove between 45 and 18 degrees of knee extension when moving from flexion, but tracks laterally within the femoral trochlear groove during the final 18 degrees.²² The patella makes initial contact with the femoral trochlear groove at 10 to 20 degrees of flexion. As the knee approaches 20 to 30 degrees of flexion, the patella becomes seated within the femoral trochlear groove. Patellofemoral contact isn't constant through the knee's range of motion, but the surface area contact is reported between 60 and 90 degrees of flexion. The amount of force placed on the patella also varies. The forces range from as low as 0.5 times the body weight when walking on flat surface to 3.3 times the body weight when walking up and down stairs or running on hills.^{19, 22} The highest compressive force placed on the patella occurs at 30 degrees of knee flexion.

The patellar retinaculum is responsible for maintaining the patella's position throughout the knee's range of motion. Originating off the vastus lateralis and the iliotibial band, the lateral retinaculum inserts onto the patella's lateral border. The medial retinaculum, inserting on the medial border of the patella, originates from the distal

portion of the vastus medialis and adductor magnus. The medial and lateral patellofemoral ligaments are formed by thickening of the superior portion of the knee's fibrous capsule and inserts on the patella's superior border.²²

The patella's function is mainly affected by the quadriceps femoris muscles. The patella is pulled inferiorly during flexion via the patellar tendon's attachment to the tibia and superiorly during extension via the quadriceps femoris and its tendon. The vastus lateralis pulls the patella laterally, while the vastus medialis oblique (VMO) guides the patella medially, preventing lateral patellar subluxation.

The patellofemoral articulation also consists of 4 bursae to protect against direct trauma and decrease friction within the joint. The bursae include the: (1) suprapatellar bursa, (2) prepatellar bursa, (3) subcutaneous infrapatellar bursa, (4) and the deep infrapatellar bursa. The suprapatellar bursa, which lies deep at the distal end of the quadriceps femoris muscle group, is an extension of the knee's joint capsule and allows free movement over the distal femur. The prepatellar bursa lies above the anterior portion of the patella, allowing the patella to move freely beneath the skin. The subcutaneous infrapatellar and deep infrapatellar bursae protect the distal portion of the patellar tendon against friction and direct blows. The subcutaneous bursa is the more superficial of the two, lying over the tibial tuberosity, while the deep infrapatellar bursa lies between the patellar tendon and the tibia. There is also an infrapatellar fat pad that separates the patellar tendon and the deep infrapatellar bursa from the knee's joint capsule.²²

2.1.8 Muscles of the Knee

The main responsibilities of muscles that act on the knee are to either flex or extend the knee, while the flexor musculature has a secondary responsibility of tibial rotation. The direction of tibial rotation depends on where the flexors attach. The flexors internally rotate the tibia if they attach on the medial side and externally rotate the tibia if they attach on the lateral side.²²

The anterior muscles that act on the knee consist of the vastus lateralis, vastus intermedius, vastus medialis, vastus medialis oblique, and the rectus femoris. This group of muscles is also commonly known as the quadriceps femoris. This group of musculature has a common insertion point on the tibial tuberosity via the patellar tendon and act to extend the knee. Along with knee extension, the rectus femoris also serves as a hip flexor because of its origination at the anterior inferior iliac spine. The vastus medialis oblique guides the patella medially when the knee is being extended.²²

Posteriorly, the muscles that act on the knee are the semitendinosus, semimembranosus, and the biceps femoris. This group of musculature is commonly known as the hamstring muscle group. Together, these muscles act to flex the knee and extend the hip. The posterior muscles also serve as rotators of the tibia. The biceps femoris externally rotates the tibia while the semimembranosus serves to internally rotate the tibia.²² The posterior muscles also help to reduce the amount of shear force placed on the ACL with flexion of the knee is beyond 20 degrees.

The popliteus muscle, which reinforces the posterolateral capsule, has two functions depending on the situation of the leg. When in an open kinetic chain, the

popliteus muscle acts as an internal rotator of the tibia on the femur, but when in a closed kinetic chain, the muscle acts as an external rotator of the femur on the tibia. The popliteus is more responsible for unscrewing the knee from its locked position in extension, rather than for flexion of the knee. Also formed by the posterior musculature is the popliteal fossa. Within this fossa is the popliteal artery and vein, the tibial, common peroneal, and posterior femoral cutaneous nerve, and the small saphenous vein.²²

Forming the pes anserine muscle group is the gracilis, sartorius, and the semitendinosus muscles. This muscle group acts to flex the knee and also serves to internally rotate the tibia when the foot is not planted and externally rotates the femur on the tibia when the foot is planted. The sartorius, even though it is located on the anterior side of the femur, is a flexor of the knee joint because the muscle crosses posterior to the knee axis.²² The sartorius also serves to help with hip flexion because its origin is proximal to the hip joint.

The iliotibial band (IT band) runs along the lateral side of the femur, attaching to Gerdy's tubercle of the tibia. As the IT band travels along the femur, the lateral patellar retinaculum and the biceps femoris tendon attach to the band. Because of the attachment to the lateral joint capsule, the IT band is a big contributor to knee stability and patellofemoral pathology.²² The IT band's angle of pull changes as the knee is flexed or extended. When the knee is fully extended, the IT band's angle of pull is that of a knee extensor, but when the knee is flexed past 30 degrees, the IT band's angle of pull becomes that of a knee flexor.

2.2 Ankle Anatomy

The lower leg includes the tibia and fibula, which form a junction with the talus to create the ankle mortise. The ankle mortise consists of three articulations, the talocrural joint, the subtalar joint, and the distal tibiofibular syndesmosis, which work together to allow movement of the rearfoot.⁷ The tibia and fibula function to distribute the weight-bearing forces along the lower leg to allow proper range of motion in the ankle mortise during walking and running. The medial malleolus is located on the distal head of the tibia and provides the site of attachment for the deltoid ligaments. The tibia is the main weight-bearing bone of the lower leg and is also the site of origination for many of the muscles that act on the ankle, foot, and toes.²² Lateral to the tibia, and connected via the interosseous membrane, is the fibula. The fibula provides lateral stability to the ankle mortise while also serving as a site for muscular origin and attachment and ligamentous attachment. The distal portion of the fibula is the lateral malleolus, which forms the lateral wall of the ankle mortise. The lateral malleolus extends more distally than the medial malleolus, thus providing more stability by being able to limit eversion better than the medial malleolus can limit inversion.²²

2.2.1 Talocrural Joint

The tibia and fibula articulate with the talus to form the talocrural joint. This joint is a modified synovial hinge joint with one degree of freedom of movement: dorsiflexion and plantarflexion.²² There are three ligaments that support the lateral side of the talocrural joint: anterior talofibular (ATF) ligament, calcaneofibular (CF) ligament, and the posterior talofibular (PTF) ligament. The ATF ligament originates from the

anterolateral surface of the lateral malleolus and inserts onto the talus by the sinus tarsi. The ATF ligament is taut during plantarflexion of the joint and limits the motion of inversion of the talocalcaneal unit in this position. The ATF ligament also limits the amount of translation of the talus on the tibia.²² The CF ligament, unlike other ligaments, is extracapsular. This ligament attaches to the lateral malleolus and runs inferiorly and posteriorly to the insertion on the calcaneus, providing the primary restraint against talar inversion. The PTF ligament, which is the strongest of the 3 lateral ligaments, runs in an inferior and posterior direction from its attachment on the posterior side of the lateral malleolus to attach onto the talus and calcaneus. The PTF ligament limits posterior displacement of the talus on the tibia.²²

Providing medial ligamentous support to the talocrural joint is the deltoid ligament. The deltoid ligament is a group of ligaments comprised of the anterior tibiotalar (ATT) ligament, tibiocalcaneal (TC) ligament, posterior tibiotalar (PTT) ligament, and the tibionavicular (TN) ligament. The ATT ligament originates anteromedially off of the medial malleolus and inserts superiorly onto the medial talus. The TC ligament runs inferiorly from the medial malleolus and attaches inferiorly to the calcaneus. On the posterior of the deltoid ligament, the PTT ligament runs from the medial malleolus and attaches to the posterior side of the talus. The ATT, TC, and PTT ligaments all work together to prevent eversion of the talus. The fourth ligament of the deltoid ligament, the TN ligament, attaches to the medial malleolus beneath the TC ligament and inserts onto the medial surface of the navicular bone to limit lateral translation/rotation of the tibia on the foot.²²

2.2.2 Subtalar Joint

The subtalar joint, formed by the articulation between the talus and calcaneus, provides one degree of freedom of movement, inversion and eversion. The subtalar joint consists of the posterior subtalar joint, formed between the inferior posterior facet of the talus and the superior posterior facet of the calcaneus, and the talocalcaneonavicular joint, formed by the head of the talus, the anterior -superior facets, the sustentaculum tali of the calcaneus, and the proximal surface of the tarsal navicular.⁷

2.2.3 Distal Tibiofibular Syndesmosis

The distal tibiofibular syndesmosis is the union between the convex facet on the fibula and the concave facet on the tibia by a dense, fatty tissue. The syndesmosis is held together by the anterior and posterior tibiofibular ligaments and the crural interosseous (CI) ligament. The distal tibiofibular syndesmosis maintains stability of the ankle mortise while allowing for rotation and slight spreading of the mortise. The anterior and posterior tibiofibular ligaments prevent anterior and posterior displacement of the fibula on the tibia, while the CI ligament functions as a fulcrum to motion at the lateral malleolus.²²

2.2.4 Muscles of Lower Leg

The muscles that act upon the ankle reside in one of the four compartments of the lower leg, either the anterior, lateral, superficial posterior, or the deep posterior. Each of these compartments also house neural structures that innervate the lower leg muscles and the blood supply to the lower leg.

The muscles in the anterior compartment of the lower leg are the tibialis anterior, the extensor hallucis longus (EHL), the extensor digitorum longus (EDL), and the peroneus tertius. All of these muscles in the anterior compartment act as dorsiflexors of the ankle. The tibialis anterior is the most superficial of these muscles and is also the prime mover for ankle dorsiflexion and inversion. The EHL and EDL not only function to extend the toes in the foot, but the EHL also assists with inversion while the EDL helps with eversion. Due to the attachment site at the dorsal surface of the fifth metatarsal, the peroneus tertius contributes more to eversion than it does to dorsiflexion. Just above the anterior part of the ankle mortise is the extensor retinaculum, which secures the tendons of the extensor muscles in the anterior compartment. Innervating most of the muscles within the anterior compartment is the deep peroneal nerve, which runs from the distal portion of the fibula along the interosseous membrane behind the tibialis anterior.²² Following the path of the deep peroneal nerve and supplying the anterior compartment with blood supply is the anterior tibial artery, which branches off into the dorsalis pedis artery to also supply blood to the dorsum of the foot.

The lateral compartment contains two muscles, the peroneus longus and peroneus brevis. The peroneus longus is the most superficial of these muscles and covers most of the peroneus brevis. Tendons of both muscles run behind the lateral malleolus and are held there by the superior and inferior peroneal retinacula.²² The peroneus brevis attaches on the lateral aspect of the foot at the styloid process on the base of the fifth metatarsal, while the peroneus longus tendon crosses the plantar portion of the foot, attaching to the base of the first metatarsal and first cuneiform. Together, these two muscles act to evert the foot and also help with plantarflexion. Inside the lateral

compartment is the superficial peroneal nerve, which innervates the peroneus brevis and the peroneus tertius. The superficial peroneal nerve also works together with the common peroneal nerve to innervate the peroneus longus. Running lateral to the interosseous membrane inside the lateral compartment is the peroneal artery. The peroneal artery branches off of the posterior tibial artery and supplies blood to the lateral compartment and lateral ankle.²²

Inside the superficial posterior compartment is the triceps surae muscle group, which consists of the gastrocnemius, soleus, and the plantaris. The gastrocnemius and the plantaris originate from the femoral condyles, making these two muscles two-joint muscles.²² The soleus crosses only one joint, the ankle, and originates off the posterior tibia. Via the Achilles tendon, the gastrocnemius and soleus insert onto the calcaneus and plantarflex the ankle. If the knee is extended, the gastrocnemius is the most involved in plantarflexion. To decrease friction between the Achilles tendon and the calcaneus lies the subtendinous calcaneal bursa. Another bursa, the subcutaneous calcaneal bursa, lies between the Achilles tendon and the skin to protect the tendon from direct blow and also to decrease friction from skin and footwear.²² The tibial nerve, the longest branch of the sciatic nerve, runs between the medial and lateral heads of the gastrocnemius to supply innervation to all muscles within the superficial and deep posterior compartments. Branches of the tibial nerve continue proximally around the medial malleolus to the plantar surface of the foot. The posterior tibial artery supplies blood supply to the superficial posterior compartment and follows along the tibial nerve.²²

The deep posterior compartment houses the tibialis posterior, flexor digitorum longus (FDL), and the flexor hallucis longus (FHL). The tibialis posterior is an adductor

of the forefoot and also assists in plantarflexion and inversion. The FDL and FHL mainly act to flex the toes, but also help with plantarflexion and inversion of the ankle.

2.3 High School Epidemiology

During the 1995-1997 seasons, Powell et al.¹⁵ conducted a cohort observational study of high school athletes to illustrate the risk of injury associated with 10 popular high school sports. Powell et al.¹⁵ compared the relative frequency of injury, the selected injury rates among sports, and the participation conditions within each sport. The study consisted of high school athletes on the varsity sports rosters for football, wrestling, baseball, field hockey, softball, girls' volleyball, boys' and girls' basketball, or boys' and girls' soccer.

Athletic trainers used a surveillance protocol defined by the authors to report daily participation and injuries within the sports programs. Exposure data during the study included the type of session (practice/game) and the number of participants for each session.¹⁵ The study also defined the meaning of a reportable injury, which included: (1) any injury that causes cessation of participation in the current game or practice and prevents the player's return to that session, (2) any injury that causes cessation of a player's customary participation on the day following the day of onset, (3) any fracture that occurs, even though the athlete does not miss any regularly scheduled session, (4) any dental injury, including fillings, luxations, and fractures, and (5) any mild brain injury that requires cessation of a player's participation for observation before returning, either in the current session or the next session.¹⁵ The data recorded when a reportable injury occurred included the date of injury, date of return, clinical impression, extremity,

time of injury, action taken, type of management, nature of injury, player position, player activity, team activity, and the playing surface. Injury data was directly linked to the athlete data that included height, weight, and age. To record the data, two systems were used during the study: (1) a customized version of the Sports Injury Monitoring System (SIMS) (Med Sports Systems, Iowa City, IA) for athletic trainers with computer capability; and (2) a parallel system of paper forms for those athletic trainers without computer capability.¹⁵

A criterion was formed for the selection of schools that participated in this study. A total of 300 athletic trainers volunteered for the study, but only 246 were selected because they (1) worked directly with high school sports programs on a daily basis, (2) fell within a geographic distribution among the 50 states, and (3) fit a broad representation from different size schools.¹⁵ Before participation, each certified athletic trainer was required to obtain written permission from his or her school's athletic director and submit the approval to the research office. The surveillance protocol was distributed to the certified athletic trainers in the form of a user's manual prior to the beginning of the study that consisted of the operational definitions and the reporting requirements. Athletic trainers reported their data monthly, either electronically or by mail, to the central office. The authors of the study consulted with any new athletic trainers at the clinical sites that entered the study to ensure a smooth transition. To help distinguish injuries, categories were developed based on calendar days lost due to injury. The categories were defined as minor (<8 days lost), moderate (8 to 21 days lost), and major (>21 days lost). Injuries that were reported were also identified as new injuries or reinjuries.¹⁵ An athletic exposure was defined as the number of participants for each

game or practice. An individual who dresses for a game, but didn't play was not counted as a game exposure.¹⁵ To accurately record and describe an injury, an extensive coding structure was developed. The injuries recorded by the athletic trainers were recoded into categories to provide a basic comparative description.¹⁵

Amongst the ten study sports, Powell et al.¹⁵ gathered data for 3,195 teams - seasons and 75,298 player-seasons. Over the three years of the study, 23,566 injuries were recorded with an average of 6,000 athletes injured at least once each year. Girls' sports accounted for 44.5% of the exposures over the three years of the study.¹⁵

At the end of the study, football had the highest player rate per 100 players, case rate per 100 players, and case rate per 1,000 athlete-exposures. The sport with the lowest player rate per 100 players was baseball and the sport with the lowest case rate per 1,000 athlete-exposures was volleyball.¹⁵ There was a difference in risk of injury, depending on whether the athlete was participating in practice or a game. Injuries that occurred in practice accounted for an average of 55.5% of the injuries recorded, with a range of 68.8% in volleyball to 40.7% in boys' soccer. The incidence density ratio (IDR) for 9 sports showed a higher injury rate per 1,000 athlete exposures for game conditions (Range: 1.5 to 5.0). Volleyball was the only sport with a lower IDR for games than practice, showing an injury rate for practice 2.3 times greater than for games.¹⁵

There were a higher percentage of reported lower extremity injuries (mean = 59.9%) than upper extremity injuries (mean = 20.8%), except for wrestling where upper extremity injuries (mean = 32.3%) occurred more than lower extremity injuries (mean = 22.2%).¹⁵ The percentage of hip/thigh/leg injuries were similar for field hockey (21.8%)

and boys' (28.0%) and girls' (25.8%) soccer, while ankle/foot injuries highest in boys' (39.3%) and girls' (36.4%) basketball and boys' (33.5%) and girls' (33.5%) soccer.¹⁵ Head/neck/spine injuries occurred more in football (13.3%) than all other sports (Range: 1.9% to 9.5%). Of the fracture injuries, the highest percentages came from boys' baseball (8.8%), basketball (8.6%), and soccer (8.5%) and softball (8.4%). The most frequent injury in boys' (44.8%) and girls' (45.2%) were sprains, while also being the largest percentage of reported injuries for baseball (31.2%) and softball (32.2%).¹⁵

Also during the study, 73.5% of the reported injuries resulted in a time loss from participation of less than 8 days. Baseball (31.0%) and wrestling (32.6%) had the highest percentage of reported injuries that resulted in more than 7 days of time loss, while field hockey (20.4%) and softball (22.9%) had the fewest.¹⁵

Out of all the sports in the study, 10% of the reported injuries were categorized as reinjuries. Boys' soccer (8.4%) reported the lowest amount of reinjuries, while girls' basketball (13.6%) reported the highest amount of reinjuries.¹⁵ Surgery was a result of 608 (2.6%) reported injuries, where girls' sports accounted for 180 (29.6%) of reported surgeries.¹⁵ Of the injuries reported for the girls' sports resulting in surgery, the most injuries came from basketball (4.0%) and the fewest came from field hockey (1.2%). A total of 369 of the 608 surgical cases were knee injuries. Four of the five girls' sports had higher amounts of knee injuries than any of the boys' sports.¹⁵

Overall, this study was performed very well. Powell et al.¹⁵ made sure to educate the certified athletic trainers on how to record and report the injuries over the duration of the study. The extensive coding system provided a system for the athletic trainers to

report the injuries and keep the data true and synonymous. Powell et al.¹⁵ did a good job comparing the injuries between each gender and sport with the use of tables. The included tables in the study showed the total injuries in each sport, amount of injured players, injury rates, reported injuries and injury rates by session (game/practice), reported injuries by body category, reported injuries by type of injury, and reported injuries by severity. To further this study, I would breakdown the injuries by grade/age and also include if it was a contact injury or a non -contact injury.

2.4 Injury Prediction

2.4.1 Star Excursion Balance Test

The Star Excursion Balance Test (SEBT) has been used as a tool to predict lower extremity injury among athletes. A study by Plisky et al.¹³ followed boys' and girls' basketball teams at 7 Indiana high schools over the 2004-2005 season. This study consisted of 235 athletes (130 boys, 105 girls) from the freshmen, junior varsity, and varsity teams of these Indiana high schools. Exclusion from this study included head cold or vestibular dysfunction, lower extremity injury within the past month, concussion within the past 3 months, or athlete electing not to participate in SEBT testing. Plisky et al.¹³ obtained written consent from athlete and parent/guardian before the study in order to participate in the SEBT testing.

Prior to the start of the season, each athlete completed a questionnaire providing baseline characteristics such as gender, age, previous time-loss injuries, current lower extremity symptoms, brace or tape use, and conditioning programs participation.¹³ To normalize the data from testing, the athletes' limb lengths were also taken, measured

from the anterior superior iliac spine to the most distal portion of the lateral malleolus prior to testing.

In the study, a SEBT protocol was developed to ensure congruency in the testing of each athlete within all the schools. The protocol began with the athletes viewing an instructional video that demonstrated the SEBT and testing procedures. In a prior study, Hertel et al.⁸ discovered a significant learning effect where the longest reach distances occurred after 6 trials followed by a plateau. Due to this discovery, Plisky et al.¹³ had the athletes perform 6 practice trials on each leg in each of the 3 reach directions before the actual testing in their SEBT protocol. For testing, the athlete stood on 1 leg in the center of the grid with toes at the starting line. While in single leg stance, the athlete was asked to reach with free leg in the anterior, posteromedial, and posterolateral directions relative to the stance foot. The testers marked the maximal reach distance on the measuring tape with erasable ink where the most distal part of the athlete's foot touched the tape. Trials were discarded and repeated if the athlete failed to maintain unilateral stance, lifted or moved stance foot from grid, touched down with reach foot (heavy touch), or if the athlete failed to return the reach foot to starting position. The process was then repeated for the opposite leg. Three trials were done for each reach direction and the greatest of the trials was used for analysis. For overall performance analysis, Plisky et al.¹³ summed up the greatest reach distances to get a composite reach distance score.¹³

Plisky et al.¹³ conducted a pilot study before the start of the basketball season to establish the reliability of the SEBT and limb length measurements. The researchers measured the limb lengths and SEBT reach scores of 10 female and 4 male basketball players (n = 28 limbs). The subjects then got 5 minutes of rest before the limb lengths

and reach scores were measured again. To calculate the intrarater reliability, Plisky et al.¹³ used intraclass correlation coefficient ($ICC_{3,1}$) and method error. Results of the $ICC_{3,1}$ for the pilot testing ranged from 0.84 to 0.87 for the 3 reach directions of the SEBT and 0.99 for the limb length measurements.¹³ To determine the test-retest reliability and response stability, Plisky et al.¹³ measured 10 male and 10 female athletes who participated in the study ($n = 40$ limbs) at the end of the season. The preseason measurements were then compared to the postseason measurements showing that the SEBT test-retest reliability had an $ICC_{3,1}$ ranging from 0.89 to 0.93 and a method error coefficient of variation ranging from 3.0% to 4.6%, indicating good stability.¹³ The method error coefficient of variation represents the percentage of variation between the preseason and postseason measurements.^{13, 14}

Before the start of the basketball season, Plisky et al.¹³ trained the coaches and certified athletic trainers in the use of the Athletic Health Care System Daily Injury Report (DIR).^{13, 17, 18} During the season, the coaches were mainly responsible for using the DIR to record injuries and athletic participation. During the season, Plisky et al.¹³ used the definition of a lower extremity injury as any injury to the limb including the hip, but not the lumbar spine or sacroiliac joint, which occurs during the school's basketball practice or game and causes restriction or inability of participation for next practice or game.^{10, 13, 15, 16} Coaches and certified athletic trainers recorded the date of injury, body part, type of injury, and date of return to unrestricted participation for each injury that occurred. At the end of each month, the DIR was collected to make certain it was completed in detail and to compare the coaches' and certified athletic trainers' reports.¹³ Any discrepancy between the coach and athletic trainer required an interview to

determine if a time-loss injury occurred. At the completion of the season, athletes were issued another questionnaire that asked athletes about any time-loss injuries that occurred during the season, any lower extremity taping or bracing used, or participation in any balance or performance training programs. Plisky et al.¹³ then compared the answers of the end of the season questionnaire to the results of the DIR received throughout the season. Any discrepancies in the final questionnaire and the DIR required an interview with the coaches and certified athletic trainers to determine if a time-loss injury occurred according to the injury definition being used.¹³

For data analysis, means and standard deviations were calculated for baseline characteristics, SEBT reach distance, and limb length. Since SEBT reach distance has been previously associated with limb length, Plisky et al.¹³ normalized the SEBT reach distance to limb length in order to have a more accurate comparison between the athletes.^{6, 13} The normalized value was calculated as a percentage of the limb length by dividing the SEBT reach distance by the limb length and multiplying the answer by 100. The composite reach distance was also normalized by dividing the sum of all 3 reach distances then dividing by 3 times the limb length and then multiplied by 100.¹³

At the end of the season, 54 athletes (23.0%) sustained a lower extremity injury and 50 of these injuries (92.5%) were considered traumatic injuries (eg, ankle sprain, knee sprain). The other 4 injuries were categorized as overuse-related injuries (eg, medial tibial stress syndrome, patellar tendonitis).¹³ Plisky et al.¹³ found that for all athletes, anterior right/left reach distance difference greater than or equal to 4 cm, decreased normalized right anterior reach distance, and decreased normalized posteromedial, posterolateral, and composite reach distances bilaterally were significantly

associated with lower extremity injury ($P<.05$). The risk of injury was also different between the girls and boys. An anterior right/left reach distance difference of greater than or equal to 4 cm and decreased normalized anterior, posteromedial, posterolateral, and composite reach distances bilaterally were significantly associated with lower extremity injury for the girl basketball players ($P<.05$).¹³ For boys, an anterior right/left reach distance difference greater than or equal to 4 cm was the only category that was significantly associated with lower extremity injury ($P<.05$).¹³

Plisky et al.¹³ made adjustments to the regression model for gender, grade, previous injury, participation in a neuromuscular training program since initial measurement, lower extremity tape/brace use and all other potential factors found to be associated with risk of lower extremity injury. The results from the adjustments show that normalized composite right reach distance of less than or equal to 94.0% was significantly associated with lower extremity injury for all players and for girls ($P<.05$). Also after the adjustments, anterior right/left reach distance difference of 4 cm or more was significantly associated with lower extremity injury for all players ($P<.05$).¹³

While the study by Plisky et al.¹³ was well orchestrated and the results provide good information, the level of functional assessment of the SEBT may be questioned. The SEBT is a good test that requires lower extremity strength, coordination, and range of motion, but a criticism of the test is how applicable are the test positions to actual competition positions that athletes assume. It is not known if other tests may be more functional for predicting lower extremity injuries in athletics.

2.4.2 Functional Movement Screen

Another injury predictor currently being used is the Functional Movement ScreenTM (FMS). In 2005, Kiesel et al.⁹ conducted a study that to examine if the FMSTM was a possible way to predict serious injury in professional football players. The team's strength and conditioning specialist, who has extensive experience working with professional football, had been using the FMSTM as part of the pre-season physical performance testing before the 2005 season.⁹ An agreement was made between the authors and the team to protect the identity of the players by only releasing limited injury information and FMSTM data and not mentioning the name of the professional football team. The study sample consisted of 46 athletes who were on the active roster at the start of the competitive season. Kiesel et al.⁹ defined a serious injury as an athlete being placed on injured reserve and a time loss of 3 weeks.

At the end of the season, Kiesel et al.⁹ used a dependent t-test ($P < .05$) to determine if there was a significant difference in the composite FMS scores between the athletes who were injured and those who weren't injured during the season. A cut-off score on the FMSTM that maximized specificity and sensitivity was also found after the conclusion of the season by creating a receiver-operator characteristic (ROC) curve.⁹ The cut-off score that is determined can be used in the future to determine if athletes are at risk of serious injury. The ROC curve determines the cut-off score by plotting the sensitivity (True +'s) versus the 1-specificity (False +'s) of the screening test. After the cut-off score was determined, Kiesel et al.⁹ created a 2x2 contingency table dichotomizing the athletes who suffered an injury and those who did not, and athletes above and below the cut-off score on the FMSTM.

Using the pretest probability, or prevalence of serious injury, and a 3-step process explained by Sackett et al.²¹, Kiesel et al.⁹ calculated the post-test probability. Due to the lack of injury rate data in professional football, a conservative estimation of prevalence, 15%, was used. In this 3-step process, a positive likelihood ratio (+LR) value is used and is the value associated with the special test used in the study. For the FMSTM, the +LR is considered negative when the subject's score is above the cut-off score and positive if the subject's score is equal to or below the cut-off score established by the ROC curve.⁹

With the highest score possible being a 21 on the FMSTM, the mean (SD) score of all athletes was 16.9 (3.0). When broken down between injured and non-injured, the mean scores were 14.3 (2.3) and 17.4 (3.1) respectively. Kiesel et al.⁹ ran a dependent t-test on the mean scores and found a significant difference between mean scores of the injured and non-injured athletes ($df = 44$; $t = 5.62$; $p < 0.05$). The ROC curve showed that a FMSTM score of 14 maximized specificity and sensitivity of the test. A sensitivity of 0.54 (CI95 = 0.34-0.68) and specificity of 0.91 (CI95 = 0.83-0.96) was represented by the cut-off score on the ROC curve. Also as a result from the testing, the odds ratio was found to be 11.67 (CI95 = 2.47-54.52), a positive likelihood ratio of 5.92 (95%CI = 1.97-18.37), and a negative likelihood ratio of 0.51 (95%CI = 0.34-0.79).⁹ The odds ratio means that athletes who score 14 or less on the FMSTM are 11 times more likely to suffer a serious injury than those who score above a 14. With the post-test probability of 0.51, it means that the probability of an athlete suffering a serious injury went from 15%, pre-test probability, to 51% if they score a 14 or less on the FMSTM.⁹

While this study appears to have been performed well, it was surprising how low the FMSTM scores were since the study was performed with professional athletes.

The definition of a serious injury was vague, but likely was a method to protect the identity of the subjects. Future studies on the FMSTM should include any injury that requires a time loss or limited participation as the injury definition instead of just serious injuries. Lastly, a performance breakdown of each of the seven tests within the FMSTM, possibly showing a relationship between scoring poorly on a test and certain injured areas, should be investigated.

Chapter 3

Methods

3.1 Experimental Design

Using a prospective cohort study, pre-season performance on the FMSTM was used to predict lower extremity injury among high school basketball players. Prior to the start of the high school basketball season, the athletes performed the FMSTM and the scores were recorded. Throughout the season, daily exposure rates during practice and competition as well as all injuries that resulted in time lost from participation were recorded. The data recorded for each injury included which extremity, type of injury, bracing or taping, and previous injury. After the season had ended, the FMSTM scores and injuries were sorted for each player and compared within groups of injured and non-injured.

3.2 Subjects and Setting

The study was performed at local Toledo area high schools. The testing included 82 athletes (50 males; 32 females) from the girls' and boys' junior varsity and varsity teams. Athletes with any of the following conditions were excluded from this study: vestibular dysfunction, a history of lower extremity surgery, concussion within the past

three months, or refusal to perform the FMSTM. The study was approved by the University of Toledo Institutional Review Board and support and permission granted from the administrations of each school. Informed written assent was obtained from the athlete and informed written consent from the parent or guardian prior to the athlete's participation in the study.

3.3 Questionnaire

Before testing, each subject completed a questionnaire providing demographics such as age, gender, previous/current injuries, brace/tape use, and participation in conditioning programs.

3.4 FMSTM Protocol

Every test was demonstrated for each subject before they performed their three trials. The FMSTM has a scoring range from zero to three with three being the best score.⁹ If the athlete had pain during the test, he/she received a zero. A score of one was given to the athlete if they were unable to complete the movement. If the athlete had to use a compensation to perform the movement, the athlete then received a two. To receive a perfect score of three, the athlete must perform the movement correctly without any pain or compensation. Bilateral scores were taken and compared in the end to also show the imbalance between the right and left sides of the athlete. Clearing screens were used in three of the tests (Shoulder Mobility, Trunk Stability Push-Up, and Rotary Stability) and were scored as either positive or negative. If the athlete had pain during one of the tests, then that test was scored positive. If the athlete had no pain, then the test was scored negative. A positive clearing screen test resulted in a zero for that test. The lowest score

is the only score that counts towards the total score, where the best score possible is a twenty-one.³ The FMSTM consists of seven specific tests including the: deep squat, hurdle step, in-line lunge, shoulder mobility, active straight leg raise, trunk stability push-up, and the rotary stability test. For our study, we used the descriptions explained by Cook et al^{3, 4} that can be found in the Appendix.

3.5 Data Analysis

The data collected was separated into three groups: all subjects, subjects with previous history of lower extremity injury, and subjects without previous history of lower extremity injury. The primary purpose of the study was to determine if there is a significant difference in FMSTM scores between athletes that were injured and athletes that were not injured during the high school basketball season. To determine this, a dependent t-test was performed on each group with significance set at the $P \leq .05$ level. The secondary purpose was to determine the cut-off score on the FMSTM that maximizes specificity and sensitivity. A receiver-operator characteristic (ROC) curve was used for each group to plot sensitivity (true positives) versus 1-specificity (false positives) for the screening test⁹. The ROC curve determines the value for which a test is considered positive by examining different points on the curve corresponding to different cut-off points.^{9, 20} The ROC curve maximizes true positives and controls for false positives and identifies this point on the curve at the left uppermost point of the graph. After finding the cut-off score on the FMSTM, a 2x2 contingency table was produced to dichotomize the athletes that suffered an injury and those who did not as well as those who were above or below the cut-off score. From the table, odds ratios, likelihood ratios, sensitivity and specificity were calculated.

To estimate the amount of influence an athlete's FMSTM score has on the probability of suffering an injury, post-test odds and probability were calculated according to the formula provided. A 3 -step calculation process, described by Sackett et al.²¹, was used to determine how much the probability of injury increased from pre -test to post-test when an athlete's score fell below the cut -off score. For the likelihood ratio, the positive LR value is negative for an athlete when their score is above the cut -off score and positive when their score is equal to or below the cut -off score determined by the ROC curve. Calculation of the increase in probability is as follows:

- 1) Convert the pre-test probability to odds:

$$\text{Pre-test odds} = \text{pre-test probability} / (1 - \text{pre-test probability})$$

- 2) Multiply the odds by the appropriate +LR value:

$$\text{Pre-test odds} \times \text{LR} = \text{post-test odds}$$

- 3) Convert the post-test odds back to probability:

$$\text{Post-test odds} / (\text{post-test odds} + 1) = \text{Post-test probability}$$

Chapter 4

Results

A total of 82 athletes that completed the 2009-2010 basketball season who participated in the pre-season FMSTM screening met our inclusion criteria. Of the 82 subjects, 20 of them suffered an injury that caused them to be removed from participation during the season. For our data analysis, we performed dependent t-tests and ROC curves for three different analysis; 1) All subjects who met the inclusion criteria, 2) Only subjects that met our inclusion criteria with a previous history of lower extremity injury, and 3) Only subjects that met our inclusion criteria without a previous history of lower extremity injury.

4.1 All Subjects

In the analysis of all subjects, the mean (SD) FMSTM score was 15.1 (2.2). The t-test did not reveal a significant difference between the mean FMSTM scores of those injured (14.6 ± 2.0) and those who were not injured (15.2 ± 2.3 ; $t_{82} = -1.22$, $P = 0.23$). Analysis of the ROC curve, to maximize sensitivity and specificity, determined the cut-off score to be 14.5 within this subject group. The associated sensitivity was 0.5 and the specificity was 0.693, giving a positive likelihood ratio (sensitivity/ $1 - \text{specificity}$) of 1.634 and a negative likelihood ratio ($1 - \text{sensitivity}$ /specificity) of 0.722. The odds ratio, computed by dividing the positive likelihood ratio by the negative likelihood ratio, was

2.26. This means that if an athlete scores a 14 or lower on the FMSTM, they are twice as likely to be injured during the basketball season. Using the cut -off score of a 14, a 2x2 contingency table was created to dichotomize the subjects by their FMSTM score and injury status (Table 4.1).

Table 4.1: 2x2 contingency table for all subjects.

FMS score \leq 14?	Injured	Non-Injured
YES	10	19
NO	10	43

4.2 Previous History of Lower Extremity Injury Group

For the second group analysis, subjects with a previous history of lower extremity injury ($n = 30$), eight suffered a lower extremity injury during the season and twenty -two did not. The mean score for all these subjects was 14.8 (2.6). The t -test did not reveal a significant difference between the mean scores of those that suffered an injury (15.1 ± 2.4) and those who were not injured (14.8 ± 2.7) in this group ($t_{30} = 0.41$, $P = 0.68$). Analysis of the ROC curve showed a cut -off score of 11.5 maximized sensitivity and specificity within this group. Using this cut -off score, a second 2x2 contingency table was created to dichotomize the subjects by their FMSTM score and injury status (Table 4.2). The reported sensitivity and specificity of this cut -off score were 0.125 and 0.818 respectively, with a positive likelihood ratio of 0.687 and a negative likelihood ratio of 1.07. An odds ratio of 0.642 was then computed from the positive and negative likelihood ratios. An odds ratio of 0.642 means that an athlete who has previous lower extremity injury and scores an 11 or lower on the FMSTM will be approximately half as likely to be injured during the basketball season.

Table 4.2: 2x2 contingency table for subjects with previous history of injury .

FMS score ≤ 11	Injured	Non-Injured
YES	1	4
NO	7	18

4.3 No Previous History of Lower Extremity Injury Group

For the third group, subjects without a previous history of lower extremity injury (n=52), twelve athletes suffered a lower extremity injury during the season and 40 did not. The mean score for all subjects was 15.2 (2.0). The t -test revealed a significant difference between the means scores of those injured (14.2 ± 1.8) and those who were not injured (15.6 ± 2.0 ; $t_{52} = 2.2$, $P = .034$). Analysis of the ROC curve showed that a cut -off score of 14.5 maximized the sensitivity and specificity of this group's data. Using this cut-off score, a third 2x2 contingency table was created to dichotomize the subjects by their FMSTM score and injury status (Table 4.3). The reported sensitivity and specificity of this cut -off score were 0.583 and 0.8 respectively, with a positive likelihood ratio of 2.915 and a negative likelihood ratio of 0.521. The odds ratio for this group was 5.6, the highest of all three groups. The odds ratio for this group means that athletes without previous lower extremity injury who score a 14 or less on the FMSTM, are over five times as likely to be injured during the season.

Table 4.3: 2x2 contingency table for subjects with no previous history of injury.

FMS score ≤ 14	Injured	Non-Injured
YES	7	8
NO	5	32

4.4 Post-test Probability

A probability of suffering an injury exists at the beginning of the season for every athlete and is known as the pre -test probability. In this study, we calculated the post -test probability for each group to determine how much the probability of suffering a lower extremity injury increased when a player scores below the cut -off score. Before we could calculate the post-test probability using the 3-step calculation process described by Sackett et al²¹, we needed to determine a pre-test probability. Based on previous research done by Kiesel et al⁹ and previous high school injury surveillance, we decided to use a pre-test probability of 15%. The post-test probability for all subjects was calculated to be 22%, while the groups with previous history of lower extremity injury and no previous history of lower extremity injury were 11% and 34% respectively.

Chapter 5

Discussion and Conclusion

5.1 Discussion

The purpose of this study was to determine if the FMSTM had the ability to predict lower extremity injury in high school basketball players. Our results indicate that the FMSTM was best at predicting injury for athletes that had no previous history of injury. Athletes who had no previous history of lower extremity injury and scored a 14 or less on the FMSTM were over 5 times more likely to get injured during the season than those who scored above a 14. The cut-off scores for the no previous injury group and the all subject group were consistent with the finding of Kiesel et al. ⁹ at 14, but significance between the means of injured and non-injured athletes was found only in the group with no previous history of lower extremity injury.

The cut-off score is a point on the ROC curve that maximizes specificity and sensitivity. The ability to predict injury from the FMSTM depends on the specificity of the cut-off score found on the ROC curve. This means that a screening test with a high specificity will have fewer false positives, which will help rule in a specific condition. The point on the ROC curve that maximizes specificity and sensitivity is shown in the

upper left portion of the curve, maximizing true positives and controlling for false positives.⁹ The FMSTM in our study didn't show as high as the 0.91 specificity found by Kiesel et al.⁹, but still showed above average specificity ranging from 0.69 to 0.82. The only group with a significant difference between the means of injured and non-injured athletes, the group with no previous history of lower extremity injury, showed a specificity of 0.80, meaning that the FMSTM can be used to predict injury if athlete scores below cut-off score. Conversely, the sensitivity was fairly low, ranging from 0.13 to .058, which limits the possibility of the FMSTM to rule out injury if athlete scores above the cut-off score.

To show the increase in the probability of injury if an athlete scores below the cut-off score, the post-test probability was calculated using a 3-step process described by Sackett et al.²¹. A probability of injury exists for each athlete at the beginning of the season prior to the FMSTM testing called the pre-test probability. We used a conservative prevalence rate of 15%, as described by Kiesel et al.⁹, because too high of a prevalence rate will indicate that the FMSTM is more powerful than the actual statistics are showing. The highest increase in injury probability of 19% was reported in the group with no previous lower extremity injury, with an overall post-test probability of 34%. The group with previous lower extremity injury had a decrease in injury probability, falling 4% to a post-test probability of 11%. In the overall subject group, the post-test probability was 22%, showing a 7% increase from the pre-test probability.

A main limitation in this study was the use of ankle braces and/or ankle taping. The FMSTM testing for all athletes was done without the use of ankle bracing/taping, but this limitation is not controllable during the season. This limitation of brace/tape use

could explain why the injured group showed a lower cut -off score than all other groups and a decrease in post-test probability of injury, as ankle bracing and taping has been proven to prevent injury.¹²

Another limitation could have been the fact that multiple examiners completed the testing. However, Minick et al.¹¹ explained that the FMSTM has a high interrater reliability and can confidently be applied by trained individuals when the standard procedure is used. Additionally, pilot work completed in the laboratory of the faculty advisor yielded strong intersession reliability of the FMS (ICC: 0.946) by the individuals performing the assessments in our study, all of which had received training in the procedures.

Future research should consider the use of ankle bracing and taping, between those previously injured and not previously injured, throughout the basketball season. Athletes with prior history of injury may have been educated to wear ankle braces or have ankles taped in order to prevent future injury. . In this study, we focused mainly on lower extremity injury, but future research should focus on broadening to any injury, as the FMSTM is a total body screening test.

5.2 Conclusion

This study demonstrated that high school basketball athletes who do not have previous history of lower extremity injury and score a 14 or below on the FMSTM, have a higher chance of suffering an injury over the period of the high school basketball season. However, the FMSTM did not have the ability to predict injury to high school basketball athletes with prior history of lower extremity injury. Clinicians should consider

implementing the FMSTM to screen for first time lower extremity injury as a low cost, reliable tool when used by trained individuals.

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Appendix

1) Deep Squat

The athlete assumes the starting position by placing her/her feet shoulder width apart with feet in line with the sagittal plane. The dowel is then placed overhead by flexing and abducting the shoulders and extending the elbows. The athlete then squats down with their heels on the floor and head and chest facing forward. Scoring for this test is as follows (if athlete cannot accomplish a three, athlete may perform test with a 2x6 board placed under heels):

Three:

- Upper torso is parallel with tibia or toward vertical
- Femur below horizontal
- Knees aligned over feet
- Dowel aligned over feet

Two:

- Upper torso is parallel with tibia or toward vertical
- Femur is below horizontal
- Knees are aligned over feet
- Dowel is aligned over feet
- 2x6 board required under feet

One:

- Tibia and upper torso are not parallel
- Femur is not below horizontal
- Knees are not aligned over feet
- Lumbar flexion is noted
- 2x6 board required under feet

2) Hurdle Step:

To begin, the athlete will align their feet together with the toes touching the base of the hurdle, which is then adjusted to the height of the athlete's tibial tuberosity. The athlete then positions the dowel across the shoulders, just below the neck. Next, the athlete is instructed to slowly step over the hurdle and touch their heel to the floor while the stance leg remains in extension. The step over leg is then returned to the starting position. Repeat bilaterally. Scoring for this test is as follows:

Three:

- One repetition is completed bilaterally

Two:

- Athlete compensates by twisting, leaning or moving the spine

One:

- If loss of balance occurs or contact is made with the hurdle

3) In-Line lunge:

The length of the athlete's tibia is measured from the floor to the tibial tuberosity.

Athlete will then be instructed to place the end of his/her heel on the end of the 2x6 board. From the end of the athlete's toes, a mark is made on the board using the tibia length. The athlete places the dowel behind the back, in contact with the head, thoracic spine, and sacrum. Hand placement on the dowel should be the hand opposite of the front foot placed at the cervical spine and the other hand at the lumbar spine. The athlete will then place the heel of the opposite foot at the measured mark on the board while the back knee is lowered enough to touch the board behind the heel of the front foot. Repeat bilaterally. Scoring for this test is as follows:

Three:

- Dowel contacts remain with lumbar spine extension
- No torso movement is noted
- Dowel and feet remain in sagittal plane
- Knee touches board behind heel of front foot

Two:

- Dowel contacts do not remain with lumbar spine extension
- Movement is noted in torso
- Dowel and feet do not remain in sagittal plane
- Knee does not touch behind heel of front foot

One:

- Loss of balance is noted

4) Shoulder Mobility:

The athlete's hand will first be measured from the distal wrist crease to the tip of the third digit. The athlete will then be asked to make a fist with each hand. The athlete then assumes a maximally adducted, extended and internally rotated position with one shoulder and a maximally abducted, flexed, and externally rotated position with the other so that the fists are located on the back. A measurement is taken of the distance between each fist at the closest point. Repeat bilaterally. Scoring for this test is as follows:

Three:

- Fists are within one hand length

Two:

- Fists are within one and a half hand lengths

One:

- Fists are not within one and half hand lengths

A clearing exam is done at the end of the shoulder mobility test. The movement is not scored, but is simply used to observe pain. If pain is produced, a score of zero is given to the entire shoulder mobility test. Clearing exam: the athlete places his/her hand on the opposite shoulder and then attempts to point the elbow upward. This screening should be performed bilaterally.

5) Active Straight Leg Raise:

To start the active straight leg raise test, the athlete is required to lie supine with the arms in an anatomical position and head flat on the floor. The 2x6 board is placed under the knees, and the anterior superior iliac spine (ASIS) and mid -point of the patella are identified. The midpoint between those two landmarks is found on the thigh, where the dowel is placed perpendicular for a reference point. The athlete is then instructed to lift the test leg with a dorsiflexed ankle and extended knee while keeping the opposite knee in contact with the board. Repeat bilaterally. Scoring for this test is as follows:

Three:

- Ankle/dowel resides between mid-thigh and ASIS (ankle of leg being lifted goes past dowel)

Two:

- Ankle/dowel resides between mid-thigh and mid-patella/joint line (ankle of leg being lifted does not go past dowel, but joint line of knee does)

One:

- Ankle/dowel resides below mid-patella/joint line (knee of leg being lifted does not go past dowel)

6) Trunk Stability Push-Up:

The athlete begins in the prone position with feet together. Athlete's hands are placed shoulder width apart with the thumbs at forehead height for males and chin height for females. With the knees fully extended and the feet dorsiflexed, the athlete should perform one push-up in this position with no lag in the lumbar spine. If athlete cannot perform push-up in this position, the hands are lowered, with thumbs aligning with the chin for males and clavicles for females. Scoring for this test is as follows:

Three:

- Males perform one repetition with thumbs aligned with the top of the forehead
- Females perform one repetition with thumbs aligned with chin

Two:

- Males perform one repetition with thumbs aligned with chin
- Females perform one repetition with thumbs aligned with clavicle

One:

- Males are unable to perform one repetition with hands aligned with chin
- Females are unable to perform one repetition with thumbs aligned with clavicle

A clearing exam is performed at the end of the trunk stability push-up test. This movement is not scored, but is simply used to observe pain. If pain is produced, a score of zero is given for the entire push-up test. Clearing exam: the athlete performs a press-up in the push-up position, putting the spine into extension.

7) Rotary stability:

The athlete assumes the starting position in quadruped with their shoulders and hips at 90 degrees relative to the torso. Athlete positions the knees at 90 degrees and the ankles in dorsiflexion. The athlete then flexes the shoulder and extends the same side hip and knee. The leg and hand are only raised enough to clear the floor by approximately six inches. The same shoulder is then extended and the knee flexed enough for the elbow and knee to touch. Repeat bilaterally for up to three repetitions. If a three is not attained then the individual performs a diagonal pattern using the opposite shoulder and hip. Scoring for this test is as follows:

Three:

- Performs one correct unilateral repetition while keeping the spine parallel to surface
- Knee and elbow touch

Two:

- Performs one correct diagonal repetition while keeping spine parallel to surface
- Knee and elbow touch

One:

- Inability to perform diagonal repetitions

A clearing exam is performed at the end of the rotary stability test. This movement is not scored, but simply performed to observe pain. If pain is produced, a score of zero is given to the entire rotary stability test. Clearing exam: Athlete assumes a quadruped position and then rocks back to touch the buttocks to the heels and the chest to the thighs. The hands should remain in front of the body reaching out as far as possible.