A Thesis

Entitled

The Ability of the Functional Movement Screen in Predicting Injury Rates in Division I Female Athletes

By

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

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An Abstract of
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Objective: To determine if the FMS™ could predict lower extremity injury in division one women’s basketball, soccer and volleyball athletes. The secondary purpose of this study was to examine factors in injury prediction related to contact mechanism. Finally, we wished to make FMS performance comparisons between women’s basketball, soccer and volleyball players to establish baseline comparisons. Design, Setting, and Data

Source: Testing and data collection was performed at The University of Toledo. The testing included the women’s basketball, soccer and volleyball teams with the ages of the athletes ranging from 17 – 22 years old. Before testing, each subject completed a questionnaire providing demographics such as age, 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 was a significant difference in FMS™ scores between athletes that were injured and athletes that were not injured during the regular competitive seasons, independent t-tests were performed on each group with significance being set at P<0.05. To determine if there was a significant difference between sports, between body parts injured groups, and between
mechanism of injury groups, one-way analysis of variances were used. To determine cutoff scores, a receiver-operator characteristic (ROC) curve was used to plot sensitivity (true positives) versus 1-specificity (false positives) for the screening test. A 2x2 contingency table was produced in order to dichotomize the athletes that suffered an injury and those who did not, as well as those who were above or below the specified cutoff score. From the table, odds ratios, likelihood ratios, sensitivity and specificity were calculated. **Results:** A total of 55 athletes were included in, and completed the study. Of the 55 subjects, 13 of them suffered an acute, lower extremity injury that caused them to be held out of one or more consecutive athletic exposures (practice or competition). There was no statistical difference between the pre-season FMS™ scores of the injured and non-injured groups ($t_{55}=-1.68; P=0.100; d=0.52; 95\%CI: -0.11, 1.15$). For all of the subjects, a cutoff score of 16.5 was found that maximized sensitivity (0.615) and specificity (0.738). An odds ratio was calculated at 4.50, meaning that an athlete has an approximately 4.5 times greater chance of suffering a lower extremity injury during a regular competitive season if they score less than 16.5 on the FMS™. One-way analysis of variance revealed no statistical difference between the ankle injury group, knee injury group, and non injury group ($F_{2,54}= 2.34; p=0.106$). No statistical significance was found between the groups with a contact, non-contact injury, or non injury ($F_{2,54}=1.48; p=0.237$). Finally, when comparing the three sports with one-way ANOVAs, a statistical difference was found between them ($F=5.83, df= 2, 54, p=0.005$). **Conclusion:** This research study demonstrated that the FMS™ shows a true potential to work as an effective and efficient predictive tool for identifying lower extremity injury in division one collegiate female athletics. More research is still necessary before implementing the
FMSTM into a PPE for athletics, but due to the low cost and its simplicity to implement, it should be considered by clinicians and researchers in the future.
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Chapter 1

Introduction

1.1 Background

It is well documented that athletic participation in the United States has increased in recent years, especially in female adolescents.\(^1\) It is reported that overall athletic participation has increased by nearly 3 million participants since 1971.\(^2\) Male participation at the high school level has increased less than 3% (from 3.7 to 3.8 million) since the passage of Title IX of the Education Assistance Act, while participation among females has increased more than 9-fold, roughly doubling every 10 years (from .3 to 2.8 million).\(^1\) With this vast increase in involvement in athletics the amount of injuries being observed has also increased. This increase is especially true in basketball and soccer. Females participating in these sports are at a much greater risk for overall injury, and specifically lower extremity injuries, due to the nature of the sports.\(^3\) Studies that have used injury surveillance throughout female sports, in comparison to their male equivalents have reported females to have much greater injury rates, especially in basketball and soccer.\(^3\)

One of the primary responsibilities of the sports medicine staff at all levels of athletics is to prevent injury. Recent research has evaluated risk factors that contribute to
overall injury rates in athletics such as previous injury, body mass index, muscle
flexibility, and biomechanics during athletic movements. Intrinsic risk factors including;
agonist/antagonist muscle ratios for strength and endurance, structural abnormalities,
neuromuscular control, core instability, contra-lateral muscular imbalances, may be of
particular interest in female athletes. Most research in this area has investigated these
factors individually, but recent attention has been modified to look at the multifactorial
influence of risk factors. The potential to screen athletes for risk of injury during a pre-
participation physical examination (PPE) could be extremely helpful and important. One
instrument that may be useful for these purposes is the functional movement screen
(FMS™). The FMS™ is a comprehensive examination that assesses seven different
fundamental movements that have been thought of as the foundation for more advanced
and dynamic movements. The FMS™ testing incorporates risk factors for balance,
strength, range of motion, flexibility, and proprioception in an attempt to identify
individuals at risk in athletic populations. According to the creators of the FMS™, it is a
method used to apply an objective value when assessing fundamental movement as a
mode to identify asymmetries and limitations as they refer to more functional and
dynamic movements.

To date there is a limited body of research available regarding whether or not the
FMS™ actually assesses what it is designed to. Noda et al compared goniometric
measurements at the ankle and hip joints to scores in the deep squat portion of the FMS™
testing, and found that there were statistically significant correlations between the two
assessment techniques. The researchers identified that the correlation between the
different factors can directly contribute to the validity of the FMS™ in identifying limitations in a subject’s functional movements.\(^8\)

In one study, a score of 14 or less on the FMS™ resulted in a 4-fold increase in risk of lower extremity injury in female collegiate athletes participating in fall and winter sports.\(^9\) Similarly, Kiesel et al\(^4\) established for professional football players that the score of 14 on the FMS™ was effective in predicting injury throughout the season with a specificity of 0.91 and sensitivity of 0.54. Athletes who had fundamental movement dysfunction or asymmetries were more likely to be injured than those who scored higher on the FMS™. The FMS™ tool has been reported to have a high interrater reliability and can be applied by trained professionals in the clinical setting.\(^4,10\)

The FMS™ has proven to detect functional limitations and therefore may have the potential to predict injury when relating to the more dynamic and sport specific movements used in athletics.\(^9,11\) However, no research has been done to use this screening tool to focus specifically on women’s sports with high risk of lower extremity injury, women’s basketball, soccer, and volleyball.\(^3\)

1.2 Problem Statement

Research shows that women’s sports such as basketball, soccer, and volleyball are at high risk for athletically related lower extremity injuries (Powell, 2000).\(^3\) Research also shows that a low score on the FMS™ correlates to increased injury, but no research has been conducted to see if these scores can predict injury prospectively in women’s basketball, soccer, and volleyball players at the collegiate division one level.

1.3 Purpose Statement:
The primary purpose of this research was to determine if the FMS™ could predict lower extremity injury in division one women’s basketball, soccer and volleyball athletes. The secondary purpose of this study was to examine factors in injury prediction related to contact mechanism. Finally, we wished to make FMS performance comparisons between women’s basketball, soccer and volleyball players to establish baseline comparisons.

1.4 Hypothesis:

**H1** - Throughout the regular competitive season for women’s basketball, soccer, and volleyball athletes that suffer lower extremity acute injuries will have a lower composite FMS™ score during the PPE than those athletes who do not suffer a lower extremity injury.

**H2** - The FMS™ score during the PPE will provide a strong predictive model for injury in division I female collegiate athletes by finding a cut-off score that maximizes sensitivity and specificity (>0.70).

**H3** - Among the female collegiate athletes, the FMS™ scores during the PPE of those that suffer ankle injuries during the regular season participation will be lower than those that suffered knee injuries and the non-injured group.

**H4** - Among the female collegiate athletes, the FMS™ scores during the PPE of those that suffered non-contact lower extremity injuries throughout the regular season participation will be lower than athletes that suffered contact injuries and the non-injured group.

**H5** - The PPE FMS™ scores of basketball players will be higher than soccer and volleyball players.

1.5 Aim of the Study
The primary aim of this study was to establish if the FMS™ could predict lower extremity injury in division one women’s basketball, soccer, and volleyball players. The secondary aim of this study was to establish a cut-off score for the FMS™ for players specific to each sport. The tertiary aims of the study were to compare factors of injury mechanism and specific sport on FMS™ PPE scores.
Chapter 2

Literature Review

This literature review provides a complete collection of current research that deals with injury rates in specific female athletic populations and the use of the functional movement screen, as a tool to prospectively identify subjects at an increased risk of injury. The chapter two literature reviews are divided into four different sections. The first portion of the review pertains specifically to female athletic participation and the risk inherent with each exposure to athletics for those females. The second section includes articles aimed at trying to identify the reasons for these risks specific to females. The third section addresses research that has attempted to predict injuries in the athletic population. The final section is on research relevant to the functional movement screen™ and its validity and reliability.

2.1 Female Athletic Participation and Injuries

In sports medicine and athletic departments across the country the issue of injuries specific to females has been at the forefront of researcher’s interest for many years now. For many different reasons, there has been a widespread increase in athletic participation amongst males and females; predominantly females. This increase in females participating in sports has brought on an understandable increase in the amount of injuries being seen in female athletes. Due to this increase in female injuries, a national
focus in predicting and preventing injury to the female athlete has arisen. If clinicians are able to determine during a pre-participation physical examination that an athlete is predisposed to injury, it may be possible to implement a prevention program to reduce the risk of injury in that specific case.

Powell et al reported that high school athletes participating in boys’ or girls’ basketball, boy’s or girls’ soccer, boy’s baseball, and girl’s softball were tracked for a total of three consecutive years at approximately 240 different institutions, looking specifically at their injury information. Injuries were defined as either minor (fewer than 8 days lost), moderate (8 to 21 days lost), or major (more than 21 days lost). In total there were 2043 team-seasons, and 8988 total reported injuries. Findings showed that injury rates were higher for softball and girl’s soccer than for their equivalent male sports, and also that girl’s soccer and basketball showed higher injury rates at the knee than their male counterparts. These results supported their hypothesis that girls have a greater risk of injury in sports participation for softball compared with baseball, and for girls’ soccer compared with boys’, as well as their hypothesis that girls have a greater risk of knee injury than boys for basketball and soccer.

Another study dealt with basketball injuries and the difference in females and males, only at the professional level; Women’s National Basketball Association (WNBA) and National Basketball Association (NBA) respectively. From both of these leagues, injury data were retrospectively reviewed for six full seasons and compared equally. After calculating the results and drawing significant comparisons, it was found that the WNBA athletes had a higher overall game-related injury rate (24.9 per 1000 ae) as compared with the NBA (19.3 per 1000 ae). It was also found that the women sustained a
higher rate of lower extremity injuries; 14.6 per 1000 as compared to 11.6 per 1000. This study by Deitch in 2006 concluded appropriately that the lower extremity is the most frequently injured body area in both the WNBA and NBA, and that the WNBA athletes are more susceptible than their male counterparts.¹²

Hewett et al hypothesized that prescreened female athletes with subsequent anterior cruciate ligament injury would demonstrate decreased neuromuscular control and increased valgus joint loading.¹³ After testing 205 female athletes chosen from high risk sports (soccer, basketball, volleyball) for their 3-dimensional kinematics and kinetics during a jump landing task, they were able to gain some valuable information. Of the nine female athletes that subsequently tore their ACLs, in comparison to the “healthy” population, average knee abduction angles at landing were 8 degrees greater, knee abduction moments were 2.5 times greater, and their ground reaction forces were 20% greater. From these analyses the authors concluded that knee motion and knee loading during a landing task were valid predictors of anterior cruciate ligament injury risk in female athletes.¹³

Similarly, Cowley and colleagues investigated the differences between landing and cutting tasks in female basketball and soccer athletes.¹⁴ Based on the well-known idea that high school female athletes are most likely to sustain a serious knee injury during soccer or basketball due to the rapid deceleration and changing of direction, Cowley’s objective was to determine if those athletes showed neuromuscular differences during landing and cutting tasks, and to examine neuromuscular differences between tasks and between dominant and nondominant sides. Using 30 high school female athletes who participated solely in basketball or soccer, Cowley measured ground
reaction forces, stance time, valgus angles, and valgus moments during a drop vertical jump with immediate maximal vertical jump, and immediate side-step cut at a 45 degree angle. The results of the study showed that basketball athletes had greater ground reaction forces and decreased stance time during the drop vertical jump, whereas soccer players had greater ground reaction forces and decreased stance time during the cut, and also that both groups had greater valgus angles during cutting. These results coincide with Hewett’s in saying that there are specific differences in the female athlete’s abilities biomechanically during dynamic and sport-specific movements.

Finally, injury rates and patterns were investigated among high school basketball athletes in an aim to discover a difference between genders. Borowski et al understood that there are over a million high school athletes playing basketball each year, and many times this can be where most injuries are seen; especially in female basketball players. By collecting data in reference to basketball related injuries during the 2005-2006 and 2006-2007 academic years from 100 national US high schools, they were able to come up with a very good representation of basketball injury occurrence nationally. With a total of 1518 injuries being reported Borowski et al came up with an injury rate of 1.94 per 1000 athlete exposures. The injury rate was found to be greater among girls (2.08) than among boys (1.83), and the lower extremity was found to be the most often injured body area; ankle foot (39.7%), knee (14.7%). In agreement with many studies read and researched in total, this study suggests that much attention need be paid to not only recognizing and treating these injuries amongst female basketball players each year, but also in targeting an injury prevention/prediction model that may help in avoiding some amount of injuries all together.
2.2 Female Injury Risk Factors

Being able to understand the injury risk factors specifically associated with females is a major element in identifying at risk females. By understanding the specific aspects of their biomechanics, alignment, intrinsic/extrinsic factors and neuromuscular activity, etc it is possible to then be able to work in the direction of addressing these issues prior to the actual injury incident; thus preventing the injury. The following section will discuss research involved with these ideas, and what has been found already in the area of specific female injury risk factors.

Chorba et al used the functional movement screening (FMS)™ tool to come up with scores for 38 NCAA division II female collegiate athletes before the start of their respective fall and winter sport seasons (soccer, volleyball, and basketball). They tracked their injuries throughout the seasons and were able to look retrospectively at their results, and their impending injuries that occurred. The mean FMS™ score for all subjects was 14.3, and eighteen injuries (17 lower extremity, 1 lower back) were recorded during the study. It was found that a score of 14/21 or less was significantly associated with injury (P=0.0496). With 14 or less being considered the “cutoff” score, Chorba’s results showed 69% of athletes scoring under that sustained an injury. Odds ratios were 3.85 with inclusion of all subjects, and 4.58 with exclusion of ACLR subjects. Sensitivity and specificity were 0.58 and 0.74 respectively. This resultant 4-fold increase in injury risk for female collegiate athletes participating in fall and winter sports really shows a good correlation to injury and the potential compensatory fundamental movement patterns that are often observed in females during dynamic movements.
Brophy et al examined the differences between genders in lower extremity alignment and muscle activation during a soccer kick in the hopes to discover identifiable results that could be addressed prior to injury. In this study, 13 male and 12 female college soccer players underwent 3-dimensional motion analysis and electromyography (EMG) of seven muscle (iliacus, gluteus maximus, gluteus medius, vastus lateralis, vastus medialis, hamstrings, and gastrocnemius) in both the kicking and support leg, and two additional muscles (hip adductors and tibialis anterior) in the kicking limb only. Five instep and five side-foot kicks were recorded for each player while their muscle activation was recorded as a comparison of the maximum voluntary isometric contraction (MVIC). The results showed that male soccer players had significantly higher mean muscle activation than their female counterparts with respect to the iliacus in the kicking limb (123% compared with 34% of MVIC) and the gluteus medius (124% compared with 55% of MVIC) and vastus medialis muscles (139% compared with 69% MVIC) in the supporting limb. The supporting limb reached significantly greater mean hip adduction during the stance phase of the kick in the females compared with that in the males (15 degrees and 10 degrees, respectively). This study shows the difference between male and female muscle activation and alignment during a soccer kick, which could very closely be related to the amount of injuries suffered comparatively in male and female soccer athletes.

Lim et al hypothesized that the female basketball players who participated in an injury prevention program would show better muscular strength and flexibility, as well as improved biomechanical properties associated with ACL injury, than they did during their pretraining period; as well as versus posttrained control group. A total of 22 high
school female basketball players were recruited and randomly divided into two groups (experimental and control). The experimental group received instruction in 6 parts of the injury prevention program and performed it for the first 20 minutes of team practice for the next eight weeks. The control group performed their regular training program. The testing for both groups was a rebound-jump task before and after the 8-week period. A comparison of the pretraining and posttraining results in the experimental group identified training effects on all strength parameters, and on knee flexion; which reflects increased flexibility. The experimental group showed higher knee flexion angles (P=.024), greater interknee distances (P=.004), lower hamstring to quadriceps ratios (P=.023), and lower maximum knee extension torques (P=.043) after the training program. There were no significant changes found in the control group between the pretraining and posttraining. At the initial testing their were no significant differences found between the experimental or control groups, but after the training the experimental group had significantly higher knee flexion angles (P=.023), greater knee distances (P=.005), lower hamstring to quadriceps ratios (P=.021), lower maximum knee extension torques (P=.124), and higher maximum knee abduction torques (P=.043) than the control group. These results show the potential for a sports injury prevention program to specifically target, successfully, the areas in which female athletes have issues and have potential deficits that cause injuries during athletics.

Using EMG to examine the female injury risk theory, Zebis et al hypothesized that “noninjured athletes with low knee flexor electromyography (EMG) preactivity and high knee extensor EMG preactivity during side cutting are at increased risk of future ACL rupture.” EMG testing 55 elite female athletes from team handball and soccer with
no history of ACL injury during a standardized side-cutting maneuver was performed with the focus on the knee extensors (vastus lateralis, vastus medialis, rectus femoris) and knee flexors (semitendinosus, biceps femoris) muscle activity. The incidence of ACL ruptures was then registered in the following two seasons. In those following two seasons’ five athletes suffered a confirmed noncontact ACL rupture. Prior to injury, all five athletes displayed a neuromuscular pattern that differed from the noninjured players; characterized by reduced EMG preactivity for the semitendinosus and elevated EMG preactivity for the vastus lateralis. On a small scale, this study shows a potential for identifiable risk factors in females that can be observed, tested for, and addressed prior to the beginning of an athletic season, and therefore hopefully reduce the risk of injury to the lower extremity.

Cowley and colleagues investigated the differences between landing and cutting tasks in female basketball and soccer athletes. Based on the well-known idea that high school female athletes are most likely to sustain a serious knee injury during soccer or basketball due to the rapid deceleration and changing of direction, Cowley’s objective was to determine if those athletes showed neuromuscular differences during landing and cutting tasks, and to examine neuromuscular differences between tasks and between dominant and nondominant sides. By using 30 high school female athletes who participated solely in basketball or soccer, Cowley measured ground reaction forces, stance time, valgus angles, and valgus moments during a drop vertical jump with immediate maximal vertical jump, and immediate side-step cut at a 45 degree angle. The results of the study showed that; basketball athletes had greater ground reaction forces and decreased stance time during the drop vertical jump, whereas soccer players had
greater ground reaction forces and decreased stance time during the cut, and also that both groups had greater valgus angles during cutting. These results showed that there are specific differences in the female athlete’s abilities biomechanically during dynamic and sport-specific movements.

In agreement with Cowley’s findings and conclusions is researcher Hewett in his study that prospectively looked into the neuromuscular control and valgus loading of the knee in female athletes. Hewett et al hypothesized that prescreened female athletes with subsequent anterior cruciate ligament injury would demonstrate decreased neuromuscular control and increased valgus joint loading. After testing 205 female athletes chosen from high risk sports (soccer, basketball, volleyball) for their 3-dimensional kinematics and kinetics during a jump landing task, they were able to gain some valuable information. Of the nine female athletes that subsequently tore their ACLs, in comparison to the “healthy” population, average knee abduction angles at landing were 8 degrees greater, knee abduction moments were 2.5 times greater, and their ground reaction forces were 20% greater. From these analyses the authors concluded that knee motion and knee loading during a landing task were valid predictors of anterior cruciate ligament injury risk in female athletes.

Mcguine et al examined the role of balance as an identifying factor in the mechanism of high school basketball ankle injuries. The researchers tested the subject by using single leg balance tests with the athlete’s eye’s open, as well as closed, and measured postural sway. The grading scale for the athlete’s balance was rated as poor, average, or good balance. A Fisher’s exact test was used to determine injury rates between these categories. The authors found that subjects who had poor balance and high
postural sway results were seven times more likely to suffer an injury as compared to those athletes with average or better balance \((p=0.0002)\).\(^1\) A measurement as simple as postural sway taken during a single leg balance test may be able to predict the risk of an athlete for injury.

Finally, Knapik investigated preseason strength and flexibility imbalances associated with injury rates in females. The authors used 138 subjects that were members of eight different varsity sports.\(^2\) Strength was measured using an isokinetic torque dynamometer, and was considered at the quadriceps and hamstrings of each leg. Flexibility was measured at the ankle, knee, and hip with a goniometer in order to identify an imbalance or disparity. The researchers found that athletes were more at risk if they had; muscular strength imbalances, differences in hip flexibility as compared bilaterally, a hamstring to quadriceps ratio of less than 0.75.\(^2\)

There are countless risk factors that have been investigated when it comes to the female athlete, including intrinsic and extrinsic factors. Many of these are practical when it comes to the incorporation of them during a pre-participation physical exam in order to identify at risk athletes. Once this can be done successfully and effectively, there are hopes for intervention programs to be put into place that will drastically reduce the occurrence of certain avoidable injuries.

2.3 Injury Prevention

It is one thing to be able to recognize the fact that female athletes are injured more than their male counterparts, or that there are multiple reasons for these injuries and “at risk” athletes, but it is a completely different aspect to actually be able to distinguish and identify the athletes who are set up for injury, and then consequently do something about
that risk and prevent them from becoming injured. It is not simply one intrinsic or extrinsic factor, or muscle imbalance, or inflexibility that predisposes an athlete for injury, but rather a combination of multiple factors. The grouping of several factors together is shown to be the best way to predict injuries in athletes, and addressing those factors and areas could very well be the best way to prevent injury. This section will review the literature related to components of injury prediction and prevention.

In a study by Bahr and Krosshaug, injury prevention and injury prediction models are described methodologically. The prevention model involved a four step process that looked into the injury problem, as well as attempted to apply successful intervention strategies. The prevention model identifies the magnitude of the injury as a first priority. The second step involves understanding the etiology and the mechanics of the problem; intrinsic or extrinsic. The next step is to address the mechanisms of injury so you can then introduce preventative measures to decrease the specific injury rate. Understanding the factors that contribute to the injury is equally as important as its actual treatment in this case. The last step of the model is to determine if the suggested prevention/intervention program decreases the injury rate.

In Bahr’s article there is also a biomechanical perspective involved in preventing and predicting injuries. An actual injury is described as a result of transfer of overloaded energy to tissue of the human body from an external source. Specific forces such as magnitude of force, rate of load, frequency of load distribution, rate of load distribution and the intrinsic factors specific to the athlete influence the injury. Understanding these influences is important due to the nature of each of them; some may be altered while others may not. An ankle injury, for example, is described as being able to be contact or
non-contact depending on the mechanism. In both instances injury may be an inevitable occurrence, but with the correct neuromuscular control through proper training, the extent of injury and possible reduction in damage is more individual to the athlete. Due to this fact it is important to take all factors into consideration when trying to predict and prevent injuries in an athletic population.

A study that focused primarily on an active, but non athletic based population used the functional movement screen to assess and design an injury related intervention program for firefighters in order to understand more fully their reason for injury and what could be done to prevent more injuries of the same nature. Due to the injury prone and awkward positions that firefighters regularly work in that require adequate flexibility as well as strength in their core musculature, the seven movements used in the FMS™ apply very well to such a group. Each exercise in the FMS™ is able to be closely related to specific activities and essential functions that firefighters perform on a regular basis; rotary stability test to the act of staying low in a burning building, hurdle step to stepping over an obstacle, in-line lunge to reach far distances in small spaces, shoulder mobility to maneuvering respirator on back, stability push ups to low level rescue, deep squat to avoiding overhead hazard, and active straight leg raise to flexibility necessary for peak performance. By testing 433 subjects on these 7 movements, and then correlating the results to past history of musculoskeletal injury while on the job could show if the deficits in the screening were related to injury history in the fire department. Based on their findings they developed an intervention protocol that the firefighters took part in, in order to compare the next year’s worth of injury data to historical data prior to the injury prevention program. Findings were such that the intervention reduced lost time due to
injuries by 62% and the number of injuries by 42% over a 12 month period as compared to a historical control group of similar demographics.\textsuperscript{21} This article shows the ability of not only the FMS to be involved in injury prevention and prediction, but also the ability of an intervention program to be successful when properly implemented on a subject population other than athletes, as is typically discussed.

Intervention programs aimed at improving biomechanical and neuromuscular training are often overlooked when it comes to increasing athletic performance as well. In an article by Gregory Myer and his colleagues, exactly that idea was investigated. The purpose of the study was to examine the effects of a comprehensive neuromuscular training program on measures of performance and lower extremity movement biomechanics in female athletes.\textsuperscript{22} The researchers hypothesized that significant improvements in measures of performance would be demonstrated concomitant with improved biomechanical measures related to ACL injury risk. In their study, 41 female basketball, soccer, and volleyball players underwent 6 weeks of training (plyometrics, core strengthening, balance, resistance training, and speed training). Similarly matched demographic counterparts also underwent the testing protocols after no training, in order to compare their results against a “no intervention” group. The results showed that the trained athletes demonstrated increased 1RM squat by 92% and bench press by 20%. Right and left single leg hop increased by 10.39 cm and 8.53 cm respectively, and vertical jump increased by almost 5 cm with training.\textsuperscript{22} Speed also increased, as well as knee biomechanics during a vertical jump landing; decreased knee valgus torque of 28%, and varus torque of 38%. These results encourage the use of an injury prevention program not only for the obvious reason of maintaining healthy athletes throughout a
season, but also for the very attractive reason of increased performance through improved biomechanics.\textsuperscript{22}

Functional testing is a fairly recent clinical tool being used to predict injury rates and identify at risk athletes who may be prone to injury. Functional testing involves subjectively evaluating risk factors such as range of motion, core strength, and muscular imbalances.\textsuperscript{23} Nadler and his colleagues investigated the functional performance of athletes following a lower extremity injury. The main focus of this research was that injury to the lower extremity associates to closed kinetic chain deficits that may result in a decrease in neuromuscular control and or decrease core strength that lasts well after the injury, if not appropriately addressed. The researchers used 231 NCAA division one student athletes as subjects. Subjects completed an injury history and were grouped into incoming freshman with a history of injury and injury free, as well as non freshman with a history of injury and no history of injury. Subjects then completed a timed 20 yard dash. The researchers findings showed that incoming freshman with a history of lower extremity injury had a significantly lower 20 yard dash time than those who entered college injury free (p=0.01).\textsuperscript{23} Non freshman had no difference in 20 yard dash time regardless of history of injury (p=0.98). This data correlates the ideas of having a previous injury to having functional deficits. By incorporating some sort of injury prevention program, these deficits would be able to be addressed in order to prevent further injury, as well as maximize performance.

In a final article by Kato, the researcher’s main goal was to evaluate a short-term intervention designed to improve the lower extremity alignment with neutral position during stop movements of female basketball players when performing a quick-stop jump
The exercise program used with this intervention emphasized the neutral position of lower extremities for dynamic alignment control, basically trying to avoid the dreaded valgus position at the knee so often seen in female athletes. The intervention exercises included the squat, forward lunge, jump landing, lunge walking, twists, and a BOSU routine. The results after the short two week intervention showed that the trained intervention group performed the jumping basketball shot with greater change of the lower extremity motion pattern during the stop action than did non-trained athletes (p<0.05).\textsuperscript{24} The results of this study show that a simple intervention of two weeks is able to improve the biomechanics short-term of female basketball athletes. This lends itself to the idea that a longer more prolonged and progressive/sport-specific intervention program would benefit athletes considerably in the face of injury prevention.

2.4 The Functional Movement Screening Tool

The idea that a screening tool could potentially be used to predict injuries prior to the beginning of the season is a very valuable initiative that should be thoroughly investigated. The functional movement screening (FMS)\textsuperscript{TM} tool is such a clinical tool. It was developed by Gray Cook in the hopes to identify multifactorial limitations during basic movements that would then translate to more dynamic and functional athletic movements.\textsuperscript{7} Limitations associated with the movements used during the screening are then attributed to decreased core stability, muscular imbalances, and decreased joint mobility. When these limitations are present in an athlete, compensatory motions are likely to occur in order to complete certain movement patterns successfully. If the compensating movements, that are done in order to get through the activities, are not corrected or identified and addressed then there is an increased chance of injury for that
The inventors of the FMS™ propose that it is not necessarily important to decide which factor is contributing to the issue (muscle imbalances, core weakness, joint mobility), but more important to realize that it exists and address it in order to correct the compensatory movements in order to prevent injury.

Chorba et al used the functional movement screening (FMS)™ tool to come up with scores for 38 NCAA division II female collegiate athletes before the start of their respective fall and winter sport seasons (soccer, volleyball, and basketball). She then tracked their injuries throughout the seasons and was able to look retrospectively at their results, and their impending injuries that occurred. The mean FMS™ score for all subjects was 14.3, and eighteen injuries (17 lower extremity, 1 lower back) were recorded during the study. It was found that a score of 14/21 or less was significantly associated with injury (P=0.0496). With 14 or less being considered the “cutoff” score, Chorba’s results showed 69% of athletes scoring under that sustained an injury. Odds ratios were 3.85 with inclusion of all subjects, and 4.58 with exclusion of ACLR subjects. Sensitivity and specificity were 0.58 and 0.74 respectively. This resultant 4-fold increase in injury risk for female collegiate athletes participating in fall and winter sports really shows a good correlation to injury and the potential compensatory fundamental movement patterns that are often observed in females during dynamic movements.

In a set of articles published by the main FMS™ authors and researchers, the idea of incorporating the FMS™ tool into a pre-participation physical exam is proposed. The authors bring it to attention that there is no widespread or mainstream tool used to identify athletes that are at risk for suffering an injury during the season. Each of the seven movements involved in the functional movement screening is then discussed in
detail, as well as the possible limitations that each may identify. The grading scale of zero to three is described as a three representing perfect execution of the movement with no observed limitation, a score of two represents completion of the movement with one or more limitation, a score of one represents that the movement was not able to be completed, and a score of zero represents pain being present during the movement. The researchers then go on to explain that even when limitations or dysfunctions are seen in the subject’s movements, they are purely observational limitations as opposed to objective measurements of muscle activation or range of motion. The tester can not definitively say that they have more range of motion on one side versus another, at least not objectively, and cannot describe how much of a difference may exist. Aspects like this make the FMS™ a more subjective tool, but still very useful in seeking out limitations that may predispose for injury.

Another study regarding the functional movement screen was conducted by Noda and it looked into the claims of the tool being able to identify joint mobility limitations. Comparisons were made between the actual goniometric measurements of the subject’s ranges of motion, and the observed limitations seen during the FMS™. The study included 36 males and 35 females who were measured for their ankle dorsiflexion, hip extension, and hip internal and external rotation under clinical protocols for measuring range of motion at these joints. The participants then completed the deep squat exercise of the FMS™ while the researchers watched for any knee shifting medially or laterally, foot turning, heel lifting, excessive leaning, back arching, or any arm movement during the squat that are considered limitations and prevent a perfect score during the motion. The results showed that the subjects who performed a heel lift during the deep squat had
three degrees less dorsiflexion then those who did not lift their heel. Also found was that those who had knee shifting had three less degrees of hip internal rotation than those without. From these results it was decided that the subjective data reported from a typical FMS™ screening could be compared relative to the objective data found from clinical examination.

When it comes to the actual “grading scale” that is applied to the FMS™, it can be considered fairly subjective from tester to tester. For this reason, Minick and his colleagues investigated the interrater reliability of the screening tool in order to determine if the scores among different testers of varying experience were consistent. In this study, 40 healthy subjects were videotaped during an FMS™ protocol. Two FMS™ experts and two novices who had completed an FMS™ class assessed the videoed subjects. The researchers compared the scores across the two groups. Findings showed that there was statistically significant congruence and similarity between the two tester groups scoring. Within groups there was statistically significant agreement in both the expert and novice groups of fourteen of the seventeen possible scores. Watching the FMS™ on video as opposed to in person in a clinical setting was cited as a potential for the small amount of disparity between testers.¹⁰

The functional movement screen has been used in two studies to evaluate the effectiveness of using it as a clinical tool to predict injury rates. Peate et al examined the relationship of Functional Movement Screen scores to injury rates of firefighters. The authors proposed that firefighters are at a high risk of injury do to the demands of being in compromised ergonomic body positions during the demands of their profession. The authors graded 433 firefighters on the functional movement screen. The authors
examined the relationship of the FMS score and musculoskeletal injury history. Findings revealed that firefighters that had a history of injury had a 1.68% (95% confidence interval: 1.04, 2.71) higher chance of failing the functional movement screen at a FMS™ cut off score of 16 than those that did not have a history of musculoskeletal injury (p=0.033). The authors did not provide rationale to why the cut off score was 16. This however demonstrates that there is variance in populations at risk of injury.

Kiesel et al was focused on predicting serious injury in professional football by using the functional movement screen in a pre-participation exam. Players participating in training camp were graded using a common functional movement screen protocol. The composite score of each players test was recorded and stored to be analyzed following the competition season. Following the season the sample size was n=46, the number of players that were tested in pre-season and remained on the roster for the regular season. Injury surveillance was tracked by a certified athletic trainer associated with the team. Limited injury data was available to the researchers due to the high profile nature of the National Football League. An injury was defined as membership on the injured reserve and a loss of playing time of three or more weeks. The authors used a dependant t-test with an alpha level of p <0.005 to determine if statistical significance was present between the players suffering an injury and those who completed the season injury free. To determine a FMS™ cut-off score a receiver operator characteristic curve was created maximizing sensitivity and specificity. Once this was created a 2x2 contingency table was created dichotomizing those who suffered an injury and those who remained injury free. Due to the lack of published injury rate data, the authors estimated
a conservative likelihood ratio of injury of 15% which is accepted from high school and collegiate injury rates.

Results of the study showed that mean FMS™ score for all subjects was 16.9. Those who suffered an injury had a mean FMS™ score of 14.3 (SD 2.3) and those who remained injury free was 17.4 (SD 3.1). Analysis of the receiver operator characteristic curve showed that a score of 14 maximized specificity and sensitivity for this study. The likelihood ratio of a player who scored 14 or less on the FMS™ screen was 11.67 (CI 95 = 1.97-18.37) times more likely to be injured than that of a player scoring 15 or higher on the FMS™. However the data of this study may be skewed as the definition of injury is not consistent with that of other injury surveillance studies.

The studies included under the heading of “functional movement screen” demonstrate the high degree of reliability, validity, and sheer functionality of the FMS™ when it comes to clinical incorporation into athletics and the possibilities of the tool to aid clinicians in predicting, and therefore preventing injuries to athletes. The functional movement screening tool has proven successful in several studies dealing with predicting injuries in specific athletic populations, but further research still needs to be conducted in order to further the validity to the great claims being made in association with the FMS™.
Chapter 3

Methodology

3.1 Experimental Design

Using a prospective cohort study design, pre-season performance on the FMS™ tool was obtained from the University of Toledo women’s basketball, soccer, and volleyball teams. During the season, daily exposure rates for practices and competitions were recorded. All incidents that resulted in missing all or part of one or more practices were counted as injuries. Specific details related to the injury, as well as preventative measures taken (taping, bracing, etc) were recorded, and at the conclusion of the season the scores on the FMS were compared with the injury information. Relationships, correlations, and overall results were drawn from the information in regard to sports, specific prediction testing, injury rates, etc.

3.2 Subjects

Fifty-five division one collegiate athletes at The University of Toledo from women’s basketball, soccer, and volleyball were recruited and volunteered for the study. The subjects were required to read and sign consent forms approved by The University of
Toledo Institutional Review Board. Athletes that did not clear the pre-participation physical exam due to a previous or existing injury were excluded from the study.

Table 1: Subject Demographics

<table>
<thead>
<tr>
<th></th>
<th>Age (yrs)</th>
<th>Height (cm)</th>
<th>Weight (kg)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mean±SD (All Subjects)</td>
<td>19.45±1.15</td>
<td>173.0±8.47</td>
<td>68.0±9.66</td>
</tr>
<tr>
<td>Mean±SD (Wom Basketball)</td>
<td>19.76±1.03</td>
<td>178±7.36</td>
<td>74±11.44</td>
</tr>
<tr>
<td>Mean±SD (Wom Soccer)</td>
<td>19.46±1.25</td>
<td>166.79±4.47</td>
<td>62±5.04</td>
</tr>
<tr>
<td>Mean±SD(Wom Volleyball)</td>
<td>19.14±1.10</td>
<td>179±7.23</td>
<td>71±8.13</td>
</tr>
</tbody>
</table>

3.3 Independent Variables

Group: Injured and Non-injured

Body Part: Ankle, Knee, No Injury

Sports: Women’s Soccer, Women’s Basketball, and Women’s Volleyball

Mechanism of Injury: Contact, Non-Contact, No Injury

3.4 Dependent Variables

Functional Movement Screen™ composite score

3.5 Instrumentation
Functional Movement Screening™ Kit; Measuring device, hurdle step, stretch bands, measuring stick necessary for the deep squat, hurdle step, in-line lunge, shoulder mobility, active straight leg raise, trunk stability push up, rotary stability.

3.6 Procedures

The subjects involved in the study were evaluated on the FMS™ using the standard 0-3 ordinal system. A score of 3 was given for performing the specific movement perfectly, a 2 was given when the movement was completed with some compensatory movements observed, a score of 1 was given when the subject could not complete the movement, and a score of 0 associated with pain being present during the movement. The FMS™ included a deep squat, hurdle step, in-line lunge, shoulder mobility, active straight leg raise, trunk stability push-up, and rotary stability test. The FMS™ testing incorporated risk factors for balance, strength, range of motion, flexibility, and proprioception to help predict injury in athletic populations. The composite score for all 7 components of the test was recorded and then compared with the injury documentation and tracking of the lower extremity that occurred throughout the season by the teams’ specific athletic trainer and sports medicine staff. The injury documentation was completed after each team session, where an exposure was considered one athlete per practice or game. Any acute, lower extremity injury that occurred and kept the athlete out of participation for one or more full consecutive exposures was counted as an injury. If an athlete suffered multiple or repeated acute injuries during the competition season, only the first injury incident was included in this analysis. Therefore, an athlete could not appear more than once in the “injured” group’s analysis.

3.7 Statistical Analysis
The FMS™ composite score, which is the lowest cumulative score from bilateral comparison of all 7 of the tests, was used in the statistical analysis. Independent t-tests were performed to determine if a statistical difference was present between injured and non-injured athletes (Hypothesis #1). Separate one-way ANOVA models were used to determine if there was a statistical difference in FMS score between different injured body parts (ankle, knee, non-injured) (Hypothesis #3), different types of injury (contact, non-contact, or non-injured) (Hypothesis #4) and different sports (volleyball, soccer, basketball) (Hypothesis #5). For all of these tests, statistical significance was set a priori at p<0.05. In the event of statistical significance in the ANOVA models, a Tukey’s post hoc test was applied. 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. The interpretation of Cohen’s d was: small <.03; moderate 0.05; large > 0.08.

Additionally, to determine a cut-off score for the FMS™ that maximized sensitivity and specificity, a receiver operator characteristic (ROC) curve analyses were used along with calculation of Likelihood and Odds Ratios (Hypothesis #2). The ROC curve plots sensitivity versus specificity and determines the value at which the test is considered positive by examining varying points on the curve with associated cut-off points. Once the cut-off score was determined, a contingency table was produced to dichotomize the athletes who suffered an injury, those who did not suffer an injury and whether or not those groups were above or below the determined cut-off score, decided
upon by the ROC curve. From the sensitivity and specificity, positive and negative likelihood ratios were calculated first. Finally, using these ratios, an odds ratio was calculated to represent a general prediction model of the FMS score on injury risk during the season.
Chapter 4

Results

Of the 55 participants, 13 (23.6%) suffered a recorded acute lower extremity injury that resulted in removal from participation for at least one full practice or game exposure. The results will be presented in the order of the stated hypotheses.

Hypothesis #1:

There was no statistical difference between the pre-season FMS™ scores of the injured and the non-injured groups ($t_{55}=-1.68$; $P=.100$; $d=0.52$; 95%CI: -0.11, 1.15) (Table 2).

Table 2: Injured vs. Non-Injured FMS comparison

<table>
<thead>
<tr>
<th></th>
<th>Injured Group (n=13)</th>
<th>Non-injured Group (n=42)</th>
</tr>
</thead>
<tbody>
<tr>
<td>FMS composite±SD</td>
<td>16.08±1.12</td>
<td>16.86±1.56</td>
</tr>
</tbody>
</table>

Hypothesis #2

For all subjects, a cut-off score of 16.5 was found that maximized sensitivity (0.615) and specificity (0.738). These findings resulted in a positive likelihood ratio (sensitivity/1-specificity) of 2.35 and a negative likelihood ratio (1-sensitivity/specificity) of 0.522. An odds ratio was calculated at 4.50, meaning that an athlete has an approximately 4.5 times greater chance of suffering a lower extremity injury during a regular season by scoring
less than 16.5 on the composite FMS™ score. By using the cut-off score of 16.5 a 2x2 contingency table was created to dichotomize the subjects by their FMS™ score and injury status after the regular competitive season (Table 3).

Table 3: 2x2 Contingency Table for FMS data

<table>
<thead>
<tr>
<th></th>
<th>Injured</th>
<th>Non-injured</th>
</tr>
</thead>
<tbody>
<tr>
<td>FMS Score ≤ 16.5</td>
<td>8</td>
<td>11</td>
</tr>
<tr>
<td>FMS &gt; 16.5</td>
<td>5</td>
<td>31</td>
</tr>
</tbody>
</table>

Hypothesis #3:
Further sub-dividing the injury data, One way ANOVA revealed no statistical difference between the ankle injury group, knee injury group, and no injury group ($F_{2,54} = 2.34; p=0.106$) (Table 4). The effect size between the Ankle Injury and No Injury Groups was 0.72 ($-1.0, 1.52$). The effect size between the Knee Injury and No Injury Groups was 0.13 ($-0.73, 0.98$). The effect size between the Ankle Injury and Knee Injury Groups was 1.09 ($-0.14, 2.17$).

Table 4: FMS Comparison between Ankle Injury, Knee Injury and No Injury Groups

<table>
<thead>
<tr>
<th></th>
<th>Ankle Injury Group (n=7)</th>
<th>Knee Injury Group (n=6)</th>
<th>Non-injured Group (n=42)</th>
</tr>
</thead>
<tbody>
<tr>
<td>FMS Composite±SD</td>
<td>15.6±1.27</td>
<td>16.7±0.52</td>
<td>16.9±1.56</td>
</tr>
</tbody>
</table>

Hypothesis #4:
Considering the mechanism of injury, the one-way ANOVA did not reveal statistically significant differences between the groups with a contact injury, non-contact injury or no injury ($F_{2,54}=1.48; p=0.237$) (Table 5).

**Table 5: FMS Comparison between Contact Injury Group, Non-contact Injury Group, and Non-injured Groups**

<table>
<thead>
<tr>
<th></th>
<th>Contact Injury Group (n=2)</th>
<th>Non-contact Injury Group (n=11)</th>
<th>Non-injured Group (n=42)</th>
</tr>
</thead>
<tbody>
<tr>
<td>FMS Composite ± SD</td>
<td>16.5±0.71</td>
<td>16.0±1.18</td>
<td>16.8±1.56</td>
</tr>
</tbody>
</table>

**Hypothesis #5:**

When comparing the three sports, one-way ANOVA revealed statistical significance between volleyball and basketball, between soccer and basketball, but not between volleyball and soccer. The one-way analysis was statistically significant for comparing differences between the three sports ($F=5.83$, df= 2, 54, $p=0.005$). The Tukey’s post hoc testing demonstrate that the differences existed between the volleyball (17.36±1.22, n=14) and basketball (15.76±1.86, n=17) athletes ($d=1.00; 95\% CI: 0.22, 1.72$), as well as between the soccer (16.92±1.02, n=24) and basketball athletes ($d=0.81; 95\% CI: 0.15, 1.44$); but not between the volleyball and soccer athletes ($d=0.40; 95\% CI: -0.27, 1.06$).

**Table 6: FMS Comparison between Basketball, Soccer, and Volleyball**

<table>
<thead>
<tr>
<th></th>
<th>Basketball</th>
<th>Soccer</th>
<th>Volleyball</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
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</tbody>
</table>
Table 7: Effect Size and Confidence Interval between Sports

<table>
<thead>
<tr>
<th></th>
<th>Effect Size</th>
<th>95% Confidence Interval</th>
</tr>
</thead>
<tbody>
<tr>
<td>Volleyball vs. Basketball*</td>
<td>1.00</td>
<td>0.22, 1.72</td>
</tr>
<tr>
<td>Soccer vs. Basketball#</td>
<td>0.81</td>
<td>0.15, 1.44</td>
</tr>
<tr>
<td>Volleyball vs. Soccer</td>
<td>0.40</td>
<td>-0.27, 1.06</td>
</tr>
</tbody>
</table>

*Volleyball athletes had a statistically significant higher FMS™ score than Basketball athletes

#Soccer athletes had a statistically significant higher FMS™ score than Basketball athletes
Chapter 5

Discussion and Conclusion

5.1 Discussion

The primary purpose of this research study was to determine if the FMS™ could predict lower extremity injury in division one women’s basketball, soccer and volleyball athletes. Specific comparisons were drawn between the two different groups (injured or non-injured athletes), as well as between subgroups determined by the specific body part injured, contact vs. non-contact injury, and sport the athlete belonged to. It was found that among all of the athletes included in the study, the injured athletes had a lower mean composite FMS™ score as compared to the non-injured athletes, but it was not found to be statistically significant. Though the scores were not statistically significant between the groups, there was a cutoff score found that maximized sensitivity and specificity by using an ROC curve for analysis. The cutoff score found was 16.5 on the composite FMS™ score. Using odds ratios and calculations this came out to mean that if an athlete scored less than 16.5 on the FMS™ they were 4.5 times more likely to have suffered a lower extremity injury as compared to those athletes who scored above a 16.5 on the FMS™.
When examining the difference in the FMS™ scores of the ankle vs. knee vs. non-injured groups, there was no statistically significant difference found. These statistically insignificant results may have been due to the nature of the sports, or to the fact that there were a low number of injuries observed during this competition season. However, those that suffered an ankle injury had the lowest pre-season FMS score, with effect sizes that were large when compared to the No Injury groups and the Knee Injury groups. It is interesting to note that there was almost no difference in the mean scores of the Knee Injury group and No Injury Group. Perhaps the FMS is able to screen more effectively for ankle injuries. At the knee it is possible to make corrections and compensatory movements both at the hip and ankle joint, but at the distal end of the kinetic chain there is less room for adjustment at the ankle joint. However, with a low number of injuries observed, it is difficult to make that a definitive conclusion.

Similarly, there were no statistically significant differences between the Contact Injury, Non-Contact Injury and No Injury groups. Supporting this conclusion were very low effect sizes. It seems that the FMS is not effective to use to predict the general mechanism of injury to the ankle or knee. Most of the movement patterns are performed in the sagittal plane, which may explain the lack of difference in injury mechanism. The exercises used throughout the FMS™ screening are primarily performed in the sagittal plane, and in athletics most movements are multiplanar. Additionally, the tasks in the FMS are performed relatively slowly. Perhaps other screening tools that emphasize other planes of movement and a faster pace of movement will be able to differentiate contact vs. non-contact injuries more effectively.
For the comparison between the FMS™ scores and injuries of the different sports (basketball, soccer, and volleyball) there were statistical differences found between volleyball and basketball athletes, as well as between soccer and basketball athletes, but not between volleyball and soccer female athletes. These differences in the FMS™ scores of the different sport-specific athletes could be due to the nature of the training involved with each sport, or the focus of their weightlifting and conditioning programs that would have altered their scores. This finding from the study could be considered valuable in the future in regards to the way that certain “prevention” or “treatment” programs are designed in order to prevent injury to those athletes with a lower composite score. If it is found and widely accepted that specific sports training is beneficial in raising an athlete’s FMS™ score, than it is conceivable that other sports may alter their pre-season conditioning to mimic another’s in order to minimize injury.

Perhaps the most important finding to come out of the study is the cutoff score found that can be used for predictive models. Using the ROC curve and related calculations, the cutoff score is found by maximizing the sensitivity and specificity of the test. As represented by the 2x2 contingency table, the goal is to maximize the number of true positives and false negatives; when the FMS™ score identifies that someone is at risk for an injury and an athlete that actually suffers an injury throughout the season, it adds further legitimacy to the FMS™ predictive model. In this particular study there were 8 true positives out of 55 total athletes, and 13 total injuries. For 8 of the 13 injuries to be “predicted” by the FMS™ is a step in the right direction to modifying and potentially using the FMS™ tool as part of a pre-participation examination in order to screen for “at risk” athletes.
The cutoff score found in this study was 16.5 on the composite FMS™ score. Other studies have reported cutoff scores of their own. Kiesel et al⁴ reported a cutoff score of 14 a for prediction of injury among professional football players. The cutoff score found in this study is not consistent with Kiesel’s study, but may be attributed to some fairly substantial differences between the studies. The most obvious difference between the two studies is the level of competition and skill at which the athletes compete. Kiesel worked with professional football players whereas our research was conducted with Division I collegiate female basketball, volleyball, and soccer athletes. The differences in athletic abilities, training and sport demands may have influenced the resultant cut-off score in both studies. Another potential difference could be the gender of athlete being tested. Females are considered to have many biomechanical differences when compared to their male counterparts, and potentially already be at risk due to gender differences, so when comparing males to females it may actually be an unfair comparison.¹ Yet another discrepancy between the studies could be their definition of “injury.” The Kiesel article classifies an injury only once an athlete had been place on injured reserve for at least 3 weeks.⁴ Our investigation categorized injury as any acute lower extremity issue that held an athlete out for one or more exposures to competition or practice.

Limitations

The main limitation in this study is that only female athletes were tested. In an ideal study there would be a variety of athletes tested; various sports, multi-gender, various ages. Females have been shown to have a higher risk of injury in specific sports as opposed to their male counterparts, so to have only tested females could have skewed
the results in regard to a cutoff score that could be used across the board in all sports when screening during a pre-participation physical exam.

Another limitation could have been the number of athletes tested in comparison to the number of injuries observed. In order to obtain very widely accepted results, a large amount of data is needed, and a large amount of injuries must be seen. While this study may not fulfill those requirements, it adds to a larger body of research that will hopefully lead in that direction. Also in dealing with the injuries observed, only two were contact injuries so this study is not very comparable to studies done in the past that looked at football specifically, which involved an increase in contact injuries as compared to this study. 4

To make the results more generalizable future research should consider the inclusion of males and females, as well as including as many different sports as possible as opposed to the “high risk” female sports used throughout this study. In addition to including males and females in the study, differences among sports and their risk of contact vs. noncontact injuries should be considered. Regardless of the capability of the FMS™ as a predictive model for injury, it would be hard to assume that a lower score on the FMS™ predisposed an athlete for a contact injury that no one could truly predict.

A final limitation that should be considered from the study is the inclusion of multiple examiners during the baseline FMS™ testing. It has been shown that the tool has a high interrater reliability when performed by clinicians with the proper training; however there is always room for error when having multiple raters assessing the athletes. 10

5.2 Conclusion
This research study demonstrated that the FMSTM shows a true potential to work as an effective and efficient predictive model of lower extremity injury in division I collegiate female athletics. More research is still necessary before implementing the FMSTM into a PPE for athletics, but due to the low cost and its simplicity to implement, it should be considered by clinicians and researchers in the future.
References


