A Thesis

entitled

Injury Prediction in Division I College Football Players Using a Modified Lower Extremity Version of the FMS

by

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

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May 2013
An Abstract of

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Background: Lower extremity injuries are prevalent in collegiate football. According to Rechel et al [3], a study that tracked collegiate football injuries from 1988-2004, 55.7% of injuries suffered during spring practice were lower extremity. The same study also found that 17.6% of all injuries suffered during fall games were due to knee injuries, 15.6% were ankle, and 3.6% were upper leg muscle or tendon strain. It appears that in the sport of football, injuries to the lower extremity are the most prevalent in collegiate athlete. It is likely that risk identification and prevention could help to reduce these injury rates. Therefore, the development of clinical prediction tools incorporated in a pre-participation exam that could help in identifying athletes who are at risk for lower extremity injuries is vitally important. One of these examination tools is the FMS. Purpose: The purpose of this study was to determine if the FMS composite score can predict injury of the lower extremity in Division I collegiate football players. A secondary purpose was to determine a cut-off score on a modified/lower extremity only FMS that can predict injury. A tertiary purpose was to examine the ability of the FMS to predict contact vs. non-contact lower extremity injuries in collegiate football athletes. Methods: 70 Division I college football players were screened pre-season using the Functional Movement Screen. Total
scores out of 21 were recorded. Injuries and exposures were tracked throughout the season by the certified athletic trainer assigned to the University of Toledo football team.

**Results:** When comparing the FMS between injured and non-injured groups, there were no statistically significant differences on any of the FMS scores (p>.05). The full FMS had a cut-off score of 18.5; MFMS 4 stations showed a cut-off score at 11.5 and the MFMS 3 stations had a cut-off score of 8.5. The MFMS 4 had the highest diagnostic odds ratio of 3.57. Only the MFMS 4 had a sensitivity that exceeded 0.70. **Discussion:** The cut-off scores found in this study were seen to be much higher than previous FMS studies. The MFMS 4 within this relatively small sample size shows promise of injury prediction capabilities with its moderate sensitivity. Further research should be done to exam this possibility. **Conclusion:** Both the full and modified versions of the FMS could not statistically differentiate injured football players. However, there may be some diagnostic usefulness within the MFMS 4 and further research should exam this possibility.
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List of Abbreviations

FMS.........................Functional Movement Screen
MFMS 3.....................Modified Functional Movement Screen with 3 lower extremity tests
MFMS 4.....................Modified Functional Movement Screen with 4 lower extremity tests
ROC .........................Receiver Operating Curve
Chapter One

Introduction

Football in the United States continues to grow at every level. Professional football continues to add teams to the NFL and college institutions continue to develop their own football programs. In just 16 years college football programs increased by over one hundred programs\textsuperscript{[1]}. The increase in programs resulted in an increase in participants by over 12,000. Along with the growing number of programs and participants comes an increase in the potential for the number of injuries. Injury rates have been reported as high as 36 injuries per 1000 exposures for games\textsuperscript{[1]}. The majority of injuries seen in college football occur to the lower extremity\textsuperscript{[1]}. Pre-participation screenings can play a potential role in detecting pre-disposing risk factors for injury. Examining and exploring different testing options can help in identifying athletes who have some pre-disposing risk factors. The Functional Movement Screen is one of the tools that has been utilized for screening for risk of injury in football athletes.

1.1 Background

Injuries occur at every level of sport competition and can be an expensive and costly problem. Approximately 1.4 million injuries are endured annually in the United States among high school athletes\textsuperscript{[2]}. An injury surveillance study completed during the 2006-2007 school year that followed 18 high schools recorded 338 injuries\textsuperscript{[2]}. The majority of these injuries were to the lower extremity, which accounted for 56\% of all injuries. Another study recorded 4350 injuries during the 2005-2006 school year in 100 schools. Men’s sports made up the majority of injuries with 76\%. The sport with the largest number of injuries was football. Of all the injuries the lower extremity accounted
Lower extremity injuries are also prevalent in collegiate football. According to a study that tracked collegiate football injuries from 1988-2004, 55.7% of injuries suffered during spring practice were lower extremity; with an injury rate of 35.90 per 1000 injuries during fall.\[^{[3]}\] The same study also found that 17.6% of all injuries suffered during fall games were due to knee injuries, 15.6% were ankle, and 3.6 were upper leg muscle or tendon strain. Other lower extremity injuries such as: pelvis, hip lower leg, and patella accounted for another 6.3% of injuries. It appears that in the sport of football, injuries to the lower extremity are the most prevalent in the adolescent and collegiate athlete. It is likely that risk identification and prevention could help to reduce these injury rates. Therefore, the development of clinical prediction tools incorporated in a pre-participation exam that could help in identifying athletes who are at risk for lower extremity injuries is vitally important.

The Functional Movement Screen (FMS) is an assessment tool used to assess an individual’s performance during seven functional movements. These seven movements have been said to be the basis of all sport related movements. The FMS combines measures of strength, flexibility, proprioception, and neuromuscular control all into one versatile screening tool.\[^{[4, 5]}\] The FMS provides sports medicine professionals with an assessment tool that can challenges the athlete’s dynamic stability and functional capacity, and allows clinicians to distinguish compensatory movements as a result of anatomical deficits. The FMS was created using kinesthetic and proprioceptive awareness principles. Each test requires proper function at every level of the body’s kinetic chain. It is theorized that athletes who do not have the proper function of each individual segment
of the kinetic chain will develop compensatory movements in order to complete a certain task.\[4\]

There is strong reliability associated with the FMS when assessed by a properly trained individual.\[6\] Previous studies have examined the FMS and its ability to predict injury in women’s soccer and professional football.\[7, 8\] Both studies found that an athlete with a score of 14 or lower will have an increased risk of injury. Currently there is no published research using the FMS as a predictor of injury in collegiate football players. Recent work under the direction of the faculty advisor suggests that the FMS may not be a strong predictor of ankle and knee injuries in collegiate athletes\[9\]. This contradicts work by Kiesel et al who reported that professional football athletes with a score of 14 or less on the FMS increased their chance of injury from 14% to 51%.\[8\] However, the definition of injury used in that study brings into question the validity of this recommendation. Similar to work from our lab, other studies have shown no correlation with FMS score and injury prediction.\[10, 11\]

A criticism of the FMS for lower extremity injury assessment is that all seven assessment stations are not pertinent to lower extremity function. It is possible that modifying the FMS to only include the testing stations pertinent to lower extremity performance may provide a better prediction model for injuries to the knee and ankle. However, there is no research on the capability of a modified FMS, focused on the lower extremity, to predict lower extremity injuries.

Football is a heavily contact sport. It is difficult to predict when these contact instances take place, which in turn makes it difficult to predict contact injuries. Noncontact injuries are more predictable because usually they are related to a
biomechanical deficiency. The FMS is a good tool to identify these deficiencies which possible makes it useful in predicting non-contact injuries as opposed to contact injuries.

1.2 Problem Statement

A more thorough pre-participation screening process in sports is needed to identify predisposing risk factors in athletes. The FMS has been suggested to help predict injury in professional football players, firemen, and officer cadets; however, these studies do have potential methodological flaws. Currently there is no extensive literature on the injury prediction capabilities of the FMS in collegiate football. Additionally, there is no current evidence on whether a modified, lower extremity focused FMS can better predict lower extremity compared to the original FMS scoring system. These approaches with the FMS are needed to verify its usefulness in predicting lower extremity injuries in collegiate football athletes. Finally, there is a need to determine if risk of non-contact lower extremities, which have a greater likelihood for prevention, can be identified using the FMS tools.

1.3 Purpose Statement

The purpose of this study was to determine if the FMS composite score can predict injury of the lower extremity in Division I collegiate football players. A secondary purpose was to determine a cut-off score on a modified/lower extremity only FMS that can predict injury. A tertiary purpose was to examine the ability of the FMS to predict contact vs. non-contact lower extremity injuries in collegiate football athletes.

1.4 Significance of Study

The FMS tests can distinguish compensatory movement patterns that may be a result of strength deficits, neuromuscular imbalances, or lack of proprioception. These
compensatory movements can develop into a learned movement pattern and can predispose an athlete to injury.\textsuperscript{[4]} By establishing a cut-off score that maximizes a successful prediction model, we can detect athletes at risk of an injury, and further prevent injury by providing an intervention to treat deficits found from the FMS. In turn, this can further reduce healthcare costs related to injury.

1.5 Hypothesis

H1: There will be a detectable difference in FMS composite scores in Division I collegiate football players that do and do not experience a musculoskeletal lower extremity injury.

H2: There will be a specific FMS composite score that will maximize sensitivity and specificity greater than 0.7.

H3: Football players that suffer a non-contact injury mechanism will have significantly lower pre-season FMS scores compared to players that experience a contact injury or no injury

H4: There will be a detectable difference in lower extremity/modified FMS scores in Division I collegiate football players that do and do not experience a musculoskeletal lower extremity injury.

H5: There will be a specific lower extremity/modified FMS score that will maximize sensitivity and specificity greater than 0.7.

H6: Football players that suffer a non-contact injury mechanism will have significantly lower pre-season lower extremity/modified FMS scores compared to players that experience a contact injury or no injury
Exploratory Approach: The lower extremity/modified FMS score will have a higher prediction capability than the composite FMS score. This relationship will not be hypothesis driven, but is exploratory in nature rather than proven with statistical analysis.
Chapter 2

Literature Review

The ability to reduce injury rates is an important aspect of clinical practice. One way clinicians can attempt to reduce injuries is to develop an injury prediction tool. Current literature on lower extremity injury prediction is limited, but shows some promise. In order to develop a prediction tool it is important to look at the current literature involving injury rates in football before recommending a proper injury prediction tool. One tool, the Functional Movement Screen, has been used in published papers to examine injury prediction in professional football and women’s college athletes.\cite{7,8} Currently, there is limited research considering collegiate football players.

Epidemiology

From 1988-2004 the number of collegiate football players rose by about 12000 athletes, contributing to an increase in the number of exposures to injury and the number of injuries reported.\cite{1} Injuries within the high school, college, and professional levels of football have been tracked using a variety of systems including: NCAA injury surveillance system\cite{1} and High School Reporting Online or RIO.\cite{3} In addition to tracking injury, daily exposures for each athlete are recorded. One exposure is defined as a time when one athlete participates in one practice or competition. By comparing the number of injuries to the number of athlete exposures, the rate of injury can be calculated.

In an NCAA injury surveillance of collegiate football players from 1998-2004, there was a reported 35.90 per 1000 exposures during games, with 3.8 during fall season, and 9.62 during spring season.\cite{1} Within the high school football population, Rechel et
al\textsuperscript{[3]} reported an injury rate of 4.36 injuries per 1000 exposures. This injury rate was higher than all of the other sports that were examined, such as: baseball, volleyball, and wrestling.\textsuperscript{[3]} Lastly, within the NFL, Feeley et al found a total of 728 injuries among 42,030, with a corresponding injury rate of 17.3 per 1000 exposures.\textsuperscript{[12]} Injury is prevalent among all levels of football, with the highest rate of injury seen at the collegiate level, followed by the professional and high school levels. This is evidence to support the need for more research to determine methods that can lower these injury rates in the sport of football.

**Body Parts Injured**

Dick et al\textsuperscript{[1]} found that the majority of injuries in collegiate football players occurred to the lower extremities; with over 50\% of the injuries observed in the lower extremity, followed by the upper extremity with 22.6\%, head/neck at 11.5\%, and trunk/back with 9.9\%. The knee and ankle accounted for the majority of lower extremity injuries with knee internal derangement making up 17.8\% and the ankle ligament sprains contributing 15.6\% of injuries during fall games. The next highest occurrence of lower extremity injury was muscle-tendon strain. During fall and spring practices upper leg muscle-tendon strains accounted for 10.7\% and 10.8\% of injuries, respectively.\textsuperscript{[11]}

Rechel et al\textsuperscript{[3]} found similar data among high school athletes, with 57.2\% of all the injuries recorded in the lower extremity; with the most frequently injured part being the ankle (22.7\%) and the thigh and upper leg (8\%). When looking specifically at the data collected from football the researchers found that the lower extremity injury was involved 48.3\% of the time during practice and 46.8\% of the time during competitions. This was more predominant than the upper extremities (practice=29\%, competition29.7\%), head
neck and face (practice=14%, competition=17.1%), and the trunk (practice=8.7%, competition=6.4%).[1]

In addition, Dick et al[1] classified the severity of injury based on the time the athlete was removed from participation. An athlete that was out for 10 or more days was considered to have a significant injury, and the most significant injuries were reported to the lower extremity. During the preseason, knee internal derangements made up 26% of these injuries, muscle-tendon strain of the upper leg made up 10.3%, and ankle ligaments sprains made up 8.7% of the significant injuries. During the season knee internal derangements (32.8%) and ankle sprains (11.8%) made up the majority of these injuries with a time loss of 10 or more days.

**Mechanism of Injuries**

Injuries are not only reported by location of injury, but also by the mechanism by which the injury occurred. Dick et al[1] classified injuries based on 3 primary mechanisms: player contact, other contact (contact with ball, ground, or other object), and non-contact. The most common mechanism of injury was player contact, accounting for 56.5% of injuries during fall practices, 77.9% during games, and 69.2% during spring practices. The second most common injury mechanism was non-contact, which was responsible for 28.8% of injuries during fall practices, 8.9% during games, and 21.8% during spring practices. Other contact was the least common mechanism of injury, making up 4.9% of injuries during fall practices, 5% of games, and 5.9% during spring practices.[1] Contact during football participation can be hard to predict, but non-contact injuries are associated with poor biomechanics and improper technique which can be evaluated.
Injury Definitions

A well-defined and comprehensive definition of injury is critical when reporting injury related data. Previous researchers have used multiple injury definitions. Kiesel et al\textsuperscript{[8]} defined an injured person as anyone on the injured reserve or with a time loss of 3 weeks or greater.\textsuperscript{[8]} On the other hand, O’Connor et al\textsuperscript{[10]} described an injury as a damage to the body secondary to physical training and that required medical treatment one or more times during the season.\textsuperscript{[10]} Kiesel’s\textsuperscript{[8]} definition is unique in that it defines an injured person compared to an injury. Additionally, he restricts his definition to significant injuries by utilizing a time period of greater than or equal to three weeks of time loss. Kiesel\textsuperscript{[8]} also limits himself in that an athlete can be placed on the injured reserve for reasons other than a musculoskeletal injury. O’Connor’s\textsuperscript{[10]} definition allows for the inclusion of more musculoskeletal injuries of varying severity. It is important to have a specific and concise injury definition in order to collect accurate injury tracking data.

Functional Movement Screen

The Functional Movement Screen is an evaluation tool that consists of 7 different tests or movements. These tests are designed to test an individual’s fundamental movement patterns. More specifically the FMS tests an individual’s proprioceptive and kinesthetic abilities.\textsuperscript{[4, 5]}

Deep Squat

The deep squat is a common movement and position utilized in athletics. For example, the three point stance in football requires a deep squat position, as well movement coordination and power to quickly propel upwards. The deep squat is useful in
assessing bilateral, functional movement of the hips, knees, and ankles. In addition it
tests shoulder and thoracic mobility, with the use of a dowel held overhead. The starting
position for the deep squat is with feet shoulder width apart and aligned in the sagittal
plane and a dowel pressed overhead with shoulders flexed and abducted and the elbows
extended. The athlete is instructed to slowly lower himself into a deep squat position.
During the squat heels should remain on the floor, the head and chest facing forward, and
the dowel maximally pressed overhead. If necessary a 2x6 block can be placed under the
individual’s heels in order to minimize the space between the heels and the floor.[4]

**Hurdle Step**

The hurdle step is used to evaluate an individual’s stride mechanics and assess
coordination and stability of the torso, hips, knees and ankles. The individual starts with
his feet together and toes touching the base of the hurdle. The hurdle is set to a height
even with his tibial tuberosity. A dowel is set on the back of the shoulders just below the
neck. The examiner instructs the individual to step over the hurdle, touch his heel to the
ground, and then return to the starting position. The leg stepping over the hurdle is the leg
that is scored. Correct form consists of the individual’s ankles, knees, and hips aligned in
the sagittal plane, minimal movement of the lumbar spine, and the dowel and string
remains parallel through the entire motion.[4]

**In-Line Lunge**

The in-line lunge test is another functional test that places the body in a position
that mimics positions simulated during sports movements. This test allows the examiner
to assess hip and ankle mobility and stability, quad flexibility, and knee stability. For this
test, the limb being measured is the limb that steps forward. The height of the hurdle
during the previous test is used to measure the length of the step taken while lunging. The individual then places both heels their on the end of the board. The dowel is held behind the back with in a vertical position with the hand opposite the front foot grasping it up top, and the other hand grasping the dowel around the lumbar spine. The individual then steps out to the pre-determined length and touches their knee to the board, behind the heel of the front foot and then returns to the starting position. The dowel must remain vertical and in contact with the lumbar spine, while the dowel and feet remain in sagittal plane.[4]

**Active Straight Leg Raise**

The active straight leg raise assesses an individual’s hamstring and gastrocnemius flexibility. The individual first lies supine on the floor in the starting position. The dowel is then placed at the mid-pint between the patella and the ASIS in perpendicularly orientation. The individual is then asked to flex the hip, or lift the test leg off the floor with the ankle dorsiflexed and knee extended. The flexed hip is the side that is scored. The examiner should watch the leg on the floor to monitor for external rotation of the limb, and flexion of both knees.[4]

**Shoulder Mobility Test**

The shoulder mobility test is the fifth of the seven tests, and is the first upper extremity test. This test assesses bilateral shoulder range of motion, scapular mobility, and thoracic spine extension. First, the person’s hand size is measured from the distal wrist crease to the tip of the third digit. The individual is then asked to make a fist with both hands with the thumb inside the fist. Then the individual is asked to adduct, extend, and internally rotate one shoulder with the goal of reaching up the back, while he
abducts, flexes, and externally rotates the other shoulder aiming to reach down the back. The goal is to reach the hands together. The examiner measures the distance between the two closest bony prominences. A clearing test should be performed after the shoulder mobility test. The individual is asked to touch the opposite shoulder and raise their elbow upward. If pain is noted then the motion receives a score of 0.[5]

*Trunk Stability Push-Up*

During the trunk stability push-up the examiner can assess an individual’s ability to control his trunk during a closed-chain upper body movement. The individual starts in a prone position with his hands shoulder width apart, and thumbs aligned at the top of the forehead. The athlete then extends his elbows to perform a push-up. If the push-up cannot be performed with hands in the initial position, the individual is allowed to move his hands so they are in line with the chin, and a second attempt at a push-up can be made. Altering the position of the hands deducts a point from the total score. A press up is performed as a clearing test after the trunk stability push-up. If pain is felt then a 0 is scored.[5]

*Rotary Stability Test*

The rotary stability test requires the individual to stabilize the trunk during a combined upper and lower extremity movement. The individual starts in a quadruped position with his shoulders and hips at 90 degrees to the torso. The ankles should be dorsiflexed. The athlete flexes one shoulder while extending the ipsilateral hip and knee. The shoulder is then extended and the knee flexed to the point that they touch, and then the starting position is resumed. If the individual cannot perform the movement the upper extremity of one limb and contralateral lower extremity limb are used. The spine must
remain parallel to the floor, and the knee and elbow must touch prior to returning to the starting position.\textsuperscript{[5]}

**FMS in Injury Prediction**

There has been previous research that suggests the FMS may have some ability to predict injury in sport. Kiesel et al\textsuperscript{[8]} studied the FMS’s ability to predict injury in professional football. The researchers tested 46 professional football players before the 2005 season and tracked all injuries throughout the season. The researchers used an injured person definition as a player being placed on the injured reserve or having a time loss of 3 weeks due to injury. The authors used a cut-off score of \( \leq 14 \) to define an athlete who is at risk for injury. The researchers did not differentiate between contact and non-contact injuries in this study. Currently, there is no research validating the FMS’s ability at predicting injuries which result from player to player contact, therefore the results of this study should be interpreted cautiously. Keeping these limitations in mind they found that individuals with an FMS score of 14 or less had an increased probability from 14\%-51\%.\textsuperscript{[8]}

Using a similar study design, Chorba et al\textsuperscript{[7]} tracked injuries in 38 female collegiate athletes and reported 18 injuries, 17 of which occurred to the lower extremity. The injuries were specific as to time missed or location of the injury. However, the cut-off score used to establish injury risk (\( <14 \)) was taken from the study by Kiesel et al\textsuperscript{[8]}, which may be skewed because it was not calculated from the data collected from the researcher’s own study. While this study also showed that athletes with a score of less than 14 were more likely to be injured,\textsuperscript{[7]} there are concerns about the methods and how the cut-off score was established.
O’Connor et al\textsuperscript{[10]} used a group of 874 officer candidates to examine the injury prediction capabilities of the FMS. Injuries were tracked during two training periods, one lasted 38 days, and the other 68 days. The authors found a cut-off score of 14 or less on the FMS to predict injury with a sensitivity of .45 and specificity of .71. Additionally, the FMS can predict serious injury with a sensitivity of .12 and specificity of .94. O’Connor et al\textsuperscript{[10]} found no significant correlation between FMS score and injury.

**Interrater Reliability of FMS**

Minick et al\textsuperscript{[6]} looked at the reliability of the FMS test between raters. The authors’ video-recorded 40 subjects performing each of the FMS tests. The videos were then watched and performance on each test was rated by four different raters, two experts and two novices. The novice testers and the experts showed a substantial agreement on all 17 parts of the test. All of the tests showed greater than 80% agreement between novice and expert raters. The FMS shows a high interrater reliability between novice and expert testers.\textsuperscript{[6]}

Recently, Gribble et al\textsuperscript{[13]} also found similar results when looking at the interrater reliability of the FMS. Gribble et al\textsuperscript{[13]} had three groups score three different individuals through the entire FMS, using videotaped clips, on two different days. The raters consisted of an FMS experienced rater group, a clinical rater group and a student rater group. They report strong reliability was associated with clinicians with prior experience using the FMS and moderate reliability between athletic trainers who had no previous experience with the FMS.\textsuperscript{[13]} The student group demonstrated poor reliability. Therefore, the FMS can be applied with strong interrater reliability by experienced athletic trainers,
making this a useful tool when there may be a team of researchers rating a large group of athletes.\textsuperscript{[13]}

**Summary**

After studying previous injury rate research, \textsuperscript{[1-3, 12, 14]} a need for a lower extremity injury predictor is obvious. The FMS has shown some potential to identify athletes at risk for injury; and more importantly has shown potential to identify football players who are at risk for an injury. However, previously published research may have some methodological flaws and has not concentrated on collegiate football athletes. Finally, although the FMS has been used no previous studies have considered using a modified version of the FMS as predictor of lower extremity injury in Division I collegiate football players, eliminating the need to evaluate aspects of the upper extremity with some of the stations of the FMS. This may provide information on how to make the FMS a more efficient evaluation tool.
Chapter 3

3.1 Study Design

Prospective cohort study

3.2 Subjects

All participants were athletes on the Division 1 Collegiate football team at the University of Toledo and cleared for full participation at the time of pre-season testing. All of the 70 subjects were males (20±1.4yrs, 107.5±30.3kg, 186.1±7.6cms). Any subject with the following was excluded from the study: vestibular dysfunction, history of lower extremity surgery, or concussion within past 3 months. Each subject signed an informed consent form as approved by the University of Toledo’s Institutional Review Board (IRB#106503) before participation. Each participant completed a questionnaire which provided us with demographics such as age, gender, injury hx, brace/tape use, and conditioning program participation.

Instrumentation

A Functional Movement Screen kit that includes a two inch by six inch board, hurdle and measuring dowel was used.

Independent Variables

Group
a. Injured
b. Non-injured

Mechanism of Injury
a. Contact
b. Non-Contact
c. Non-injured

**Dependent Variables**

1. Functional Movement Screen score (score out of 21)
2. Modified/lower extremity Functional Movement score (out of 12)
3. Modified/lower extremity Functional Movement score (out of 9)

**3.3 Procedures**

Prior to performing the test, the test movements were demonstrated for them. The tests were performed using the guidelines set by Cook.[4, 5] All participants were tested on all seven movements and the athletes were tested prior to fall camp. For each of the seven tests, the subjects were given a score between zero and three. A score of zero was given automatically if the person experienced pain at any time during the movement. A one was given if the person could not complete the movement or assume the position necessary for the test. The individual was scored as a two if they could perform the movement but compensatory movements were made to perform the movement. A three was given if the movement was performed correctly with no compensatory movements. The FMS was performed bilaterally. Additionally, each movement was performed three times with the lowest score being utilized.[4, 5] Three separate versions of the FMS were used. We used the full FMS which included all 7 tests, a 4 station version, and a 3 station version. The four station version included the deep squat, the in-line lunge, the hurdle step, and the straight leg raise test and had a maximum score of 12 points. The three station test included the deep squat, the in-line lunge, and the hurdle step and had a maximum score of 9.

**3.4 Injury Monitoring**
Daily exposure rates during practice and games were recorded by the ATC assigned to the University of Toledo football team. Injury occurrences were recorded by the ATC and included which extremity was injured, the type of injury, and the mechanism of injury. An exposure was defined as one athlete participating in one practice or game in which he was exposed to the possibility of athletic injury regardless of the time associated with participation. An injury is defined as: 1) one that occurred to the ankle or knee as a result of participation in an organized intercollegiate practice or competition, (2) required medical attention by a team certified athletic trainer or physician, and (3) resulted in restriction of the athlete’s participation or performance for one or more calendar days beyond the day of injury.\[15\]

3.5 Data Analysis

Separate independent t-tests were used to determine if there was a significant difference between athletes with an in-season injury and non-injured athletes on the FMS and the MFMS scores. Separate one-way ANOVAs were used to compare the different mechanism of injury groups (contact, non-contact, non-injured) and the location of injury (ankle, knee, and non-injured) on the standard and the modified FMS scoring. A Receiver Operator Curve (ROC) was utilized to determine an FMS composite score cut-off that maximizes sensitivity/specificity. This analysis compares the number of true positives (sensitivity) with the number of false positives (1-specificity). The optimum injury threshold score is the portion of the curve closest to the left, upper corner of the graph. Calculation of likelihood ratios and diagnostic odds ratios were performed to determine the strength of prediction of the scores from the ROC analysis. For all statistical analyses SPSS 19.0 was used with an a-priori alpha level of P<.05.
Chapter 4

Results

Seventy one athletes were screened during the pre-season. Of the 70 athletes that were screened, 21 athletes (30%) suffered an injury to the lower extremity that met all components of the injury definition. Forty-nine athletes (70%) did not suffer an injury (Table 1).

Table 1 – Demographics

<table>
<thead>
<tr>
<th></th>
<th>N</th>
<th>Age</th>
<th>Height (cm)</th>
<th>Mass (kg)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Injured</td>
<td>21</td>
<td>20</td>
<td>186.5</td>
<td>116.9</td>
</tr>
<tr>
<td>Non-Injured</td>
<td>49</td>
<td>20</td>
<td>185.9</td>
<td>127.2</td>
</tr>
</tbody>
</table>

When comparing the FMS between injured and non-injured groups, there were no statistically significant differences on any of the FMS scores (p>.05) (Table 2).

Table 2 – Means and Standard Deviations for Injured vs. Non-Injured Group Comparisons

<table>
<thead>
<tr>
<th>Group</th>
<th>N</th>
<th>Mean</th>
<th>Std. Deviation</th>
<th>t-value</th>
<th>p-value</th>
<th>Effect Size</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>FMS Total</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Injured</td>
<td>21</td>
<td>17.8571</td>
<td>1.42428</td>
<td>-1.096</td>
<td>.277</td>
<td>.29 (-0.23, 0.80)</td>
</tr>
<tr>
<td>Non-injured</td>
<td>49</td>
<td>18.3265</td>
<td>1.72467</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>MFMS 4 Stations</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Injured</td>
<td>21</td>
<td>11.0952</td>
<td>.76842</td>
<td>.508</td>
<td>.613</td>
<td>.13 (-0.38, .64)</td>
</tr>
<tr>
<td>Non-injured</td>
<td>49</td>
<td>10.9592</td>
<td>1.11727</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>MFMS 3 Stations</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Injured</td>
<td>21</td>
<td>8.1905</td>
<td>.67964</td>
<td>.031</td>
<td>.975</td>
<td>.01 (-0.50, .52)</td>
</tr>
<tr>
<td>Non-injured</td>
<td>49</td>
<td>8.1837</td>
<td>.90539</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

(MFMS 4 stations include the deep squat, in-line lunge, hurdle step, and the straight leg raise. MFMS 3 Stations include the deep squat, in-line lunge, and the hurdle step.)

In Table 3 the Cut-off scores derived from the ROC curve analysis along with the associated sensitivity and specificity are shown. Also shown are the diagnostic odds ratios which show the likelihood that a score below the associated cut-off will lead to

<table>
<thead>
<tr>
<th></th>
<th>N</th>
<th>Mean</th>
<th>Std. Deviation</th>
<th>t-value</th>
<th>p-value</th>
<th>Effect Size</th>
</tr>
</thead>
<tbody>
<tr>
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<td></td>
</tr>
</tbody>
</table>
future injury. The full FMS had a cut-off score of 18.5; MFMS 4 stations showed a cut-off score at 11.5 and the MFMS 3 stations had a cut-off score of 8.5. The MFMS 4 had the highest diagnostic odds ratio of 3.57. The MFMS 3 had the second highest diagnostic odds ratio of 2.46. The full FMS had the lowest diagnostic odds ratio of 1.8. Only the four station MFMS had a sensitivity that exceeded 0.70.

Table 3 – Cut-off and Diagnostic Odds Ratios

<table>
<thead>
<tr>
<th></th>
<th>Cut-off</th>
<th>Sensitivity</th>
<th>Specificity</th>
<th>Diagnostic Odds Ratio</th>
</tr>
</thead>
<tbody>
<tr>
<td>FMS Total</td>
<td>18.5</td>
<td>.67</td>
<td>.47</td>
<td>1.8</td>
</tr>
<tr>
<td>MFMS 4 Station</td>
<td>11.5</td>
<td>.71</td>
<td>.59</td>
<td>3.57</td>
</tr>
<tr>
<td>MFMS 3 Station</td>
<td>8.5</td>
<td>.67</td>
<td>.55</td>
<td>2.46</td>
</tr>
</tbody>
</table>

(Max scores of tests shown: FMS Total: 21, MFMS 4 station: 12, MFMS 3 station: 9)

There was no statistically significant difference on the full FMS, MFMS 4 station, or MFMS 3 scores between athletes that suffered an injury by a contact mechanism, non-contact mechanism, and the non-injured athletes (P≥0.05).

Table 4 – Contact injuries vs Non-contact vs Non-injured FMS Scores

<table>
<thead>
<tr>
<th></th>
<th>N</th>
<th>Mean</th>
<th>Std. Deviation</th>
<th>F-value</th>
<th>P-value</th>
</tr>
</thead>
<tbody>
<tr>
<td>FMS Total</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Contact</td>
<td>9</td>
<td>18.1111</td>
<td>1.36423</td>
<td>.782</td>
<td>.462</td>
</tr>
<tr>
<td>Non-contact</td>
<td>12</td>
<td>17.6667</td>
<td>1.49747</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Non-injured</td>
<td>49</td>
<td>18.3265</td>
<td>1.72467</td>
<td></td>
<td></td>
</tr>
<tr>
<td>MFMS 4 Stations</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Contact</td>
<td>9</td>
<td>11.1111</td>
<td>.60093</td>
<td>.129</td>
<td>.879</td>
</tr>
<tr>
<td>Non-contact</td>
<td>12</td>
<td>11.0833</td>
<td>.90034</td>
<td></td>
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</tr>
<tr>
<td>Non-injured</td>
<td>49</td>
<td>10.9592</td>
<td>1.11737</td>
<td></td>
<td></td>
</tr>
<tr>
<td>MFMS 3 Stations</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Contact</td>
<td>9</td>
<td>8.1111</td>
<td>.60093</td>
<td>.069</td>
<td>.933</td>
</tr>
<tr>
<td>Non-contact</td>
<td>12</td>
<td>8.2500</td>
<td>.75378</td>
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<td></td>
</tr>
<tr>
<td>Non-injured</td>
<td>49</td>
<td>8.1837</td>
<td>.90539</td>
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</tr>
</tbody>
</table>
Table 5 portrays the differences in FMS scored when compared by body segment injured. The ankle injured group scored the lowest in all three tests (values), but there are no statistically significant differences noted (p>.05).

<table>
<thead>
<tr>
<th></th>
<th>N</th>
<th>Mean</th>
<th>Std. Deviation</th>
<th>F-value</th>
<th>P-value</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>FMS Total</strong></td>
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<tr>
<td>Ankle</td>
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<td>17.7692</td>
<td>1.16575</td>
<td>.641</td>
<td>.530</td>
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<tr>
<td>Knee</td>
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<td>18.0000</td>
<td>1.85164</td>
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</tr>
<tr>
<td>Non-injured</td>
<td>49</td>
<td>18.3265</td>
<td>1.64443</td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>FMS 4 Stations</strong></td>
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<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Ankle</td>
<td>13</td>
<td>10.9231</td>
<td>.75955</td>
<td>.608</td>
<td>.547</td>
</tr>
<tr>
<td>Knee</td>
<td>8</td>
<td>11.3570</td>
<td>.74402</td>
<td></td>
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<tr>
<td>Non-injured</td>
<td>49</td>
<td>10.9592</td>
<td>1.11727</td>
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<tr>
<td><strong>FMS 3 Stations</strong></td>
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</tr>
<tr>
<td>Ankle</td>
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<td>8.0000</td>
<td>.57735</td>
<td>.876</td>
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</tr>
<tr>
<td>Knee</td>
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<td>8.5000</td>
<td>.75593</td>
<td></td>
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</tr>
<tr>
<td>Non-injured</td>
<td>49</td>
<td>8.1837</td>
<td>.90539</td>
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<td></td>
</tr>
</tbody>
</table>
5.1 Introduction

The primary purpose of this study was to determine if the FMS composite score could be used to predict lower extremity injury in Division I collegiate football players. The secondary purpose was to determine a cut-off score on the full, and two versions of a modified/lower extremity specific FMS that could predict injury. Athletes who suffered a lower extremity injury scored lower on the FMS total test than those who did not suffer an injury, while the injured groups scored slightly better on both versions of the modified test. However, there were no statistical differences between the groups on any of the FMS versions.

This study is the first known study that utilized a lower extremity specific FMS test and determined its injury prediction capabilities. The MFMS 4 had the highest diagnostic odds ratio of 3.57 with a sensitivity of .71 and a specificity of .59, indicating the MFMS 4 has a moderate ability to rule out athletes at risk for a lower extremity injury. The MFMS 3 had a diagnostic odds ratio slightly lower than the MFMS 4 of 3.46, but had a lower sensitivity of .67. The MFMS 4 station shows a stronger ability to rule out athletes at risk for a lower extremity injury compared to the full FMS, perhaps because the MFMS 4 station was focused on lower extremity specific movements. Overall, the diagnostic capability of any version of the FMS to identify football athletes at risk for a lower extremity injury appears to be low. However, the moderate sensitivity associated with the 4-station FMS suggests the potential usefulness of the tool, if it is coupled with other diagnostic evaluations. The moderate sensitivity only provides the
ability to rule out injury risk. If this assessment could be partnered with another tool that had moderate or strong specificity, this would improve the goal of the pre-participation examination.

Comparisons were made between athletes who suffered a contact injury and athletes who suffered a non-contact injury. In the full FMS and the 4 station FMS the non-contact group scored the lowest on both the full FMS and four station FMS, whereas the contact injury group scored the lowest on the 3 station test. These relationships were not statistically significant, but it raises interesting points to consider. Perhaps with larger sample sizes these relationships might grow. It is interesting to note that the test that is included in the MFMS 4 station that is not in the MFMS 3 station is the straight leg test. It is possible that including the straight leg test makes the MFMS 4 station more effective at identifying athletes who are at risk for a contact injury. Continued research in this area may be warranted.

Additional comparisons were made between an ankle injury group, a knee injury group, and a non-injured group. In all 3 versions of the FMS the ankle injury group scored the lowest which tends to suggest that the FMS may be useful at predicting ankle injuries compared to knee injuries. Other pre-participation tests have also shown to have predictive capabilities when trying to identify athletes at risk of ankle injuries such as the Star Excursion Balance Test\(^{[16]}\). These researchers state that the SEBT combines strength, flexibility, neuromuscular control, core stability, ROM, balance, and proprioception in order to produce the given task. Also, this test is performed in a single leg stance bilaterally. The SEBT has been shown to identify athletes at risk to up to 7x more likely for injury\(^{[16]}\). It is possible that the FMS may not combine all of these
components successfully enough in a single leg scenario to differentiate athletes at risk. Because the FMS also combines most of these components it could be that the single leg part of the SEBT may make it more useful as a diagnostic tool.

5.2 Comparison to previous FMS research

Previous FMS research has reported various cut-off scores to identify injury risk. Kiesel et al\cite{8} reported findings of an FMS score lower than 14 in the total FMS testing significantly increased a professional football player’s risk of suffering an injury. This contrasts with our findings of a cut-off score of 18.5. Our data also did not show a statistical significant increase in risk according to the cut-off score in any version of the FMS. The differences in findings between the two studies could be contributed to the different demographics. In our study Division I college football players were used, whereas in Kiesel et al\cite{8} professional football players were used. Also the college and professional seasons are quite different when comparing number of games and types of practice schedule the athletes are subjected too.

The differences in findings may also be contributed to injury definition. Kiesel et al\cite{8} used all injuries that resulted in loss of playing time and in our study we only recorded significant lower extremity injuries. Kiesel et al\cite{8} had more injuries to base their scores off of because they included upper extremity injuries as well. In our study we were only interested in the FMS’s capabilities of predicting a lower extremity injury. Also in the NFL there are injuries that are shown on an injury report that are not significant and do not hold a player out of competition. Additionally, there may be greater pressure on a professional player to play and perform with an injury that may be listed on an injury report, than a collegiate player over which there may be more
oversight by the medical staff. In our opinion, the designation of the injury resulting in actual time loss is more universally important.

O’Connor et al\cite{10} also found a cut-off score of 14 maximized injury prediction. However, demographics were again very different than the demographics of our study. The group of participants in our study were elite college athletes whereas O’Connor et al\cite{10} used military officer candidates as their population. Our subjects were competing at a higher intensity of competition than military officer cadets competing in intramural competitions. Collegiate athletes also practice more often than intramural athletics which increases their number of exposures. Also this increase in intensity and exposures can lead to some structural breakdown that put college athletes at greater risk of injury. Also college athletes train specifically for the sports they are participating in which may make them more coordinated and competent at the demands placed on their bodies during competition. Also, there were differences in injury definition which may have caused the outcomes to differ from our own.

The exercises included in the MFMS 3 and 4 were chosen because we were looking for a specific group of tests that focused on the lower extremity. Our purpose was to find a functional lower extremity specific test that would have injury prediction capabilities for lower extremity injuries. The overhead squat, in-line lunge, and hurdle step are all great example of functional activities that are in turn also lower extremity specific. By selecting the most functional types of movements we were also able to select tests that focused more on the lower extremity. The straight leg test is included in the MFMS 4 and not the MFMS 3. The straight leg test is not a functional movement, but it is a very lower extremity specific test. We decided to use this in one of our
modified versions of the FMS to determine if it would improve our lower extremity injury prediction capabilities. The straight leg test did improve the sensitivity and diagnostic odds ratio of the MFMS 4 which is interesting to consider when looking at injury prediction capabilities. This suggests that a hamstring flexibility test should be included in a PPS.

5.3 Clinical Significance

Overall, there were no differences in full FMS and modified FMS scores between the injured and non-injured groups. Previously, the FMS has been suggested as a useful prediction diagnostic tool. However, when combined with other injury prediction tests such as the Star Excursion Balance Test, perhaps injury prediction could be maximized. Further studies should be performed to examine the combination of multiple injury prediction tests and if the combined scores could lead to a better prediction model. Ultimately, with this information combined with other research, clinicians can consider implementing these functional tests to determine athletes at risk, as well as what deficits should be targeted with an injury prevention program.

5.4 Limitations

While we tried to minimize them, limitations in this study did exist. Our injury definition only included lower extremity injuries that caused a player to be limited in one or more practices. With this definition there are some injuries that were overlooked as being not severe enough to interrupt activity. Also upper extremity injuries were not included in this study and future research should look at all injuries as a whole and at the upper extremity alone. Also, it is possible with the high level of competition that some injuries went unreported by athletes who continued to compete with what some would
consider to be a significant injury. At this level of competition the athletes are placed under high levels of stress to continue playing even if it means playing through an injury as many athletes fear losing their position on the team.

5.5 Conclusions

While the FMS and modified FMS scores could not statistically differentiate injured football players, there may still be diagnostic usefulness of the tool. The four station MFMS had moderate sensitivity, which may make it an attractive component of a PPE. Additionally, there were differences that suggest the MFMS may be more effective at screening for ankle injury risk, but these relationships require more investigation. Continued research should investigate the usage of the MFMS 4 as it could be a more cost effective and time efficient way to analyze large athletic teams and depict athletes that may be at risk for injury.
References


16. Gribble, P., Hertel, J., Plisky, P., Using the STAR Excursion balance test to assess
dynamic postural-control deficits and outcomes in lower extremity injury: a
357.