A Thesis

entitled

Functional Movement Screening as a Predictor of Injury in Division One Collegiate Football Athletes

by

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

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An Abstract of

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Objective: To determine if there was a significant difference in FMS$^\text{TM}$ scores between athletes that were injured and athletes that were not injured during a division one collegiate football season, to discover a cut-off score that maximizes specificity and sensitivity of the FMS$^\text{TM}$ and to examine FMS$^\text{TM}$ scores between positions groups, body part injured, and mechanism of injury. Design, Setting, and Data Source: Testing and data collection was performed at the University of Toledo. The testing included the men’s football team with the ages ranging from 18-22. Prior to testing, subject’s completed a questionnaire providing demographics of age, height and weight and history of injury. The data collected was separated into groups, injured and non-injured and into position, skill and non-skill. To determine if there is a significant difference in FMS$^\text{TM}$ scores between groups, a dependant t-test was performed on each group with significance set at P<0.05 level. To determine cut-off scores, a receiver-operator characteristic (ROC) curve was used to plot sensitivity (true positives) versus 1-specificity (true negatives) for the screening test. A 2x2 contingency table was produced to dichotomize the athletes that experienced and injury and those who did not, as well as those who were above or below the cut off score. From the table, odds ratio, likelihood ratio, sensitivity and
specificity were calculated. **Results:** A total of 92 athletes were FMS™ tested who met the inclusion criteria and participated in the 2010 competitive season. Of the 92 subjects, 18 of them experienced an acute lower extremity injury that caused them to be removed from participation. Subjects who experienced an injury (15.8±1.29) had a lower composite FMS™ score than those who did not experience an injury (16.5±1.41). However, a t-test revealed no significant difference between the groups (t_{92} = -1.72; P=0.089). A t-test revealed skill position subjects had higher FMS™ scores (16.8±1.42) than non-skill position groups (15.7±1.08, t_{92} = 3.926 P<0.001). Analysis of the ROC curve showed that a cut-off score of 15.5 maximized the sensitivity and specificity in this study. The odds ratio were roughly 3 times more likely to experience an injury during the season if they scored a 15 or below on the FMS™. The post test probability was calculated to be 35% an increase of 20% from pre-test probability.

**Conclusion:** This study demonstrated that the FMS™ shows potential to be an effective predictor of injury in division one collegiate football athletes. However, more research of the injury prediction capabilities of the FMS™ should be conducted before making a formal conclusion. The time commitment and personnel demands required to test an entire football should be considered before clinicians implement FMS™ testing as a predictor of injury.
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Chapter 1

Introduction

1.1 Background

Athletic participation in the United States has increased by nearly 3 million participants since 1971.\(^1\) The increase in exposure to athletics has subsequently resulted in an increased injury rate. It is estimated that high school athletes accounted for 1.4 million injuries in 2005.\(^2\) A primary responsibility of the sports medicine team is to decrease injury risk in physically active populations. Kiesel\(^3\) has evaluated risk factors that contribute to injury rates in the athletic population such as history of previous injury, body mass index, muscle flexibility, and biomechanics. Most research has investigated these factors individually, but recent attention has been shifted to look at the multifactorial influence of risk factors.\(^4\) The Functional Movement Screen\(^\text{TM}\) (FMS) was developed as a clinical assessment tool to evaluate a combination of these risk factors.

The FMS\(^\text{TM}\) is a comprehensive examination that assesses seven fundamental movements that are hypothesized to be the foundation for more advanced athletic movements.\(^3\) The movements included in the FMS\(^\text{TM}\) are: 1) deep squat, 2) hurdle step, 3) in-line lunge, 4) shoulder mobility, 5) active straight leg raise, 6) trunk stability push up, and 7) rotary stability test. The FMS\(^\text{TM}\) incorporates proposed risk factors of...
balance, strength, range of motion, flexibility, and proprioception to help predict injury in athletic populations.\textsuperscript{5,6} A subject will perform the seven fundamental movements of the FMS\textsuperscript{TM} while being assessed on an ordinal scale ranging from zero to three by a clinician.

This composite FMS\textsuperscript{TM} score has conventionally been hypothesized to be an objective value used to identify asymmetries and limitations as they refer to functional movements.\textsuperscript{5} Noda et al\textsuperscript{7} investigated the validity of the FMS\textsuperscript{TM} by examining a significant correlation of goniometric measurements to decreased scores in the deep overhead squat. Two studies\textsuperscript{3,8} determined a high interrater reliability of the FMS\textsuperscript{TM}.

Another study\textsuperscript{3} examined the predictive capability of the FMS\textsuperscript{TM} in professional football players, discovering a cut-off score that maximized both specificity and sensitivity to stratify injury risk by FMS\textsuperscript{TM} score.

Although the FMS\textsuperscript{TM} has been proven to detect functional limitations that can contribute to the prediction of injury rates in athletic populations, no research has been conducted investigating the effectiveness of the FMS\textsuperscript{TM} in predicting injuries among division one collegiate football athletes.

1.2 Problem Statement

Recent research has demonstrated that a low composite score on the FMS\textsuperscript{TM} correlates to an increased incidence of athletic injury. However, no research has been conducted that establishes a particular FMS\textsuperscript{TM} score to predict lower extremity athletic injury in division one collegiate football athletes. Additionally, the FMS has not previously been used to differentiate injury at different joints (ankle vs. knee), mechanisms of lower extremity injury (contact vs. non-contact), or athletes that play...
different positions. These final three problems may contribute to identifying specific risk factors for injury, which may allow for success with injury prediction.

1.3 Purpose Statement

The purpose of this research is to determine if the FMS™ can predict acute injury risk to the lower extremity in division one collegiate football athletes and to compare descriptive injury data related to FMS™ scores.

1.4 Hypothesis

**H₁** – Throughout the regular season athletes that suffer lower extremity acute injuries will have a lower composite FMS™ score during PPE (pre participation exam) than those athletes who do not suffer a lower extremity acute injury during the season.

**H₂** – A FMS™ cut-off score maximizing sensitivity and specificity (>0.70) will be discovered to predict lower extremity acute injury.

**H₃** – Non-Skilled positions (Offensive and defensive lineman) will present with lower composite FMS™ scores than Skilled positions (Non-offensive and defensive lineman) during the PPE.

**H₄** – Athletes experiencing an ankle injury will not have a lower composite FMS™ score than subjects experiencing knee injury when compared to non-injured subjects.

**H₅** – Subjects that experience a non-contact mechanism of injury will have a lower composite FMS™ score than subjects experiencing a contact mechanism of injury and non-injured subjects.

1.5 Aim of the Study

The primary aim of the study is to establish if the FMS™ is a reliable tool to differentiate lower extremity acute injury occurrence in division one collegiate football
players. The secondary purpose of this study is to determine an established cut-off score that can maximize injury prediction among these athletes. Collectively, these aims could prove beneficial for clinicians at identifying athletes at an elevated risk of injury and allowing for an intervention to decrease injury prevalence in these subjects. The third aim of this study is to examine differences in the injury patterns among different skill positions among these athletes. The final aim of this study is to examine the relationship of the body part injured as well as the mechanism of injury among injured versus non-injured athletes. The findings from examining these variables could also prove beneficial at identifying key factors of athletes at an elevated risk of injury.

1.6 Limitations

There is a possibility for interrater reliability variance among clinician’s assessing FMS™ scores. While one clinician assessed the majority of the subjects, four total clinicians helped with data collection. Lack of formal FMS™ training could have been a limiting factor. However, all of the clinicians/raters were given instruction on how to grade the FMS™, and these procedures followed instruction methods that were used previously in the research lab group producing a strong intra-tester and inter-session reliability.

While not a primary focus of this study, prophylactic techniques such as taping and bracing may influence injury rates. We did not limit the usage of these prophylactic treatments were recorded with injury surveillance data. Prophylactic treatments were not considered in the present study, but will be considered as a factor in future studies by the principal investigator.
A final limiting factor is the athletes that could potentially be classified into both skilled and non-skilled groups. For example, an athlete that plays the position of Tight End could be considered a lineman (non-skilled) or receiver (skilled), depending on individual plays during the course of a game. Prior to the beginning of the competition season, athletes were designated into the positions groups based on discussions with the coaching staff to determine how particular players would be used primarily in games.
Chapter 2

Literature Review

The literature review will provide an inclusive collection of research that is concerned with injury rates of athletic populations as well as the use of the FMS$^\text{TM}$ as an effective clinical tool to identify subjects at an increased risk of injury. The chapter is divided into four sections. The first section will address injury rates and patterns associated to both amateur and professional athletes as well as examine differences between sports. The second section will address risk factors associated with athletic injuries that include previous history of injury, strength, balance, skill level and muscular imbalance. The third section will address research that has attempted to predict injuries in the athletic population. The final section will address principles of the FMS$^\text{TM}$ along with research investigating the use of the test as an effective clinical tool.

2.1 Injury Rates and Patterns

A national focus to improve and promote a healthy lifestyle has caused an increase in participation of high school athletics in the United States. The increase in athletic participation has consequently led to an increase in injuries.$^2$ Researchers have focused on tracking these elevated injury rates and stratifying these rates by sport and other variables such as body part injured.$^2$ If injury rates can be determined for high risk sports, preventative measures may be introduced to decrease injury rates by identifying
high risk athletes. Each year approximately seven million high school students engage in organized athletic events.\(^2\) The Centers for Disease Control began injury surveillance during the 2005-06 academic school years to determine injury rates among high school athletes. Certified athletic trainers (ATC) employed by the one hundred participating high schools as well as physicians associated with the high schools documented injuries among the sports of baseball, football, wrestling, softball, volleyball, men’s and women’s basketball, as well as boy’s and girl’s soccer. The schools that volunteered to participate met geographical and size requirements that allowed them to be an accurate representation of national high school injury rates.

Weekly injury logs were entered by the clinicians into injury surveillance software designed by the researchers at the Columbus Children’s Hospital in Columbus, Ohio. An injury was recorded if it occurred during an organized high school practice or competition, required medical attention from the supervising ATC or team physician, and restricted the athlete from activity for one or more consecutive practices or competitions. Injury data was logged into the system and divided into what sport the injury occurred in and when the injury occurred in either practice or competition. Injuries were recorded for each sport in terms of how many injuries occurred per 1000 athletic exposures (AE). Nationally in the nine sports included in the study, an estimated 1.4 million injuries occurred.\(^2\) Football athletes suffered the highest rate of injury at 4.36 injuries per 1000 AE. Injury rates for the remaining sports were as follows: Wrestling at 2.5 per 1000 AE, 2.43 per 1000 AE for men’s soccer, 2.36 per 1000 AE for women’s soccer, and women’s basketball at 2.01 per 1000 AE. Men’s basketball, baseball, softball and volleyball all had injury rates of less than 2.0 per 1000 AE. Other key findings of this research were
that more injuries occurred during competition than during practices and that 80% of all injuries were first time injuries.²

Another study observing the injury rates over a two year period was also conducted by Powell⁹ in 1999. The aim of this study was to characterize at risks sports in order to possibly identify preventative measures that could lower injury rates. Subjects included were 75,298 high school student athletes participating in the sports of baseball, softball, football, volleyball, field hockey, wrestling, men’s and women’s soccer, and men’s and women’s basketball. Three hundred ATCs participated in the injury surveillance study by documenting weekly athletic exposure rates, recordable injuries, and also classifying to which part of the body the injury occurred. There were 23,566 recordable injuries during the three year study. Football subjects experienced the highest rate of injury of 8.1 injuries per 1000 AE.⁹ The remaining sports had rates of baseball 2.1, men’s basketball 4.8, men’s soccer 4.6, wrestling 5.6, women’s basketball 4.4, field hockey 3.7, softball 3.7, women’s soccer 5.3 and volleyball 1.7 per 1000 AE. Researchers observed that the hip, thigh, leg, knee, and ankle categories experienced the highest rate of injury not only with football but with all of the high school sports.⁹

While certified ATCs and physicians are considered qualified to record injury rates, it is not practical for these health care professionals to be available at all times to contribute to national injury surveillance. Many times coaches are asked to report injury rates for athletic teams in which trained medical professionals are not always readily available. A study¹ was conducted to compare high school coaches’ injury tracking to that of ATCs. The subjects were coaches and ATC’s from eighteen United States high schools. Subjects were instructed on the definition of an injury and how to complete
weekly injury logs that have previously been demonstrated successful in determining injury rates by the national high school sports related injury surveillance study. Participants were instructed to complete the weekly injury logs as well as athletic exposure rates to the data base for 45 weeks. Results of the study demonstrated that coaches only reported injuries and athletic exposures 36.5% of the time compared to the rate of 96.7% by the ATCs. This demonstrates that injury rates that include data contributed by high school coaches may be estimated lower than the actual rate. The authors contribute this to the non-compliance by the coach to correctly identify or report an injury. The data in the national injury surveillance study included information contributed by high school coaches, suggesting that the national rate of high school football injuries could be higher than what the authors suggested.

There is an inherent risk of injury with all organized athletics. Football has been observed as having the highest rate of injury in high school athletics. Much research has been conducted in determining high school injury rates but due to limitations specific information regarding injuries have not been included in injury surveillance research. Over a two year period eighty seven California high schools participated in a research study that specifically observed football overall injury rates, injury rates by position, location of injury, and type of injury suffered. Injury rates were categorized into how many injuries occurred per 100 session contact hours the players had. The overall injury rate was 8.4 injuries per 100 session contact hours. By position injury rates were recorded at how many injuries occurred per 100 players at that position. Offensive running backs with 32.0 injuries per 100 players and defensive linebackers with 29.9 injuries per 100 players suffered the highest rate of injury. For all player injuries 45.1% of injuries
occurred to the lower extremity while only 23.2% were associated with the upper extremity and another 12.4% with the head.

A similar study was conducted in the state of Texas monitoring injury rates among one hundred high school football teams by certified athletic trainers. In a single football season injuries were documented by the teams head athletic trainer. An injury was defined as an incident causing an athlete to miss part or all of competition or practice or an incident requiring medical attention from the certified athletic trainer or a physician. Results yielded that of the 4399 student athletes there were 2228 injuries reported for an incidence of injury of 0.506 per athlete. The authors also discovered that the knee was the highest injured anatomical location followed by the ankle. These football specific injury surveillance studies demonstrate the likely occurrence of lower extremity injury and the elevated injury rates relative to high school football players.

Limited research on injury rates and injury location has been documented at the collegiate and professional football. Shankar et al was the first to compare the widely documented high school football injury rates to that of collegiate football rates. The authors hypothesized that the varying levels of competition would have different injury rates among high school versus collegiate football players. Injury data was collected for one year among one hundred high school teams and fifty-five National Collegiate Athletic Association teams. Injuries were categorized into practice and competition as well as the anatomical location in which the injury occurred. Results from the high school football season yielded rates of 12.04 per 1000 AE for competition, 2.56 per 1000 AE for practice, and a collective injury rate for both of 4.36 per 1000 AE. The most common location of injury for high school football players was the lower leg, ankle, and
foot at 22.4%, the knee at 15.2% and the torso, spine, and neck at 11.6%. The most common position for high school football players to be injured was defensive linebackers at 15% and offensive wide receivers at 14.8%. At the collegiate level the injury rates were elevated compared to the high school level. During competition NCAA football players suffered injuries at the rate of 40.23 per 1000 AE during competition, 5.77 per 1000 AE during practice, and an overall injury rate of 8.61 per 1000 AE for the season. The most common positions for injury at the collegiate level were offensive running backs and defensive linebackers. The anatomical structures injured most frequently in collegiate football players were the lower leg, ankle, and foot at 20.5%, hip and thigh 17.3%, and the knee at 16.4% of all occurring injuries. The study also determined more collegiate injuries were the result of non-contact mechanisms suggesting that underlying functional limitations may have predisposed these athletes to injury.

Feeley et al. examined football injuries at the professional level over a ten year period. The authors collected injury data from one National Football League team during the pre-season training camp of each year of the study. The authors defined an injury as an incident that required medical attention by an ATC or team physician and restricted the athlete’s competition at least one day past the incident. During the ten years of data reporting, a total of 696 players were involved with this team’s training camp. The results revealed that during pre-season competition there was an injury rate of 64.7 per 1000 AE, injury rate for practices was 12.7 per 1000 AE and an overall injury rate of 17.3 per 1000 AE. The positions most likely to be injured were defensive linebackers and secondary players with a rate of 2.3 and 2.6 injuries per 1000 AE as well as offensive wide receiver and tight ends with an average of 2.5 injuries per 1000 AE. The anatomical
structures injured the most frequently were knee sprains at 10.8 injuries per 1000 AE and ankle sprains with a rate of 7.8 injuries per 1000 AE.\textsuperscript{13}  

This research demonstrates the inherent risk with participation in organized athletic competition. However, there is an elevated risk of injury in those participating in football.\textsuperscript{2,9} There are increased rates of injury at higher levels of competition and a greater percentage of injuries occur during competition than during practice.\textsuperscript{2,12} Lower extremity injuries are at the highest risk with football athletes.\textsuperscript{9-11,13}  

\textbf{2.2 Injury Risk Factors}  

Understanding injury risk factors is a key component to identify at risk athletes as well as providing a model to apply appropriate intervention to decrease injury rates. The following will provide an overview classifying risk factors as well as research that has attempted to identify at risk athletes such as previous history, body mass index, muscle tightness, muscular flexibility and balance deficits.  

Turbeville\textsuperscript{14} examined the relationship of strength, body mass index and history of injury to injury rates over a two year period in high school football players. The authors used 120 subjects and recorded baseline variables of playing experience, position and previous history of injury as well as body mass index, height, weight and grip strength. Injury rates were then tracked over a two year period. There were 132 injuries suffered over the two year period. The lower extremity experienced a significantly higher rate of injury at 62\% than the upper extremity at 38\% (P < 0.05). The knee and ankle accounted for 76\% of all injuries occurring to the lower extremity. The authors used a chi-squared and Fisher’s exact test to determine if a correlation was present between the variables being examined and an increased injury rate. Results of the study found that players with
more experience and players with a history of an injury were more likely to be injured (P=0.01). Body mass index, weight, height, and strength were not accurate indicators of athletes at risk to be injured (P=0.24). The authors discussed the relationship of the athletes experience level to the rate of injury, stating an athlete with more experience will have more playing time, increasing their risk of injury. The authors also state that no direct correlation was made using playing experience as a risk factor and that their explanation was rationalized in theory.

McHugh attempted to determine risk factors for noncontact ankle sprains in high school athletes. The authors examined 169 high school athletes from football, basketball, soccer and gymnastics teams. PPEs measured height, weight; body mass index, hip abduction and adduction strength, as well as balance in single limb stance and ligamentous laxity were recorded as independent variables. Athletes also reported any history of ankle injury on a medical questionnaire. Strength was measured using a handheld dynamometer using accepted clinical protocols. Balance was tested using the single leg stance on a tilt board for one minute. Ligamentous laxity was measured using five tests (1) placement of the palms on the floor with the knees maintained in full extension; (2) hyperextension of the elbow with the wrist in supination and the shoulder flexed to 90 degrees; (3) standing external rotation of the hips and knees; (4) hyperextension of greater than 10 degrees at the knee in standing; and (5) thumb adduction to the volar forearm with wrist flexion. An athlete was considered as positive for generalized ligamentous laxity when three or more of the criteria were met. Twenty non-contact ankle sprains were recorded during the study. The authors found that balance ability (P=0.72), hip abduction (P=0.66), hip adduction (P=0.41), and hip flexion strength
(P=0.87) were not statistically significant as risk factors for ankle sprains.\textsuperscript{15} There was a higher rate of injury for those who had previously suffered an injury compared to those who did not have a history of previous ankle injury (1.12 vs. 0.26 per 1000 AE, P<0.05). Male athletes that had a higher body mass index were associated with increased risk of ankle injury (P<0.05). When a combination of elevated body mass index and history of previous ankle injury was present there was an even higher rate of injury than when these variables occurred independently (P<0.01).

Tyler et al\textsuperscript{16} expanded on the previous study by targeting specifically high school football players. The authors recorded body mass index, height, weight, and history of ankle injury on 152 varsity and junior varsity football players. The authors tracked ankle injury rates over a three year period during the high school team’s competition season. There were twenty four ankle sprains over the experimental period, fifteen non-contact mechanisms and nine with contact mechanisms. The rate of injury was recorded as 1.08 noncontact ankle sprains for every 1000 AE. The authors found that athletes with a history of ankle injury were 6.6 times more likely of spraining their ankle than that of athletes with no history of injury (2.65 vs. 0.41 injuries per 1000 AE, P<0.001). Having an increased body mass index was nearly 4 times more likely to experience a non-contact ankle sprain than those with a normal or lower body mass index (P=0.04). Injury rates were 1.05-2.03 versus 0.52 injuries per 1000 AE for at risk or overweight players to that of subjects with a normal body mass index. Athletes that had both history of ankle injury and were considered to have an above normal body mass index were 19 times more likely to experience an ankle injury.\textsuperscript{16}
McGuine et al\textsuperscript{17} examined the role of balance as indentifying high school basketball athletes at risk for suffering an ankle injury. The authors used 210 basketball players from five high schools as subjects for the study. Subjects were tested during single leg stance with eyes open and eyes closed using postural sway as a measure of balance. The subject was graded to either have good, average or poor 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 sway were seven times more likely to suffer an injury than subjects who had average or good balance (P=0.0002).

Krivickas et al\textsuperscript{18} examined the relation of ligamentous laxity and lower extremity muscle tightness in regards to lower extremity injuries in college athletes. The authors assessed 201 subjects (131 men and 70 women) for ligamentous laxity on a nine point scale. A score of zero associated with being tight while a score of none associated to being hyperlax. Muscle tightness was assessed for the rectus femoris, hamstrings and gastroc/soleus complex by using a goniometer for objective measurements. The iliotibial band tightness was assessed using the Ober’s test and the iliopsoas was assessed using the Thomas test. Lower extremity injuries were monitored over the course of a competition season. The authors discovered that for males only there was a higher rate of injury than females for muscle tightness and ligamentous laxity (P=0.008).

A final study by Knapik\textsuperscript{19} examined preseason strength and flexibility imbalances associated with injury rates in female athletes. The authors used 138 subjects participating in eight varsity sports. Strength was measured using an isokinetic torque dynamometer of the quadriceps and hamstrings complex of each leg. Flexibility was assessed by measuring joint angles of the ankle, knee and hip with a goniometer. The
authors discovered that an athlete was more at risk if they had muscular strength imbalances, imbalances in hip flexibility from left to right side and a ratio less than 0.75 of hamstring to quadriceps strength.\textsuperscript{19}

Many risk factors have been examined to determine at risk athletes prone to injury. While some of risk factors have been proven successful, many are not practical to perform on a pre-participation exam.

2.3 Predicting and Preventing Injuries

It is important to understand a multi-factorial approach to predicting injuries in order to implement a successful intervention strategy to decrease injury rates. Multiple risk factors have been discussed previously with little accuracy in predicting athletes at an elevated risk of injury independently.\textsuperscript{3,14,15} Examination of these factors collectively could potentially demonstrate the most successful and efficient way to predict injury rates and furthermore introduce interventions to decrease these rates. This section will review literature related to components and models in predicting and preventing injuries.

Bahr\textsuperscript{20} describes injury prevention and prediction into methodological models. The prevention model involves a four step process to research the injury problem and to also apply successful intervention strategies.\textsuperscript{20} This model begins by identifying the magnitude of the of the injury problem. The second component involves understanding the etiology and the mechanics of the problem whether those mechanics are intrinsic or extrinsic. This involves examining all possible factors that may contribute to the injury epidemic and injury rates. The next step is to address the considered injury mechanisms by introducing a preventative measure to attempt to decrease the injury rates. It is important to understand the factors that contribute to the injury as it may include one
primary factor or many interconnected factors. The final step is to determine if the structured intervention influences the injury problem to decrease the rate.\textsuperscript{20}

There is also a biomechanical perspective that influences preventing and predicting injuries. Bahr\textsuperscript{20} describes injury as a result of transfer of overloaded energy to tissue of the human body from an external source. The mechanical properties of the injured tissue (stress-strain relationship) determine how the body will respond to external forces of stress. Other factors such as magnitude of the external force, rate of load, frequency of load distribution, the rate of load distribution and a variety of intrinsic factors influence the probability to become injured. It is important to understand these influences when preventing injuries as some of these factors are not able to be influenced while others are. Athletes can influence the energy load absorbed to potentially injured structures through musculoskeletal activation and training.\textsuperscript{20} Bahr discusses possible mechanisms for inversion ankle sprain injuries as being both contact (being hit by another athlete) and non-contact (stepping on another player’s foot).\textsuperscript{20} Both situations may lead to an unavoidable injury, but with proper neuromuscular control through training and proper muscle activation, the ankle would be in a less vulnerable position or be able to counteract the external force. This could potentially decrease the absorbed energy to the ligament and decrease the likelihood or severity of injury.\textsuperscript{20}

Functional testing is a recent clinical tool 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{21}. Nadler et al\textsuperscript{21} investigated the functional performance of athletes following a lower extremity injury. The principle of the research is that injury to the lower extremity
associates to closed kinetic chain deficits that may be identified by examining a decrease in neuromuscular control or core strength. The researchers used 231 NCAA division one collegiate athletes as subjects. Subjects completed an injury history questionnaire and were grouped into incoming freshman with a history of injury, incoming freshman with no history of injury, non-freshman with a history of injury, and non-freshman with a history of injury. Subjects were tested in the twenty yard dash and then data by group was compared. Results 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 ($P=0.01$). Non-freshman had no difference in 20 yard dash time regardless of history of injury ($P=0.98$). This data correlates having a previous injury to having functional deficits. Further research was suggested by the authors due to the variables of non-freshman with an injury having no statistically significant difference in 20 yard dash times of non-injured non-freshman.

The Star Excursion Balance Test (SEBT) is also a clinical tool that has recently been researched to predict injury rates. The SEBT is a cost effective and reliable clinical tool to determine lower extremity dynamic balance and stability. The SEBT has been shown to be accurate in indentifying subjects who suffer chronic ankle instability, with those subjects having a decreased reach distance than those with no instability. Plisky tested 235 boy’s and girl’s high school basketball players using the SEBT reaching in the anterior, posteromedial and posterolateral direction on both legs. Reach length was normalized using leg length measurements. Through the course of the basketball season 54 subjects experienced a lower extremity injury. Results of the study showed that subjects with an anterior reach that differed four or more centimeters from
their right to left leg, decreased normalized data in all directions were over double the risk of suffering a lower extremity injury (P<0.05). Females that reached less than 94.0% of their limb length on the composite reach were almost seven times more likely to suffer a lower extremity injury (P<0.05).

2.4 Functional Movement Screening

The Functional Movement Screen™ is an emerging clinical tool developed by Gray Cook to identify multifactorial limitations in basic exercise movements. The FMS™ is a set of seven fundamental human movements that are proposed to be the foundation of more dynamic and sport specific movements. Limitations associated with these movements are then attributed to decreased core stability, muscular imbalances, and decreased joint mobility. When these limitations are present, compensatory motions are likely to occur in order to complete the movement pattern. When compensatory mechanisms are not identified or addressed the likelihood of the athlete to suffer an injury remains elevated. The creators of the FMS™ propose that it is not necessarily important to isolate whether the limitation is due to decreased mobility, core stability or muscular asymmetries due to the combination of these factors during basic and advanced human motion.

In a two part published article the creators of the FMS™ discuss the role of the FMS™ an element of pre-participation physical assessment. The authors discuss the absence in most PPE’s of any protocols that may identify athletes that are at risk for suffering injury during the competition year. The authors discuss the seven movements in detail as well as discuss possible clinical limitations that each movement may identify. The authors introduce a zero to three scoring system that is as follows: A score of three
represents perfect execution of the movement with no observed limitations, 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.\textsuperscript{5} Cook proposed what fundamental limitations are present in each exercise as far as muscular imbalance, decreased core strength, decreased range of motion, and decreased flexibility. An example is as follows regarding the first movement of the FMS\textsuperscript{TM}, the deep squat. Possible limitations that cause compensation include decreased glenohumeral and thoracic spine mobility as well as decreased ankle dorsiflexion and hip flexion.\textsuperscript{5} Cook addresses the possibility observed compensations are primarily subjective observations and do not provide objective measurements.\textsuperscript{5,6} A possible method of eliminating the limitation and add validity to the claims could be to apply goniometric measurements or electromyograph data to the movement patterns with observed compensations.

A research study conducted by Noda\textsuperscript{7} in 2009 investigated the claims of the FMS\textsuperscript{TM} to identify joint mobility limitations. The authors investigated the relationship between observed limitations defined by the creators of the functional movement screen and goniometric measurements of the seventy subjects participating in the study. Measurements were taken for passive ankle dorsiflexion, hip extension, hip internal and hip external rotation using a goniometer and accepted clinical protocols to measure the range of motion at these joints. The subjects then completed the deep squat as described in the FMS\textsuperscript{TM}. The researchers observed whether there was any knee shifting in or out, the feet turning outwards, a heel lift, excessive forward lean, low back arch, or if the arms fell forward during the deep squat movement. These are all considered compensation of
the deep squat.\textsuperscript{7} The results of the study found that subjects who had heel lift during the deep squat had three degrees less dorsiflexion than those who did not have heel lift ($R_{pb} = 0.173$). The results also found that subjects who had a knee shifting out movement had three less degrees of hip internal rotation than those who did not experience any knee out movement ($R_{pb} = -0.0194$). The authors stated that from these results objective data could be applied to subjective observed limitations of the deep overhead squat in this study.\textsuperscript{7}

A possible limitation to the reliability between clinicians of the FMS\textsuperscript{TM} is the guidelines given to grade the test. Minick\textsuperscript{8} examined the interrater reliability of the FMS\textsuperscript{TM} to determine if scores among clinicians of varying FMS\textsuperscript{TM} experience are consistent. Forty healthy subjects were videotaped performing the FMS\textsuperscript{TM} protocol. Two FMS\textsuperscript{TM} experts and two novices who took a FMS\textsuperscript{TM} class assessed the subjects performing the test. The authors investigated the scores between the groups using weighted kappa statistics. Findings revealed that there was significant agreement between the groups in all seventeen possible scores. Within groups, there was significant agreement in both the expert and novice groups in fourteen of seventeen scores. Possible variations between groups were proposed by the authors to be from watching the test being performed in video instead of in person.\textsuperscript{8}

The FMS\textsuperscript{TM} has been used in two studies\textsuperscript{3,25} to evaluate the effectiveness of using it as a clinical tool to predict injury rates. Peate et al\textsuperscript{25} examined the relationship of FMS\textsuperscript{TM} scores to injury rates of firefighters. The authors proposed that firefighters are at a high risk of injury due to the demands of being in compromised ergonomic positions from the demands of their profession. The authors graded 433 firefighters on the FMS\textsuperscript{TM}
and examined the relationship of FMS™ score to a history of musculoskeletal injury. Findings revealed that firefighters that had a history of injury had a 1.68% (CI95: 1.04, 2.71) higher chance of failing the FMS™ at a cut off score of sixteen than those that did not have a history of musculoskeletal injury (P=0.033). The authors did not provide rationale to why the cut of score was sixteen.

In another study by Kiesel et al26 focused on predicting serious injury in professional football by using the FMS™ in a PPE. Players participating in training camp were graded using the standard FMS™ protocol. The composite score of each players test was recorded and stored to be analyzed following the competition season. Forty-six subjects remained with the team throughout the entirety of the season. Injury surveillance was tracked by an ATC 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 and 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 free3. 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.3

Results of the study showed that mean FMS™ score for all subjects was 16.9. Those who suffered an injury had a mean (SD) FMS™ score of 14.3 (2.3) and those who
remained injury free was 17.4 (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.$^{1,9,12,13}$

The same authors also completed a study that examined if FMS™ scores could be improved with a structured off season intervention program.$^{26}$ The authors completed an FMS™ evaluation consistent with the same protocol in the previous study. Subjects who were identified as having limitations in FMS™ were instructed to complete an intervention program with specific exercises designed to eliminate the compensations indentified. The subjects completed program for seven weeks, completing the sessions four times per week with two optional sessions each week. There were thirty-two subjects divided into lineman and non-lineman groups with no control group. Post-test FMS™ scores were recorded and compared to the baseline scores using repeated measures ANOVA. No time by position interaction was discovered (P=0.78). The pretest FMS™ average for lineman was 11.8 (1.8) and for non-lineman was 13.3 (1.9). The post-test average scores for lineman was 14.8 (2.4) and for non lineman 16.3 (2.4). This demonstrates that FMS™ scores can be improved following structured intervention programs.$^{26}$ However this study had no control group to determine a cause and effect relationship of the score improvement as it could have been a result of repeated measures. Exercise protocols were not made available which questions the control of the protocols consistency among subjects.
These research studies demonstrate that the functional movement screen has a high degree of reliability and has also demonstrated some validity in applying subjective clinical assessments to objective findings. The FMS™ has proven successful in two studies\(^3,25\) in predicting injuries and at risk populations with a history of injury. More research should be conducted to further add validity to the claims of the FMS™ as presented by its creators and also a more detailed structured study to determine if FMS™ scores can be improved following intervention.
Chapter 3

Methodology

3.1 Experimental Design

Using a prospective cohort design, pre-season performance using the FMS\textsuperscript{TM} was used to predict acute lower extremity injury among division one collegiate football athletes. FMS\textsuperscript{TM} scores were recorded prior to the competitive season and daily exposure rates for each practice and game were recorded by an ATC. Lower extremity injuries were recorded along with information such as the nature of injury, body part injured, use of prophylactic intervention, and history of previous injury. An injury was defined as an athlete seeking medical attention from a certified athletic trainer or physician that resulted in missing all or part of one or more consecutive games or practices. At the conclusion of the competitive season, FMS\textsuperscript{TM} scores were compared between injured and non-injured groups, further subdivided for comparisons between ankle and knee injuries, and finally between positions of skill and non-skill.

3.2 Subjects

Ninety-five division one collegiate football athletes at The University of Toledo were recruited. 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-
season participation exam and not allowed to participate in football activities were excluded from the study.

**Table 3.2**: Mean subject demographics (SD).

<table>
<thead>
<tr>
<th>Age (Years)</th>
<th>Height (CM)</th>
<th>Mass (Kg)</th>
</tr>
</thead>
<tbody>
<tr>
<td>19.6 (1.29)</td>
<td>181.1 (33.5)</td>
<td>99.2 (25.9)</td>
</tr>
</tbody>
</table>

3.3 **Independent Variables**

1. Group – Injured and Non-Injured
2. Position – Skill and Non-Skill
3. Injured Body Part – Ankle, Knee, and Non-Injured
4. Mechanism of Injury – Contact, Non-Contact, and Non-Injured

3.4 **Dependant Variable**

1. Functional Movement Screen™ composite score

3.5 **Instrumentation**: Functional Movement Screen™ kit.

3.6 **Procedures**:

Subjects were evaluated on the FMS™ using a zero to three ordinal system. The grading system used was the description provided by Cook et al.⁵,⁶ that can be found in the appendix. A score of three indicates the movement was performed perfectly, a score of two was given when the movement was completed but with one or more compensations observed, a score of one was given if the subject could not complete the movement, and a score of zero was given if pain was present during the movement. Three trials of each movement were completed and the lowest score for each side was recorded. A cumulative composite score was recorded for all seven movements as well as bilateral scores to identify asymmetries. Subjects participated in the competitive
season and information related to lower extremity acute injuries were recorded by an ATC.

3.7 Statistical Analysis:

Utilizing the analysis used by Kiesel\(^3\) to determine if a statistical difference was present between injured and non injured athletes, independent t-tests were performed with significance set at P<0.05 \(a\) prori. Effect sizes were calculated using the mean difference between groups divided by the pooled standard deviation of the variables. To determine a cut off score on the FMS\(^{TM}\) that maximizes specificity and sensitivity, a receiver-operator characteristic (ROC) curve was constructed. The ROC curve plots sensitivity (true positives) versus 1-specificity (false positives) and determines the value at which the test is considered positive by examining varying points on the curve with associated cut-off points \(^3,27\). Once the cut-off score was determined, a 2x2 contingency table was produced to dichotomize the subjects who suffered an injury, those who did not suffer an injury and whether or not these groups were above or below the cut off score determined by the ROC curve.

To estimate a subjects risk of being injured relative to their FMS\(^{TM}\) score, a three step calculation\(^28\) was implemented utilizing the cut off score. The likelihood ratio for athletes at or above the cut off score is negative and the likelihood ratio is positive for those athletes with a score at or below the cut-off score. The following is the three step calculation to determine the increase of probability to become injured.

1) Convert pre-test probability to odds

\[
\text{Pre-test odds} = \frac{\text{pre-test probability}}{1 - \text{pre-test probability}}
\]

2) Multiply the odds by the appropriate (+) Likelihood Ratio Value

\[27\]
Pre-test odds (x) Positive Likelihood Ratio = Post-test odds

3) Convert the post-test odds back to probability

Post-test odds / (post-test odds + 1) = Post-test probability

To compare the skilled and non-skilled subject’s performance (Hypothesis #3), an independent t-test was performed. To determine the relationship of body part injured (Hypothesis #4) and the relationship of mechanism of injury to an FMS™ score (Hypothesis #5), a one way analysis of variance were performed. Significance was set at P<0.05 a priori for these analyses. SPSS 17.0 (SPSS Inc, Chicago, IL) was used for all statistical testing.
Chapter 4

Results

A total of 95 subjects met the inclusion criteria and participated in the pre-season FMS$^\text{TM}$ testing. Three of the 95 subjects did not participate in the 2010 football season due to transferring from the institution or being dismissed from the team. Eighteen of the 92 subjects suffered a lower extremity injury that resulted in removal from participation. Dependant t-tests and ROC curves were performed for analysis of all subjects meeting inclusion criteria and by position.

4.1 All Subjects

The mean (SD) FMS$^\text{TM}$ score for all subjects was 16.3 (1.38). There was no difference between the FMS$^\text{TM}$ scores of the injured (15.8±1.29, n=18) and the non-injured (16.5±1.41, n=74) groups ($t_{2,92} = -1.72; P=0.089$) with an effect size of 0.50 (95%CI -0.02, 1.02). The t-test revealed a significant difference between skill (16.8±1.42, n=57) and non-skill (15.7±1.08, n = 35) position groups ($t_{2,92} = 3.926$, $P<0.001$) with an effect size of $d=0.84$ (95%CI 0.40, 1.28). For all subjects, a cut-off score of 15.5 was discovered to maximize sensitivity and specificity determined by the ROC curve analysis. The associated sensitivity was 0.556 and specificity was 0.716, resulting in a positive likelihood ratio (sensitivity/1-specificity) of 1.96 and a negative likelihood ratio (1-sensitivity/specificity) of 0.620. An odds ratio was calculated at
3.157, demonstrating that an athlete has an approximately three times greater chance of suffering a lower extremity injury during a football season by scoring less than 16 on the composite FMS™ score. Utilizing the cut-off score of 15.5 a 2x2 contingency table was created to dichotomize the subjects by their FMS™ score and injury status (Table 4.1).

**Table 4.1: FMS™ Scores by group**

<table>
<thead>
<tr>
<th>Number</th>
<th>FMS™ Score (SD)</th>
</tr>
</thead>
<tbody>
<tr>
<td>All Subjects</td>
<td>92</td>
</tr>
<tr>
<td>Injured</td>
<td>18</td>
</tr>
<tr>
<td>Non-Injured</td>
<td>74</td>
</tr>
</tbody>
</table>

**Table 4.1.1: 2x2 contingency table for all subjects.**

<table>
<thead>
<tr>
<th>FMS™ Score ≤15.5</th>
<th>Injured</th>
<th>Non-Injured</th>
</tr>
</thead>
<tbody>
<tr>
<td>Yes</td>
<td>10</td>
<td>21</td>
</tr>
<tr>
<td>No</td>
<td>8</td>
<td>53</td>
</tr>
</tbody>
</table>

**4.2 Injured Body Part**

Analysis of body part injured examined the relationship of seven subjects who suffered an ankle injury, eleven subjects who suffered a knee injury, and seventy four subjects who did not experience an injury. The mean score for the subjects with an ankle injury was (15.7±0.95, n=7), knee injury was (15.9±1.51, n=11) and the control was (16.5±1.41,n=74). One way analysis of variance revealed no significant difference between groups (F_{2,92}=1.50, P=0.228).

**Table 4.2: Effect Size – Body Part vs. Control**

<table>
<thead>
<tr>
<th>Effect Size</th>
<th>95% CI</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ankle vs. Control</td>
<td>0.58</td>
</tr>
<tr>
<td>Knee vs. Control</td>
<td>0.42</td>
</tr>
<tr>
<td>Ankle vs. Knee</td>
<td>0.15</td>
</tr>
</tbody>
</table>
4.3 Mechanism of Injury

Analysis of mechanism of injury examined the relationship of eight subjects who experienced a non-contact mechanism of injury, ten subjects who experienced a contact injury and seventy four subjects who did not experience an injury. The mean score for subjects with a non-contact mechanism was (16±1.20,n=8) contact was (15.7±1.42,n=10) and control was (16.5±1.41,n=74). One way analysis of variance revealed no significant difference between groups (F_{2,92}=1.57, P=0.214).

**Table 4.3: Effect Size – Mechanism of Injury vs. Control**

<table>
<thead>
<tr>
<th></th>
<th>Effect Size</th>
<th>95% CI</th>
</tr>
</thead>
<tbody>
<tr>
<td>Non-Contact vs. Control</td>
<td>0.36</td>
<td>-0.38, 1.09</td>
</tr>
<tr>
<td>Contact vs. Control</td>
<td>0.58</td>
<td>-0.10, 1.35</td>
</tr>
<tr>
<td>Non-Contact vs. Contact</td>
<td>0.23</td>
<td>-0.72, 1.15</td>
</tr>
</tbody>
</table>


Chapter 5

Discussion and Conclusion

5.1 Discussion

The primary purpose of this study was to examine if the FMS\textsuperscript{TM} had the ability to predict acute lower extremity injury in division one collegiate football players. While the subjects that suffered an in-season injury had a lower composite FMS\textsuperscript{TM} score than non-injured subjects, this difference was not statistically significant. Further analysis of data revealed that subjects that experienced ankle and knee injuries as well as subjects experiencing contact and non-contact mechanisms of injury had lower composite FMS\textsuperscript{TM} when compared to subjects who did not experience an injury.

Subjects who scored below the cut-off score determined by the ROC curve of 15.5 were three times more likely to suffer an injury than subjects who scored above the cut-off. Although the risk factor discovered by this study was not as significant as previous FMS\textsuperscript{TM} research\textsuperscript{3}, our findings demonstrate that the FMS\textsuperscript{TM} shows consistency among populations at identifying limitations.

A higher composite FMS\textsuperscript{TM} score was discovered in skill position athletes than non-skill position subjects. This could prove beneficial in identifying deficits between position groups. However, this may diminish the convenience factor of the FMS\textsuperscript{TM} as a
screening tool for injury risk as future research will examine individual segments of the FMS\textsuperscript{TM} to identify limitations.

The cut-off score is a point on a curve calculated by maximizing specificity and sensitivity. This specificity value is representative of the ability by the FMS\textsuperscript{TM} to decrease the incidence of false positives, correctly identifying those with an increased risk of injury. The sensitivity is representative of the ability by the FMS\textsuperscript{TM} to increase the incidence of true positives, correctly identifying those with a baseline risk of injury. The specificity in our study, 0.716, would be considered to be good. The sensitivity of 0.556 is not considered to be a useful score. For the purpose of our study, specificity was considered a more important value than sensitivity, meaning if the cut-off score is used, and an individual scores high, clinicians may be able to determine with confidence that the individual is less likely to become injured. Subsequently, athletes that score lower may present a potential concern to the clinician and further evaluation of the athlete may be needed.

The main limitation in this study could have been the use of prophylactic devices. All subjects participating in the study were required to wear ankle braces or have their ankles taped in accordance with team rules. Ankle taping and bracing has been demonstrated to show a decreased injury rate.\textsuperscript{29} Offensive linemen were also required to wear prophylactic knee braces for all organized team activities. The lack of conclusive research suggests there is a possibility of prophylactic knee braces to decrease the rate of ligamentous injury.\textsuperscript{30} In spite of this limitation, we were still able to identify some ability of the FMS to discriminate injury risk. Ideally, further investigation should eliminate
prophylactic supports, but this will be very challenging to institute in light of the current traditional clinical practice.

A second limitation of this study could have been the mechanism of injury to the subjects. Ten of the eighteen injuries experienced in the study were contact in nature. It can be assumed that the performance on the FMS™ may not necessarily predict an athlete’s risk of suffering a contact injury that is attributable to external rather than internal factors. More research will be needed before definitive conclusions can be made.

An additional limitation of this study could have been the use of multiple examiners during baseline testing. However, it has been demonstrated that there is a high interrater reliability of grading the FMS™ procedure in clinicians with appropriate training. Additionally, recent unpublished research conducted by the faculty advisor demonstrated a strong intersession reliability of the FMS™ (ICC: 0.946) by the individuals with the same background and training that performed the assessments in our study.

Future research should consider the correlation of the use of both knee and ankle prophylactic devices to an FMS™ score. It may also be beneficial for further research to examine injury rates of a particular athlete or team over multiple seasons. Finally, future research should consider differences and factors that may potentially lead skill position players to have higher FMS™ scores than non-skill positions, and whether there are different cut-off scores between position groups in division one collegiate football players.
5.2 Conclusion

This study demonstrated that the FMS\textsuperscript{TM} shows potential to be an effective predictor of acute lower extremity injury in division one collegiate football athletes. However, more research of the injury prediction capabilities of the FMS\textsuperscript{TM} should be conducted before making a formal conclusion. The time commitment and personnel demands required to test an entire football team should be considered before clinicians implement FMS\textsuperscript{TM} testing as a predictor of injury.
References


Appendix

1) Deep Squat

The subject begins the movement in the starting position with feet shoulder width apart in line in the sagittal plane. The subject then places the dowel overhead by flexing and abducting the shoulders and extending the elbow. The subject is instructed to slowly descend into a squat position keeping their heels on the floor, head and chest facing forward, and the dowel extending overhead. If a score of three was not achieved the subject may repeat the test with a 2x6 board under the heels.

| Three | • Upper torso parallel with tibia or vertical  
|       | • Femur below horizontal  
|       | • Knees and dowel aligned over feet |
| Two   | • Upper torso parallel with tibia or vertical  
|       | • Femur below horizontal  
|       | • Knees and dowel aligned over feet  
|       | • 2x6 board required under feet |
| One   | • Upper torso not parallel or vertical  
|       | • Femur above horizontal  
|       | • Knees and dowel are not aligned over feet  
|       | • Observable lumbar flexion  
|       | • 2x6 board required under feet |

2) Hurdle Step

The subject begins the movement in the starting position by placing the feet together and in contact with the hurdle. The hurdle high is adjusted to the subject’s tibial tuberosity. With the dowel resting on the subjects shoulders, the subject is instructed
to step over and clear the hurdle and touch their heel to the floor while maintaining balance and returning to the starting position

| Three                          | • Lower extremity aligned in sagittal plane  
|                               | • No lumbar movement                        
|                               | • Dowel remains parallel to floor           |
| Two                           | • Lower extremity does not remain in sagittal plane  
|                               | • Observable lumbar movement                
|                               | • Dowel not parallel to floor               |
| One                           | • Loss of balance                           
|                               | • Contact with any part of the hurdle       |

3) In-Line Lunge

The subject begins by placing one heel on the end of a board and placing the toes of the opposite foot the distance of their tibial tuberosity to the ground (measured by clinician). The subject holds the dowel in line with the thoracic spine with the hand placement being the opposite hand of the forward lunge leg at the spine and the other hand at the lumbar spine. The subject then slowly descends touching their back knee to the board and returning to the starting position.

| Three                          | • Dowel remains in line with the spine      
|                               | • No torso movement observed                
|                               | • Dowel and feet remain in sagittal plane   
|                               | • Knee makes contact with board             |
| Two                           | • Down does not remain in line with spine   
|                               | • Observed torso movement                   
|                               | • Dowel and feet do not remain in sagittal plane  
|                               | • Knee does not touch board                 |
| One                           | • Observed loss of balance                  |

4) Shoulder Mobility

First, hand length is measured using the distal wrist to the tip of the third digit. The subject is instructed to make a fist with each hand. The subject then assumes a
maximally adducted, extended, and internally rotated position with one shoulder and a maximally abducted, flexed, and externally rotated position with the other shoulder attempting to touch the hands together.

<table>
<thead>
<tr>
<th>Three</th>
<th>Fist are within one hands length of touching</th>
</tr>
</thead>
<tbody>
<tr>
<td>Two</td>
<td>Fists are within one and a half hand lengths of touching</td>
</tr>
<tr>
<td>One</td>
<td>Fists are greater than one and a half hand lengths of touching</td>
</tr>
</tbody>
</table>

5) **Active Straight Leg raise**

The subject assumes the starting position lying supine in anatomical position on the floor. Mid-point between anterior superior iliac spine and mid patella is marked by placing a dowel perpendicular to the ground. The subject is instructed to lift the test leg with the ankle dorsiflexed and the knee extended as high as possible. The opposite knee as well as the head is to remain in contact with the ground. Repeat on opposite limb.

<table>
<thead>
<tr>
<th>Three</th>
<th>Malleolus reaches dowel</th>
</tr>
</thead>
<tbody>
<tr>
<td>Two</td>
<td>Knee joint reaches dowel but lateral malleolus does not</td>
</tr>
<tr>
<td>One</td>
<td>Knee joint and malleolus do not reach dowel</td>
</tr>
</tbody>
</table>

6) **Trunk Stability Push-Up**

The subject assumes the starting position prong with feet together and hands at shoulder width at the forehead level. The subject will perform a push-up from this position keeping the knees extended, the ankle dorsiflexed, and having no lag in the lumbar spine. If unable to complete, the athlete lowered to chin level and the push-up is attempted again.

<table>
<thead>
<tr>
<th>Three</th>
<th>Execution of the push-up with hands at the forehead level</th>
</tr>
</thead>
<tbody>
<tr>
<td>Two</td>
<td>Execution of the push-up with hands at the chin level</td>
</tr>
<tr>
<td>One</td>
<td>Inability to complete push-up with hands at the chin level</td>
</tr>
</tbody>
</table>
7) **Rotary Stability**

The subject assumes the starting position in a quadruped stance with shoulders and hips at 90 degrees. The subject extends the hip and flexes the shoulder of the same side by approximately six inches and then touches the extended knee to the elbow of the flexed shoulder. Repeat bilaterally. If unable to complete the subject repeats the test in a pattern of extending the same leg but flexing the opposite shoulder and touching knee to elbow in a diagonal pattern.

<table>
<thead>
<tr>
<th>Three</th>
<th>Execution of the movement with the same side touching while maintain the spine parallel to the floor</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Two</strong></td>
<td>Execution of the movement with the opposite elbow and knee touching while maintain the spine parallel to the floor</td>
</tr>
<tr>
<td><strong>One</strong></td>
<td>Inability to complete movement</td>
</tr>
</tbody>
</table>