A Thesis

entitled

FMS™ Scores as a predictor of Acute Lower Extremity in Division 1 Intercollegiate Basketball Players.

by

Mary J. Cuson, ATC

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

Masters of Science Degree in Exercises Science

Dr. Phillip Gribble, Committee Chair

Dr. Kate R. Jackson, Committee Member

Dr. Brian Pietrosimone, Committee Member

Dr. Patricia Komuniecki, Dean of
College of Graduate Studies

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An Abstract of

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Pre-participation screening is a critical part of preventing injury in an athletic population. It helps clinicians determine if athletes are physically fit for participation or if they are at serious risk for health complications as a result of participation. The Functional Movement Screen (FMS™) is a tool that has been suggested could help clinicians evaluate the normal movement patterns that athletes use during athletic performance and daily living. Determine if the FMS is a reliable measure of injury differences suffered during a competitive season in intercollegiate basketball athletes. This will be important for clinicians in applying and utilizing the information from that FMS if it is verified that the test can be used to predict injury, and become a test that clinicians can use to quickly and cost effectively screen their athletes for injury risk.
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List of Abbreviations

FMS™ . . . Functional Movement Screen
ACL . . . . Anterior Cruciate Ligament
ATC . . . . Athletic Training Certified
EMG . . . . Electromyography
MRI . . . . Magnetic Resonance Imaging
EOH . . . . Environmental Occupational Health
ROC . . . . Receiver Operator Characteristic
Df . . . . . Degrees of Freedom
NCAA . . . National Colligate Athletic Association
NHL . . . . National Hockey League
APR . . . . Active Proprioceptive Repositioning
PPR . . . . Passive Proprioceptive Repositioning
Chapter 1

Introduction

1.1 Background Information

For many years, clinicians have evaluated flexibility, core stability, and muscle imbalances following injury, but only recently have clinicians thought that of the possibility of decreasing the occurrence of injury by screening an athlete’s flexibility and core stability before athletic activity and intervening on any identified deficits. Identifying deficits that could contribute to injury are just as important as a clinician’s ability to evaluate injuries. If clinicians can predict injury risk, protocols can then be put in place to avoid the potential injury. This avoidance could save clinicians time and effort in rehabilitation and protect intercollegiate athlete from pain and missed playing time.

The functional movement screen (FMS™) is a series of tests that attempts to grade the quality of movement patterns and is suggested as a tool to assess deficits in core stability, flexibility, and muscle strength. It has been suggested that this type of testing should be added to pre-participation physical exams for identifying injury risk factors which may lead to appropriate injury prevention. As rehabilitation protocols continue to progress away from isolated assessment and strengthening and toward a more functional approach it is important to have a way to evaluate the functional movement that clinicians
are trying to restore. Past researchers have established that there is not a set standard for
determining who is physically ready to participate in athletic activity.\textsuperscript{2,3,4,5} This past
research also suggests that pre-participation examinations only include the minimum
testing required to determine if someone is physically fit for athletic competition.\textsuperscript{1}

The FMS\textsuperscript{TM} is purported to assess three critical categories of athletic performance
that are related to athletic injury risk; muscle imbalances, flexibility, and core stability.
Previous research shows a consistent link between muscle imbalance and athletic injury.\textsuperscript{6,7,8,9,10,11,12,13,14,15}

Additionally, decreases in flexibility and joint range of motion, especially in the
lower extremity, have been associated with increased injury risk in athletic populations.\textsuperscript{16,17,18} The FMS\textsuperscript{TM} attempts to assess deficits in a considered functional movement
pattern instead of an isolated evaluation of flexibility in a single plane. If it is possible to
use the FMS\textsuperscript{TM} to identify these asymmetries it is possible that a component of a pre
participation examination could be used to identify those at risk for injuries beyond the
minimum requirements used to disqualify participants from athletic activity.

It is suggested that a comparison in asymmetries may be helpful in identifying
those at risk; however simple bilateral flexibility deficits do not seem to place someone at
risk for injury.\textsuperscript{13,19,20,21,22} While most research supports this, others have reported\textsuperscript{23} that
flexibility testing can help identify athletes at risk for developing hamstring or quadriceps
injuries as well as an increased risk for injury among collegiate male athletes.\textsuperscript{24} While
the research is slightly inconclusive as to the exact benefits of flexibility analysis, it is
possible that asymmetries between limbs rather than gross bilateral deficits can identify
those at risk for injury.
The final element that the FMS™ includes is core stability and its link to injury. Core stability is defined as the ability to control the position and motion of the trunk over the pelvis to allow for optimum production, transfer, and control of motions and forces that act on the terminal segment in integrated athletic activities. Several studies have examined the link between core stability and injury risk. Previous studies have concluded that core stability is linked to lower extremity injury overall and more specifically knee injuries, as well as a link between core strength and performance in division I Women’s soccer players. If clinicians are able to assess core stability with the FMS™ appropriately they would be able to identify a factor that has a link to athletic injury and performance, and in turn do the best possible job at trying to eliminate this specific deficit.

The FMS™, by Gray Cook and Mike Boyle, is a group of seven exercises that is meant to create an objective assessment of functional human movement. These exercises include deep squat, hurdle step, in-line lunge, shoulder mobility, straight leg raise, stability push up, and rotational stability. The uses for this assessment include: establishing a functional baseline for conditioning program, planning and implementing of training programs, determining a pre-injury functional baseline, and identifying specific areas to focus your prevention program. One study has shown that this test has high specificity and sensitivity at a cut off score of fourteen. Additionally, this study suggests that the FMS™ could identify those at risk for serious injury in the specific population of professional football players. The findings of the study showed that players with dysfunctional fundamental movement patterns, as measured by the FMS™, are more likely to suffer a serious injury than athletes that had a higher scoring on the
FMS$^{TM}$ Minick et al$^{33,34}$ went on to report that this test has some inter-rater reliability, however these two studies$^{33,34}$ are the only studies out there to show that the FMS$^{TM}$ is reliable and can be used in athletics to predict injury risk.

While core stability, flexibility, and muscle imbalances have been shown to predict athletic injuries there has been no research done in the field to show that the FMS$^{TM}$ can predict injuries in division I basketball players.

1.2 Problem statement

While previous research shows that a low score on the FMS$^{TM}$ has been connected to a higher risk for injury, there has not been any research conducted to determine if a specific FMS$^{TM}$ score can be applied for predicting injury in intercollegiate athletics.

1.3 Purpose Statement

The purpose of the study is to determine the ability of the FMS$^{TM}$ to identify acute lower extremity injury risk in college-aged division I female and male basketball players.

1.4 Hypotheses

H1: Intercollegiate basketball athletes that suffer a lower extremity injury during the season will present with a lower score on the FMS$^{TM}$ during the pre-season compared with athletes that do not suffer a lower extremity injury.
H2: Females will have lower FMS\textsuperscript{TM} scores than males during the pre-season assessment.  

H3: A cut-off score on the FMS\textsuperscript{TM} that can maximize sensitivity (> .70) and specificity (> .70) will be discovered.

1.5 Operational Definitions:

Core stability- The ability to control the position and motion of the trunk over the pelvis to allow for optimum production, transfer, and control of motions and forces that act on the terminal segment in integrated athletic type activities.\textsuperscript{35}

Functional Movement Screen (FMS) – A group of seven exercises that is meant to create an objective assessment of how humans move functionally.\textsuperscript{36} These exercises include deep squat, hurdle step, in-line lunge, shoulder mobility, straight leg raise, stability push up, and rotational stability.\textsuperscript{28}

Flexibility- the range of motion of a joint, which may be increased by stretching\textsuperscript{20,21,22}

1.6 Aim of the study

The primary aim of this study is to determine if the FMS\textsuperscript{TM} is a reliable measure of injury differences suffered during a competitive season in intercollegiate basketball athletes. This study will compare the pre-season FMS\textsuperscript{TM} scores between the athletes that do and do not suffer a lower extremity injury. A secondary purpose is to develop a lower extremity predication model for intercollegiate basketball athletes, using cut-off scores that maximize sensitivity and specificity. Finally, this study will examine pre-season differences in male and female collegiate basketball players’ FMS\textsuperscript{TM} performance, as well as differences in those athletes that had a previous history of injury. These will be
important for clinicians in applying and utilizing the information from that FMS™ if it is verified that the test can be used to predict injury, and become a test that clinicians can use to quickly and cost effectively screen their athletes for injury risk.

1.7 Limitations

Multiple investigators were involved in assessing FMS™ scores of the athletes in this study, which could have created a discrepancy in scoring between the assessors. The raters involved in this study did not take the class pertaining to FMS™ formally, instruction was given through articles and books on how to do the scoring and perform the tests, because of this each rater may interpret the scoring differently. However, a recently completed project in the laboratory of the faculty advisor showed that the inter-rater reliability of the individuals performing the FMS™ assessments in this study was very strong (ICC=0.946). While the focus of this study is acute lower extremity injury, the absence of recording upper extremity injuries and chronic injuries may decrease the significance of the study. Another limitation is if the assessors will be able to correctly identify the asymmetries that may be present. While certified athletic trainers (ATCs) will assess the injuries among the athletes according to pre-determined categories, there may be some discrepancy in injury classification. Also, the scoring for the testing has been modified for time efficiency. This modification changed the FMS™ from the way it was originally expected to be used.
Chapter 2

Literature Review

2.1 Introduction

The literature review will address areas related to the need and how the functional movement screen can be helpful in screening intercollegiate athletes to see if they are at risk for injury. The first section in this review will address the need for such a screen in pre-participation physicals and why it could be helpful in intercollegiate athletics. The second section will address research related to core stability and its effects on injury. The third section will discuss research relating to decreases in flexibility and how it is related to injury. The fourth section will discuss musculature imbalances and how it is related to injury frequency. Finally, there will be a summary showing how all of these factors could be screened for in the FMS™ and therefore be helpful to clinicians in predicting those athletes at risk for injury.
2.2 Review of Core

Function of the central core of the body for stabilization and force generation in all sports activities is being increasingly recognized as pivotal for efficient biomechanical function to maximize force generation and minimize joint loads in all types of activities ranging from running to throwing. However, there is less clarity about what exactly constitutes the core, either anatomically or physiologically, and physical evaluation of core function is also variable. Kibler et al. attempted to provide a general functional definition of core stability, describe the anatomy and physiology of core muscles, discuss core stability in function and dysfunction, provide principles of clinical evaluation of core stability, and describe rehabilitation and conditioning programs to maximize the effect of core stability on athletic function. The musculoskeletal core of the body includes the spine, hips and pelvis, proximal lower limb and abdominal structures. The musculature includes the muscles of the trunk and pelvis that are responsible for maintenance of stability of the spine and pelvis and help in the generation and transfer of forces and energy from the larger body parts to the smaller body parts during many athletic activities. Their primary function is to provide proximal stability for the distal mobility and function of the limbs. The definition of core stability that they use is the ability to control the position and motion of the trunk over the pelvis and less to allow production, transfer, and control of force and motion to the terminal segment in integrated kinetic chain activities. It was noted that there is no single universally accepted definition of core stability.

Kibler et al. describe the anatomy of the core. The prime mover muscles for the distal segments (latissimus dorsi, pectoralis major, hamstrings, quadriceps, and iliopos)
attach to the core of the pelvis and spine. 35 Most of the major stabilizing muscles for the extremities (upper and lower trapezius, hip rotators and glute i) also attach to the core.

Numerous muscles make up the core muscles. The muscles are activated in force dependent activation patterns (the muscles that span numerous spinal segments and function as prime mover muscles to integrate several joints and produce force) and length dependent muscle activation pattern (small, short muscles with small lever arms that span a single joint). 35 These muscle activation patterns are in kinetic chain function and based on pre-programmed patterns of muscle activation that are task oriented, specifically for athletic activities and these are improved by repetition. 35 The coordination of both of the patterns is needed in multi-segmented structures like the spine. The abdominal muscles consist of the transverse abdominus, the internal and external obliques, and rectus abdominus. 35 Core stability requires control of trunk motion in all three planes. In order to give stability in all of the planes of motion the muscles may be activated in different patterns then they are used to. 35 The roof of the core muscle structures is the diaphragm. Simultaneous contraction of the diaphragm, the pelvic floor muscles, and the abdominal muscles is needed to increase the intra-abdominal pressure to provide a more rigid cylinder for trunk support. 35 This decreases the load on the spine muscles and allows increased trunk stability. 35 Then there are the pelvic floor muscles that are often ignored in rehabilitation. 35 Synergistic activation patterns exist involving the transverse abdominus, abdominals, multifidi and pelvic floor muscles that provide a base of support for all the trunk and spinal muscles. 35 The hip and pelvis and their associated structures are the base of support for the core structures. 35 All of the muscle groups in this area are needed to function. 35 Because of the large cross sectional areas of these muscles they are
capable of creating great force as well as acting as stabilizers. This makes them very important for athletic activity. The glutei are stabilizers for the trunk over a firmly planted lower extremity and provide the power needed for forward leg movement. The thoracolumbar fascia is vital because it connects the lower limbs to the upper limbs via the connection between the gluteus maximus and the latissimus dorsi. This allows the core to be involved in multi kinetic chain athletic activities like throwing. The thoracolumbar fascia also attaches to the internal obliques and transverse abdominus muscles. These attachments provide a three dimensional support for the lumbar spine and this in turn helps in the stability of the core. Core muscle activation is used to generate rotational torques around the spine, and stiffness to the entire central mass, making a rigid cylinder that makes a long lever arm around rotation can occur and that muscles can be stabilized when they contract.

Weak hip muscles and resulting alteration of hip/trunk position are a common finding associated with knee injury. Weak hip abductors and tight hip flexors are seen in association with anterior knee pain and chondromalacia. Alterations in the hip muscle activity can be associated with knee valgus stress in squatting or landing activities, which increase the load on the ACL (anterior cruciate ligament). Alternation of knee flexion has also been associated with an increase in stresses in the arm. When an athlete does not flex their knee they break the kinetic chain and decrease the contribution from the hip and trunk and that increases loads in horizontal adduction and rotation at the shoulder and places a valgus load on the elbow. If an athlete has weakness or tightness in the hip it can also affect the arm. A decrease in hip flexibility in rotation or strength in abduction was seen in athletes with arthroscopically proved
posterior-superior labral tears. To evaluate the core there really is no standard. Different techniques have been used to try and gauge the strength of specific core muscles, but evaluation of a specific single muscle is questionable. Muscles should be tested in functional position when possible. The muscles need to be tested in the position and contraction pattern in which they are primarily used. This method is harder to quantify but is similar to how the core functions normally, in three different planes of motion. Rehabilitation of the core should concentrate on both the intrinsic needs of the core for flexibility, strength, balance, endurance, and on the function of the core in relation to its role in extremity function and dysfunction. Usually both altered patterns of motion of the hip, trunk and shoulder, and actual weakness or inflexibilities, and weakness need to be addressed but all should be addressed on a global level involving the entire kinetic chain motions. Rehabilitation for extremity injuries, such as shoulder or ankles, should begin with core emphasis. In order to make a stable base, the protocol should start with primary stabilizing musculature like the transverse abdominus, multifidus, and the quadratus lumborum. These muscles are responsible for the most central portion of the core stability. Core stabilization should avoid emphasis on single planar exercises that isolate single muscles or joints. Rehabilitation should be viewed as a flow of exercises that build a base or stability and force, and then proceed distally to establish control of the forces while allowing maximal mobility of the distal extremities. These authors concluded that core stability is a pivotal component in normal physical activity, and is best understood as an integration of multiple segments. These segments provide force generation, proximal stability for distal motion, and generate interactive moments.
2.3 Why Functional Movement Screen?

The purpose of a series of two articles by Gray Cook et al.\(^1\) was to provide the background and rationale for the analysis of fundamental movement, and in addition they describe the functional movement screen that attempts to screen these fundamental movement patterns and how they attempt to find deficits. The reason tests such as the FMS are necessary, in the opinion of the authors of this article, is that clinicians need to change focus from isolated joint movement and begin to look at full body motion patterns that a person will employ when competing in athletic activity. This rationale has come more into common thinking as clinicians have begun to use the functional rehabilitation model, recognizing the needed to analyze an athlete’s ability to correctly move in functional movement patterns has become more important. They argue that the FMS\(^{TM}\) would provide a standard for evaluating basic movement patterns to establish baseline comparisons, but also to determine who is ready for advanced physical activity. Cook et al.\(^1\) sited four articles by past researchers who had the perception that no set standard exists that can determine who is physically prepared to participate in activities.

An example given to describe why screening the movement pattern is important involves how firefighters train\(^1\). A typical protocol used to train involves starting with controlled, voluntary movements. Then they train through repetition and that movement becomes stored as a motor program. Eventually cognitive commands are less needed and that leads to improved subconscious performance, which is known as cognitive programming. If these movements are learned incorrectly and practice over and over in training protocols like this they become learned inefficiently or asymmetrically. When
movement patterns are learned incorrectly a person compensates to still be able to perform the task, but this is at the cost of efficient movement and at the risk of potential injury. A screen that analyzes basic movement patterns could show an asymmetry before it has the chance to become a hazard to the athlete’s health. The authors briefly explain how each test identifies weaknesses or asymmetries; however they do not provide strong support for this. Inclusion of an EMG study during these tests would be warranted for empirical proof that each test activates the target muscles when examining symmetries during certain tests. While each description of clinical implications is logical, the conclusions could have been stronger if EMG studies would solidify the legitimacy of the functional movement screen as a tool to use for movement analysis. It has been well documented that asymmetries, core strength, and decreases in range of motion have been linked to increases in injury in an athletic population, which will be discussed later. It would be reassuring to see subjective proof that the FMS™ can find what they say it can.

Peate et al 27 focus on flexibility and strength in the trunk stabilizers and performance on the functional movement screen to assess trunk strength and flexibility to design an intervention. The purpose was to explore methods to better assess the risk of firefighter injury due to functional movement performance, and to decrease the amount of injuries using the information to determine if the functional movement enhancement programs (as defined and determined by FMS™) would prevent injuries in workers whose work involves awkward positioning during performance. Their other purpose was to determine if core strength improvements would help prevent injuries in these workers, which will be discussed in the next section. The Environmental Occupational Health (EOH) unit of the University of Arizona was awarded a contract to provide medical
surveillance and injury prevention and treatment for Tucson Fire Department. This is an urban fire fighting agency in a community of about 765,000.

All 433 subjects (408 males and 25 females) were involved in fire suppression activities and were on a full duty status. Ages ranged from 21 to 60 years of age with the mean age being 41.8 years for males and 37.4 years for females. Scores taken on the seven FMS\textsuperscript{TM} tests were based on the firefighter’s ability to perform the respective test. They used the zero to three grading scale making for a total of 21 points for a perfect score. The series of FMS\textsuperscript{TM} tests were performed on the 433 firefighters over a four week period in late 2004. They analyzed the correlation between FMS\textsuperscript{TM} performance and a history of previous musculoskeletal injuries. There was also a correlation found between FMS\textsuperscript{TM} score and age, gender, tenure, and rank. The firefighters were then enrolled in a training program. For one year following training, information on the type and number of injury cases, cost of treatment, and lost days due to injury were gathered by the organization’s worker’s compensation department.

Data was retrieved from personnel, absentee and medical records for a one year period. For the exploratory data they used bivariate methods. The primary hypothesis was assessed with multivariate analysis (logistic and linear regression). For part two, the intervention, all injury cases were reviewed for the year before the study and the year following, ICD 9 codes were tabulated and all injury cases underwent medical review. Injuries not related to functional movement, such as burns, abrasions, and lacerations were excluded from analysis. A historical control group was formulated and compared with the intervention group. The results for part one showed that increasing age, rank and tenure were associated with lower functional movement score. Each yearly increase in
age resulted in a 0.1 unit decrease (p < .0001). They then adjusted for age and ran a multiple linear regression, and found that firefighters with a previous history of injury scored 0.24 points lower than those without a previous history of injury. This was not statistically different (p=0.25). They dichotomized the outcomes into pass and fail, with above a score of sixteen being passed and below sixteen being considered a failure. Multiple logistic regression suggested that after they adjusted for participant age, the odds of failing the functional movement screen were 1.68 (with a 95% percent confidence interval of 1.04, 2.71) times greater for firefighters with a history of injury (p=.033).

In part two of this study, in order to test if the percent change in injuries before and after the intervention was significant, a two sample test of proportions was calculated. This test assumes under the null hypothesis that the probability of injury pre and post intervention is equal. When comparing the number of injuries pre to post of the 433 firefighters lost time injuries were reduced by sixty two percent, whereas total injuries were reduced by forty four percent compared to a historical group. The two sample test of proportions indicated that significant reductions were made among injuries of the back (p=.024) and upper extremities (p=0.03). However, no significant change was found in injuries in the lower extremities (p=0.46). Similar results were seen with lost time injuries, significant reductions in both injuries to the back (p=0.004) and upper extremities (p=0.014). The main conclusion for this article suggests that development and implementation of functional movement enhancement programs to prevent injuries in high risk workers such as firefighters is warranted. Based on a linear regression there was a correlation between past musculoskeletal injury and FMS score, a history of an injury
lowered the FMS score by 3.44. Based on a logistic regression there is no significant correlation between injuries and FMS score however, there was a significant correlation between age, rank, and tenure and FMS score.

A few limitations to this study are that there is no reason to define a failure on the FMS™ test at a score of 16. Also, the authors told us that the average lose of FMS™ score due to injury is 3.44 points but they did not clarify if this average decrease in score from the uninjured group gave the previously injured group a failing score. Also, We have no way of knowing what the score was previously before the injury so this 3.44 was likely an average of the healthy vs. injured population and not a true deviation from what the injured persons score was before the injury occurred. Some unanswered questions mentioned in the discussion section included to what degree did prior injury hamper the subjects’ ability to perform the FMS™ test? If a firefighter had residual physical limits from a past injury would it be logical to assume their performance would be diminished on the testing? In the discussion they discussed that annual physicals noted the residual physical limitations that could diminish their performance in the FMS™ testing for this study. The correlations between age, rank, and tenure and FMS™ score are chronologically related and increase with time in service as fire fighters. In general flexibility and strength also decline with age and injuries are more likely to accumulate. This could attribute to the differences in FMS™ score. One of the major caveats to the two sample test of proportions in this study is the loss of power from the underutilization of paired data. The authors suggest that McNemar’s test would have been better for assessing significant differences before and after interventions; however, the paired data needed to calculate those estimates were unavailable to the testers at the time that they
ran their analysis. Even with this, the results of the two sample test of proportions should have provided a relatively unbiased estimate of the before and after differences in injuries.

A third article relating the FMS\textsuperscript{TM}, by Keisel et al\textsuperscript{33} was focused on determining if serious injury in professional football can be predicted by a preseason assessment with the FMS\textsuperscript{TM}. Participation in football is one of the leading causes of sports related injury. They have identified risk factors for injury in high school and collegiate levels of competitive football. Evaluation of isolated risk factors does not take into consideration how the athlete performs the functional movement patterns required for sports. Tests assessing multiple domains of function (balance, strength, and range of motion) simultaneously may improve the accuracy of identifying athletes at risk for injury through pre participation assessment. The purpose of this study was to examine the relationship between professional football players’ score on the FMS\textsuperscript{TM} and the likelihood of a player suffering a serious injury over the course of one competitive season.

The strength and conditioning specialist associated with the team studied had eleven years of experience as a professional football strength and conditioning specialist and utilized the FMS\textsuperscript{TM} as part of preseason physical performance testing prior to the 2005 season. All players who attended training camp were tested on each of the seven tests in the FMS\textsuperscript{TM}. The composite score for each player was the variable analyzed in this retrospective study. For protection of the identity of the subject only limited injury information and FMS\textsuperscript{TM} data were available to the authors for analysis which is why common demographic data could not be used in this study. Also the authors agreed not to
reveal the name of the team involved. Forty-six players on the active roster at the beginning of the season were used in this study. The surveillance time for this study was one full competitive season, about 4.5 months. Membership on the injured reserve and time loss of three weeks was used as the injury definition.

For data analysis a significant difference existed in composite FMS™ scores between those who were and were not injured. A dependent t test was performed with significance set at p< .05. The cut offs for FMS™ score were determined from a receiver-operator characteristic (ROC) curve to maximize specificity and sensitivity. An ROC curve is a plot of the sensitivity (True +’s) versus specificity (false +’s) of a screening test. Different points on the curve correspond to different cut off points used to determine at what value a test is considered positive. The test value (FMS™ score) which maximizes both true +’s and false +’s identified on the ROC curve as the point at the upper left portion of the curve. Once the cut off score was identified, a 2x2 contingency table was created dichotomizing those who suffered an injury and those who did not, and those above and below the cut off score on the FMS™. They then calculated odds ratios, likelihood ratios, sensitivity and specificity. Post test odds and post test probability were calculated according to a formula provided, which allowed for the estimation of how much the FMS™ score would influence the probability of an injury. At the beginning of the season there was a probability (pre test) that existed for suffering a serious injury. To determine how much the probability of serious injury increased when a player’s score was below the cut off score (magnitude of shift from pre test to post test probability), the post test was calculated utilizing a three step calculation process that they got from an article by Sackett et al 37. They calculated a positive likelihood ratio value which is
associated with the FMS™ as a special test. The FMS™ scale was considered positive if a given subject’s score was equal to or below the cut off score determined by the ROC curve. The pretest probability was the probability of a player suffering a serious injury as defined earlier. They were unable to define an injury rate for professional football so they use 15%, based off of high school and collegiate injury surveillance studies.

Results showed that the mean score on the FMS™ was a 16.9. The mean score for those who suffered injury was 14.3 and for those who were not injured the score was 17.4 which was statistically different (df= 44, t= 5.62, and a p <.05). When they analyzed the ROC curve and the corresponding table of sensitivity and specificity values they found that FMS™ score of 14 maximized specificity and sensitivity of the test. Specifically the point is chosen so that the test correctly identifies the greatest number of true positives while minimizing the number of false positives found. The cut off score represents a sensitivity of .54 and specificity of .91.

The odds ratio was 11.67, positive likelihood ratio was 5.92, and negative likelihood ratio was .51. The odds ratio can be interpreted as a player having an eleven-fold increase chance of injury when their FMS™ score is 14 or less, when compared to a player whose score was greater than 14 at the start of the season. The post test probability was calculated at .51, supporting that if an athlete scores a 14 on the FMS™ or less their probability of suffering a serious injury increased from 15% to 51%. The main conclusion from this article was that professional football player with a lower composite score (< 14) on the FMS™ had a greater chance of suffering a serious injury over the course of one season. This study is strongly dependent on the calculation of pre test probability. This number influences the magnitude of the shift from pre to post test
probability when using the positive likelihood ratio. Too high of a value used would inflate the magnitude of the shift and imply that the FMS™ test is more powerful than it really is. For this reason they used the conservative prevalence rate of 15%, while most health care professionals would actually expect this to be on the low end of the spectrum when looking at professional football over the course of one season. The finding suggest that dysfunctional movement patterns, as measured by the FMS™, are more likely to suffer time loss injury, but not a cause effect relationship between the two. A limitation of this study is the inclusion of only one team. The same data set that was used to determine the ROC curve cut off score was used to test the cut off score in the prediction model. Using the same data to determine cut off score and evaluate those cut off scores as a predictive model is more likely to demonstrate meaningful findings than when using cut off scores determined with different data33. Ideally, a cut off score should be stabilized from a separate study33. Then that value should be applied to the prediction model to prevent inflation of the post test probability and odds ratio33. Another limitation included the definition of injury that they used. Only those on the injured reserve for at least three weeks were used to define an injury. This might not have encompassed injuries that were meaningful but not long enough to place the athletes on the injured reserve list.

Minick et al34 determined the inter-rater reliability of the FMS™. The authors videotaped forty healthy subjects performing the FMS™. The videos were then scored by four raters (2 experts who instruct FMS™ courses and 2 beginners who had completed standardized training courses on the FMS™). The authors then analyzed the inter-rater reliability by using weighted kappa statistic. The beginners demonstrated significant agreement on 14 out of 17 tests; however the expert raters did the same on 14 out of 17
tests. When the beginners were paired with expert raters all 17 of the components demonstrated significant agreement. The authors concluded FMS can be applied by trained individuals. They also suggest that the FMS can therefore by used to assess movement patterns in athletes and make decisions related to interventions for performance enhancement.

The mild amounts of scoring variability could be attributed to using video instead of live subjects for testers to score. Some of the testing could have benefited from a 3-dimensional approach to allow the scores to see all planes of movements for the tests. Also, the authors should have included an untrained group of clinicians. This third group could have demonstrated if formal training is necessary for the use of this testing protocol. The authors could have achieved this by explaining the tests and scoring protocol in a brief training session and then allow them to score the videos.

2.4 Core Stability and Athletic Injury

Zazulak et al. examined causes of knee injuries, specifically core proprioception. The core is considered the passive structures of the thoracolumbar spine and pelvis and the active contributions of the trunk musculature. The stability of the body’s core hinges on neuromuscular control of the trunk in response to internal and external forces; including forces that are created by the distal segments of the kinetic chain. For this study the definition used for core stability was the body’s capacity to maintain or resume a relative position of the trunk after perturbation. They noted that deficits in core neuromuscular control may contribute to unstable behavior and injury throughout all segments of the kinetic chain. Many athletic maneuvers are unstable and
require neuromuscular control to maintain stability. The purpose of this study was to identify potential factors related to neuromuscular control of the trunk that predispose athletes to knee injuries. Subjects were 277 Yale varsity athletes who volunteered for the study [140 women (19.4 years ± 1.0 ; 1.7 m ± .08; 65.6 kg ± 8.7; 22.6 kg/m² ± 2.2) and 137 men (19.3 yrs ± 1.8; 1.83 m ± .08; 79.9 kg ± 11.9; 23.8 kg/m² ± 2.8)].

Athletes were tested at baseline and then followed for three years to track any knee injuries sustained during that period of time. Before experimental testing, every subject completed a detailed, 45 item questionnaire pertaining to personal data, athletic experience, varsity level sport affiliations, and history of injury. None of the athletes had a history of knee injury. The definition used for knee injury was any ligament, meniscal, or patellofemoral injury diagnosed by the university sports medicine physician. Fractures and contusions were excluded. The injuries were further classified as only ligament or meniscal, and then only ACL injuries. The athletes were not injured at the time of testing. All injuries were confirmed by MRI. Core proprioception was evaluated using a previously validated apparatus as described by Taimela et al that produces passive lumbar motion in the transverse plane. The subjects were positioned in the apparatus so that the vertical pivot axis extended through the L4/L5 vertebrae. The seat was driven by a stepper motor at a steady, slow rate to minimize tactile cueing. The contribution of the vestibular system was eliminated since the upper body remained fixed to the backrest with a four point seatbelt and the lower body moved in the plane parallel to the ground. They eliminated visual and auditory cues of the apparatus motion, so that this proprioception test focused on the feedback from muscular and articular mechanoreceptors of the trunk. Subjects were initially rotated to 20 degrees away from
the neutral spine posture and briefly held in that position for three seconds. In the passive
test the subjects were slowly rotated toward the original position by the motor. In the
active test the subjects rotated themselves after the clutch was disengaged from the motor
drive. In both tests, the subjects stopped the apparatus by pressing a switch when the
perceived they were in the original, neutral position. There were 4 practice trials in each
direction. Then they performed 5 random trials in each direction.

For the statistical analysis the average absolute repositioning errors from all 10
trials were calculated. To determine the most appropriate set of parameters for regression
analysis, and 2-factor ANOVA with Tukey’s post-hoc test was used to identify the
measures that differed significantly between the injured and uninjured athletes (P = 0.05).
The two factors were knee injury versus no knee injury during the follow-up and male
versus female. The dependent measures were the average absolute error in active
proprioceptive repositioning (APR) and passive proprioceptive repositioning (PPR). A
prior analysis determined that 21 injuries were required to achieve an adequate power of
0.8. The reproducibility of both measures were tested by computing intra-class
 correlation coefficients between the averages of the first 5 trials and the last 5 trials for
each of the 277 subjects. The APR and PPR reproducibility was good as indicated by the
intra-class correlation coefficients of 0.61 and 0.58. The results showed that during the 3
year posttest follow up period, 25 of the 277 athletes sustained knee injuries. 11 occurred
in female subjects and 14 occurred in the male subjects. There were 16 ligament and/or
meniscal injuries; 7 occurred in women and 9 in men; of these 11 were ligament injuries.
Six subjects sustained ACL ruptures, 4 female and 2 male subjects. All ACL injuries
were confirmed by using MRI. There was a significant interaction between sex and knee
injuries. Deficits in the APR were observed in female subjects with knee and ligament/meniscal injuries compared with uninjured female subjects (P = 0.05). There was no significant difference in average error in APR between injured male subjects compared with uninjured male subjects (P = 0.05). Uninjured female subjects demonstrated significantly less average error in APR than uninjured male subjects (P = 0.05). No difference in the average error in PPR was observed in knee injured versus uninjured athletes (P = 0.05). For each increase in the degree of the average APR error, a 2.9 fold increase in the odds ratio of knee injury (P=0.005) and a 3.3 fold increase in the odds ratio of ligament/meniscal injury was observed (P=0.007). APR predicted knee injury status with 90% sensitivity and 56% specificity, and ligament/meniscal injuries with an 86% and 61% specificity in female athletes. They concluded that decrease in active core proprioception predicted knee injury risk in female athletes. The authors noted that athletes should be evaluated for proprioceptive deficits before competition and targeted for specific active core neuromuscular training, and that programs that train core neuromuscular training may prevent knee injuries. This is supported mainly due to the fact that the deficits were seen in APR and not PPR in the injured female athletes. The APR, or active, and PPR, or passive, tests differ with respect to the relative contribution of the muscle receptor sensory input. During APR more muscle spindle feedback is involved. However, during PPR activity from muscle spindles are decreased and most likely the input comes from cutaneous and joint receptors play a greater role in sensory feedback. This means that the level of input from the muscle spindles during reproduction of the trunk position likely differed between the active and passive tests. The deficits in active proprioception may have been translated to active athletic maneuvers associated
with knee injury. Their second hypothesis found agreement with earlier studies that female athletes who did not subsequently suffer knee injury had significantly better trunk proprioceptive ability than male athletes who did not go on to sustain knee injury.  

This study had relatively low number of injuries, particularly injuries to the ACL. This low number may have decreased their ability to detect poor APR as the predictor of ligament and ACL injuries. However, the power analysis was met for total injuries in this study. Strength in this article is that they did use a prior analysis to determine that 21 injuries were needed to get an adequate power of 0.8. This study actually had 25 injuries among 277 subjects; meaning the negative results relative to ligament and ACL injuries are not reported to avoid potential beta-type errors. For the tests were conducted in the lumbar spine the proprioception was measured under relatively artificial conditions and postures. The pelvis was immobilized to isolate trunk movement while they note that this is a more direct measure of core proprioception, This could also be considered a non-functional measurement in that it does not measure the core neuromuscular control in functional activity, but it does tell us that poor core proprioception does predict knee injury risk.

Zazulak et. al also investigated deficits in neuromuscular control of the trunk predicting knee injuries. This research was based off the theory that female athletes are at a significantly greater risk for ACL injury than male athletes in the same high risk athletic activities, and that decreased trunk, or core, neuromuscular control can potentially compromise dynamic knee stability. They defined dynamic stability as the ability of the knee joint to maintain position (static stability) or intended trajectory (dynamic stability) after internal or external disturbance. The author of this article stated
that inadequate neuromuscular control of the body’s trunk can compromise dynamic stability of the lower extremity and can result in abduction torque at the knee and that would lead to strain on the knee ligaments and lead to an injury. The purpose of this study was to identify neuromuscular factors that are related to trunk stability that predisposes an athlete to injuries in the knee. They tested four hypotheses: (1) that increased trunk displacement after sudden forces release would be associated with increased knee injury risk, (2) lateral angular displacement of the trunk in the coronal plane would be the best predictor of ligament injury, (3) logistic regression models of combined factors related to core stability would predict knee, ligament, and ACL injury with high sensitivity and moderate specificity; and (4) the predictive value of these models differs in males and female athletes.

The subjects consisted of 277 athletes volunteers [140 women (19.4 years ± 1.0; 1.7 m ± .08; 65.6 kg ± 8.7; 22.6 kg/m² ± 2.2) and 137 men (19.3 yrs ± 1.8; 1.83 m ± .08; 79.9 kg ± 11.9 23.8 kg/m² ± 2.8)]. Before testing the subjects completed a 45 item questionnaire pertaining to demographic data, athletic experience, varsity level, sport affiliation, and history of injury. Injury was defined as any injury that resulted in a trip to see a sports physician, and a knee injury was defined as a ligament, meniscal, or patellofemoral injury to the knee joint. None of these athletes had a history of injury to the knee joint. Fractures and contusions were excluded in the knee injured athlete group. The study used a quick force release in three directions of isometric trunk exertions for assessing the trunk response to sudden unloading. Subjects were placed in an apparatus for isometric contraction of flexion, extension, and lateral bending. Pelvic movement was retrained but the upper body was allowed to move in any direction. Each subject
performed five trials at a constant force level corresponding to 30% of maximal isometric trunk exertion. Visual feedback was used to help athletes reach and maintain target force. Then the force was released and a flock of birds electromagnetic device was used to record trunk motion. The statistical analysis was run with 6 parameters, flexion, extension, and lateral flexion angular displacement at 150 milliseconds and maximum displacement. The first three factors were force release direction, gender, and injury. Analysis of variance and Tukey post hoc test used to identify displacement parameters that were significantly different between injured and uninjured athletes. Those parameters served as input into backward stepwise binary logistical regression model for predicting knee injury. They found that 25 athletes sustained knee injuries across the time span of three years. The trunk displacement was strongest in predicting ligament injuries. The logistic regression consisting of trunk displacement, proprioception, and low back pain history, showed a prediction for knee ligament injuries with 91% sensitivity and 68% specificity. The same model predicted knee, ligament, and risk of ACL injury in female athletes at a level of 84%, 89%, and 91% accuracy. The only significant predictor of knee ligament injury risk in male athletes was a history of low back pain. The authors of this article concluded that risk of athletic knee, ligament, and ACL injuries can be predicted by factors relating to core stability. \(^{30}\) With high sensitivity and moderate specificity in female athletes but however did not show any in male athletes. \(^{30}\) Limitation of the study includes having a lower number of injuries even though the power level required 21 injuries and this study had 25 injuries. \(^{30}\) Another problem with this study is that there was a varied amount and type of pre-participation neuromuscular training. Also, the objective measures taken in the study did not use the entirety of the potential components of core
stability. The authors did use important components of core stability including: displacement after trunk force release, history of low back pain, and active proprioceptive repositioning, which are highly effective at predicting knee injuries. The tests were preformed under artificial conditions and posture; and not in a functional activity or positioning. The restraint of the pelvis also is not present in functional movement. The position that they did chose was used to control other neuromuscular response strategies mediated when the hips, knee, and ankles move.

In the next article Nesser et al. looked at core strength and transfer of forces generated with the lower extremities through the torso, and to the upper extremities. Core strength was defined as the individual’s ability to stabilize the torso from the hips up to the shoulders in order to produce force, and control and transfer to one or more extremities. The subjects consisted of 16 division 1 female soccer players who completed strength and conditioning evaluation before the start of the season. Subjects completed two strength tests: the one rep maximum of their bench press and squats; and three performance variables; countermovement vertical jump, 40 yard spring, and 10 yard shuttle run; and core strength; back extension, trunk flexion, and left and right bridge. No significant results were identified between core strength and power. These results show that core strength is not related to strength and power measures. This means that core strength does not contribute significantly to strength and power and it should not be the main focus of strength and conditioning programs with the intent of improving sport performance. The main limitation of this study is that the measurement that they used for core strength/stability is not a true measure of stability and also has a weak specificity. All of the measures taken in this study were one repetition, quick, explosive movements,
where as in soccer injury may happen or core stability may be needed after periods of fatigue. These are all reasons why the results showed no significant correlations. Another possibility is that core strength does not contribute to strength and athletic performance; however a more quantitative test of core stability could show a connection to athletic performance.

Leetun et al focused on the decrease in stability of the core and its contribution to lower extremity injuries, particularly females. They compared core stability measures between genders and between athletes who reported having an injury during their competitive season versus those who did not. Lastly, the article investigated a possible combination of the strength measures that could be used to screen athletes who could be at risk for lower extremity injury. Before the season, 80 female and 60 male college basketball and track athletes were analyzed for hip abduction and external rotation strength, abdominal muscle function, and back extensor and quadratus lumborum endurance. Males produced greater hip abduction, hip external rotation, and quadratus lumborum measures. Athletes who did not have any injuries had significantly stronger hip abductors and external rotators. The logistic regression analysis that the authors ran showed that hip external rotator strength was the only helpful component in predicting injury status. These results lead to the conclusion that core stability has an important role in preventing injury. A few potential limiting factors for this study include the measurement in which the authors measured hip strength, and the two examiners were not tested for intra-tester reliability. The strength measures were taken in units of force instead of torque. If the authors would have taken the measurements in torque they would have found that there would have been a less significant difference than the force.
measurement used in taller subjects than shorter subjects. However considering that females are shorter than males it would only have compounded the author’s results. Also, as seen in many articles these measures of core strength were not measured in functional positions.

2.5 The Role of Flexibility in Athletic Injury

It is established that adductor muscle strains are the most common injuries seen in the National Hockey League (NHL). Tyler et al. attempted to determine if hip muscle strength and, more applicable to this section, flexibility have a role in adductor and hip flexor strains in the National Hockey League (NHL) players. The measures of hip flexion, abduction, and adduction were taken in 81 players before the beginning of the season for two consecutive years. 34 of the players were taken out of the study due to trade, cut, or being sent to the minor league. The authors collected injury data and exposure data for the remaining 47 athletes. Eight players experienced 11 strained adductors, and there were 4 strained hip flexors. In the preseason the authors found the adductor strengths to be 18% lower in athletes who had sustained a strain to their adductor compared to the athletes who had not had any injury. Adduction strength was about 95% that of the abduction strength in the uninjured players but in the injured athletes it was only 78% of their abduction strength. The results that are prevalent to this section showed that preseason hip adductor flexibility was not any different between athletes who were uninjured and those who had a hip adductor strain. The authors concluded that pre-season strength measures could help indentify athletes at risk, but no contribution from flexibility was found. One limitation for this study is that they only
measured hip adductor flexibility and did not look at hamstring or abductor flexibility. If they had looked at all of the ranges of motion they may have found that one could have been a significant component in hip adductor strains. Also, while the goniometer is frequently recognized as a reliable source for measuring joint motion, there is a subjective component to the goniometer, and human error that could have impacted the results. They also did not discuss why they picked the position of the Thomas test for hip flexors flexibility measure, which could have impacted the measure of the hip flexor flexibility.

Muscular tightness is a frequent intrinsic risk factor for an athlete sustaining a musculoskeletal injury. Witvrouw et al. determined if an increase in muscle tightness is a risk factor for musculoskeletal injury in a soccer player. In this study the authors’ examined 146 male professional soccer players before the 1999-2000 Belgian soccer competition. The players did not have a history of previous muscle injuries in the lower extremity in the previous two years. The flexibility of the hamstring, quadriceps, adductors, and calf muscles were measured goniometrically before the players began their competitive season. The authors followed the athletes through exposures for injury for the entire competitive season and registered any sustained injuries. They found that players who had a quadriceps or hamstring injury had a significant lower measure of flexibility in these muscle groups before they sustained their injury compared with the uninjured group. They did not find any significant difference in the flexibility measures in players who sustained an adductor injury or a calf injury versus the uninjured group. With these results the authors concluded that soccer players with increased tightness of the hamstrings or quadriiceps muscles are more likely to sustain a musculoskeletal injury.
A limitation of this study is that they failed to discuss the circumstances in which the injury occurred. Also, there are many reasons, intrinsic and extrinsic, that injuries could occur. They authors were aware that they only investigated muscle flexibility and that must be considered a limitation. Other parameters for injury should not be overlooked as causes for the injuries or that muscle flexibility is more significant a reason for the injury.

The next article focused on the belief that conditioning programs for sports including flexibility, strength, and cardio respiratory endurance training reduce injury and improve performance. Krivickas et al. wanted to investigate two components of flexibility, muscle tightness, and ligamentous laxity in intercollegiate athletes to determine if these factors were associated with the athletes sustaining a lower extremity injury. Athletes were division one athletes of St Peters College in New Jersey whose flexibility measurements were made by the same examiner. This resulted in a sample size of 201 intercollegiate athletes (131 men and 70 women). The athletes were tested for ligamentous laxity with the Beighton scale and for muscle tightness with a scale based on the tightness of the iliopsoas, iliotibial band, hamstring, rectus femoris, and gastroc soleus muscles. Lower extremity injuries sustained during a period of exposure were recorded during the next year. An injury was defined as a back or lower extremity injury that limited athletic activates or prevented play in practice or competition. The results showed that 71 of the athletes in the study had a total of 115 injuries. They found that or every additional point on the ligamentous laxity scale; the risk for injury would decrease by 16%. The authors also found that the risk of injury increased by 23% for every additional point on the muscle-tightness scale. Women had a greater mean laxity score than men, and lower muscle tightness scores. Within female athletes, the rate of lower
extremity injury was not related to flexibility or laxity in ligaments.  

In the male subjects they found that lower extremity injuries were associated with lower laxity scores and greater muscle tightness. The authors concluded that based on the new scales introduced in this study tight ligaments and muscles are related to injury in mean, but not in women in this specific population. A weakness of this study is that the limited number of athletes participating in each sport it was not possible for them to analyze data by each sport. Also, the study had a significantly higher number of males than females, which could contribute to such high significant differences between male and females. For the new scale used in this study they only tested the intra-rater reliability and not inter-rater reliability, which would need to be addressed in future research to increase the validity of this tool as a measure of flexibility.

Hennessy and Watson examined the connection between hamstring flexibility and history of injury, and the relationship between hamstring strain injury history and posture. Flexibility and posture were investigated in 34 athletes from rugby, hurling and Gaelic football in Ireland. Athletes were divided into a group of non-injured athletes, i.e. athlete who did not have a history of hamstring injury in the past 12 months, and a group of injured athletes who had an incident of hamstring injury 12 months prior to the study. They assessed ten postural components: head erectness, shoulder symmetry, spinal curvature, hip symmetry, foot and ankle alignment, knee hyperextension, upper back roundness, trunk erectness, abdomen protrusion, and lumbar lordosis. Hamstring flexibility was measured in both legs. Results showed no difference between groups for flexibility. Also, no difference was observed between the limbs, in injured subjects. A significant difference was seen between groups when looking at low back posture.
There were no other significant differences seen in any of the other postural measures. Only 53% of common variance was seen between and two components, head and shoulder components. All other correlations were 40% or less in common variance between the components. The authors of this article concluded that poor low back posture was found in the injured group, but flexibility was not an evident component in injured or the non-injured group. Some significant limitations of this study are that the athletes who had a previous history of hamstring injury received treatment from a physiotherapist and therefore could have improved their flexibility and prevention techniques before the study. Also, the measurements were not clearly explained as to how they measured flexibility or the postural assessments that they used. Also they did not note the circumstances that the injury occurred.

Mahieu et al identified measurable intrinsic risk factors for Achilles tendon overuse injuries. The subjects consisted of 69 male officer cadets; entering the Belgian Royal Military Academy. Before this training, each cadet was evaluated for anthropometrical characteristics, isokinetic ankle muscle strength, ankle joint range of motion, Achilles tendon stiffness, explosive strength, and leisure and athletic activity. All overuse tendon injuries were recorded and evaluated by the same physician. To identify the intrinsic risk factors the authors performed, a multivariate analysis with the use of stepwise logistic regression. The sensitivity, specificity, and cutoff values of the risk factors were evaluated by receiver operating characteristic curve analysis. Out of the 69 cadets, 10 had overuse Achilles injuries as determined by history and clinical evaluation. Recruits that had lower plantar flexor measures and increased dorsiflexion excursion were at a greater risk of Achilles tendon overuse injuries. The cut off value
of the plantar flexor strength at 85% sensitivity was 50.0 N·m, with a 4.5% specificity; the cut off value of the dorsiflexion range of motion at 85% sensitivity was 9.0°, with 24.2% specificity. Based on these results the authors concluded that the strength of the plantar flexors and the amount of dorsiflexion excursion were identified as significant predictors of overuse injury in the Achilles. Planter flexion force lower than 50.0 N·m, and dorsiflexion range of motion higher than 9.0 degrees were possible thresholds for developing Achilles pathology. A limitation of this study is that the stiffness of the Achilles was not an intrinsic factor for overuse injury. The power of this parameter was at a level of 0.781. The authors state that most other researchers have found stiffness of the Achilles to be a related factor. Also, knowing that the calf muscles and Achilles do not really contribute to the performance in the standing broad jump might explain why a difference was not found between injured and uninjured subjects.

The purpose of a study by Verrall et al was to establish if there was a reduction of hip range of motion in athletes who have chronic groin injuries whose diagnosis was osteitis pubis. The subjects consisted of 89 Australian Rules footballers, all males recruited during the end of a six-week preseason training period. All had a history of groin pain or current groin pain symptoms. Clinical history and MR-criteria were used to diagnose a pubic bone stress injury. The authors measured internal rotation and external rotation with a goniometer. Athletes with and without symptoms were divided into two groups and compared against each other. Additionally, the injured athletes were divided into those with current symptoms compared against those who had recovered from a groin pain episode. Forty-seven athletes were diagnosed with chronic groin injury and thirty-seven were diagnosed with pubic bone stress. Thirteen athletes
had history of previous groin injuries. \textsuperscript{18} Correlation coefficients were calculated for the range of motion findings with increasing age to rule out as a confounder. Equal variance was used to compare the two different groups. \textsuperscript{18} A reduction of internal and external hip range of motion was seen in athletes with pubic bone stress and in athletes who had current symptoms compared to those who had no current symptoms but a history of groin pain. This study concluded that athletes who had chronic groin pain specifically diagnosed as a pubic bone stress injury demonstrated reduction in hip internal and external range of motion. \textsuperscript{18} Their suggestion is that this could be a goal in rehabilitation for athletes with current groin pain. \textsuperscript{18} One limitation of this study is that they took a single measurement each time the joint was examined, and with joints like the hip that have a wide variation of motion, multiple measures should be performed. Also they did not assess other ranges of motions. Also the study used multiple t-tests demonstrating statistical significance and others only demonstrated trends to reduction in hip range of motion, which may have an impact on the conclusion.

The final study of this section focused on hamstring injuries being one of the most common injuries in athletic events. Gabbe et al. \textsuperscript{16} examined risk factors associated with hamstring injuries using the community of Australian football players. The study used a total of 126 community level Australian football players and provided baseline measures, completed a questionnaire and had a musculoskeletal evaluation done during the 200 preseason. \textsuperscript{16} These athletes were then followed through the competitive season and collected data on injuries and exposures. \textsuperscript{16} The authors used Cox Proportional hazards regression to identify independent predictors of hamstring injury, Kaplan-Meier curves used to compare subgroups. \textsuperscript{16} The first injury of the season was a hamstring injury in 20
players. After adjusting for exposure, they found that increased age and decreased quadriceps flexibility were identified as significant independent predictors of hamstring injuries.\textsuperscript{16} Age was associated with an increasing risk of hamstring injury, and it was discovered that increased quadriceps flexibility decreased the risk of injury.\textsuperscript{16} They concluded that the development of hamstring injury prevention strategies could be used from the results of this study.\textsuperscript{16} Hamstring injuries were a relatively common event. However, the number of cases in the multivariate modeling was small which limited the power of the study and the ability to identify all but the effects that were the largest.\textsuperscript{16} Another limitation could be that they used clinical evaluation to diagnose the injury instead of imaging which could have been more reliable, yet the cost of such tests would have been unreasonable. Also, it could have helped if the same evaluator for all the subjects, however all the evaluators were qualified medical professionals.

2.6 Imbalances and Injury

Devan et al.\textsuperscript{8} examined the influence of hamstring to quadriceps (H: Q) ratio and structural abnormalities on the rate of overuse knee injuries in female intercollegiate athletes. The subjects consisted of 53 assumed healthy females from National Collegiate Athletics Association (NCAA) division one women’s field hockey, soccer, and basketball teams. They\textsuperscript{8} then determined the H: Q ratio from a preseason isokinetic test done on a Biodex system at 60 degrees per second and 300 degrees per second. They\textsuperscript{8} measured each athlete for genu recurvatum and Q-angles with a 14 inch goniometer. Iliotibial band flexibility was also measured by using the Ober’s test. The authors used a chi -square 2x2 contingency tables and the Fischer exact test to look at associations in H:Q ratios,
overuse knee injuries, and structural abnormalities. They found 10 overuse injuries in the knee occurring in 9 athletes. The H: Q ratio below the normal range at 300 degrees per second was seen in athletes with overuse knee injuries, and the presence of genu recurvatum was also seen. Athletes that possessed lower H: Q ratios at 300 degrees per second and genu recurvatum had more chronic knee injuries than athletes without the abnormalities. The authors concluded that the presence of genu recurvatum and an H: Q ratio below normal range was associated with an increased prevalence of overuse knee injuries among female intercollegiate athletes. The authors mentioned that investigation with larger sample size and appropriately timed isokinetic testing is needed to see if decreased hamstring strength and endurance in relation to quadriceps strength and endurance and genu recurvatum are contributing factors in overuse knee injuries. It is clear that the presence of these abnormalities increases a female athlete’s likelihood to sustain a overuse knee injury.

Croisier et al. examined the frequency of strength disorders in athletes with a history of hamstring muscle injury and recurrent strains and discomfort. They determined the frequency in these disorders in 26 male athletes. They used eccentric and concentric isokinetic assessment on a Kintrex 500. Eighteen athletes were found to have strength deficits, by cutoffs found of peak torque in a statistical analysis; bilateral differences; and the flexors: quadriceps ratio. The discriminating characteristic of the eccentric trial was demonstrated, combining a preferential eccentric peak torque deficit and a significant decrease of the mixed eccentric flexors/ quadriceps ratio. Subjects that displayed muscle imbalances completed a rehabilitation protocol that was designed for their individual deficits. There were 10-30 sessions resulting in isokinetic parameter
normalization in 17 or the 18 athletes who had deficits. 19 After the normalization the athletes were monitored for 12 months after they returned to athletic activity, none of them sustained a significant hamstring muscle injury diagnosed clinically. 19 The amount of subjective pain they felt was significantly reduced and they all returned to full participation. 19 The results lead the authors to conclude that muscle strength abnormalities may give rise to recurrent hamstring injuries and pain. 19 A rehabilitation protocol focusing on eccentric training based on individual deficits reduced subjective pain in return to play. 19 The authors 19 were conscious of the controversial nature of the conventional flexors/quadriceps ratio and thus used the mixed eccentric flexor/concentric quadriceps ratio to obtain muscular imbalance measures. While the normal ratio had no results this mixed ratio showed much more significant imbalances. 19 They stated that these results do not pertain to all hamstring injuries and that other limiting factors may cause an athlete to have more difficulty in return to play.

In a follow-up study Croisier et al. 9 examined professional soccer players performing a preseason isokinetic testing aimed to determine if 1) strength variables could be predictors of hamstring strain and 2) if normalization of strength imbalances could reduce the incident of hamstring injuries. 9 A standardized concentric and eccentric isokinetic assessment was used to identify athletes with strength imbalances. Athletes were classified into 4 subsets in accordance with the imbalance management content. The authors then recorded hamstring injuries after that allowing them to define injury frequency and risks between groups. 9 They found that of the 687 athletes that were tested during the preseason, a complete follow up was done on 462 athletes, and of that 462 athletes 35 hamstring injuries were reported. 9 The rate of muscle injury was
significantly increased in athletes with untreated strength deficits when compared to athletes; showing no deficits in the preseason. The risk of injury is significantly higher in athletes with strength imbalances who had compensation training but no final isokinetic control test than in athletes without imbalances. Also, normalizing the parameters reduced the risk factor for injury to that of athletes without any deficits. The authors concluded that isokinetic intervention can detect strength imbalances, which is a factor that increases the risk of hamstring injury. They also found that restoring normal strength can decrease the muscle injury incident. While other factors are involved in hamstring injury, the authors believes that due to previous research and this study it is evident that strength imbalances play a key role. They think that the variation in the definition of injury could be the key in inconsistent results in this type of research.

Limitations of the study include a lack of randomization in players in sports. Also an inconsistency exists in the evaluation of the subjects; because the athletes are on several different clinicians performed the testing and observers involved in recording the injuries were also different.

Lehance et al. compared the preseason muscular strength and power profiles in soccer players throughout aged 15-21. They compared isokinetic data with previous history of injury. They subjects consisted of 57 elite and junior elite male soccer players that were assigned to three groups: PRO (n=19), U-21 (n=20), and U-17 (n=18). Subjects went through isokinetic testing consisting of concentric and eccentric knee flexor and extensor exercise. Muscle disorder was defined using statistically selected cut-offs. Functional performance was tested by going through squat jumps and 10 m sprints. The PRO group ran faster and jumped farther than the U-17 group, however no significant
difference in isokinetic muscle strength was observed between the three groups when normalization in body mass parameters was performed.\textsuperscript{6} Isokinetic profiles allowed to identification of thirty-two subjects presenting with lower limb muscular imbalance. In this study 64% of the previously injured players still showed muscular imbalances representing a risk factor to undergo another injury.

Finally, Yeung et al.\textsuperscript{7} compared hamstring muscle injuries in sprinters over a complete athletic competition season to determine predictors of the injuries. The subjects of this study included 44 sprinters from the Hong Kong Sports Institute, the Hong Kong Amateur Athletic Association, and intercollegiate athletic teams (35 men and 9 women ages ranged from 17.2-21.2 years). The authors conducted preseason assessment that collected hamstring flexibility and concentric and eccentric isokinetic peak torque and peak torque angle data. They also completed a questionnaire that detailed their demographic characteristics, running career, training profiles, and previous injuries. This data was collected before the beginning of the competitive season. They monitored the athletes through a 12 month period and were asked to report all injuries resulting from training and competition. The results showed that 8 athletes sustained hamstring injuries over their season. The injury rate was 0.87 for every 1000 hours of exposure. The incident of injury was higher during the beginning of the season, with 58.3% of the injuries sustained in the first 100 hours of exposure. A Cox regression analysis was run, and showed that athletes with a decrease in hamstring: quadriceps peak torque ratio of less than 0.6 at an angular velocity of 180 degrees per second have a 17 fold increase risk of sustaining a hamstring injury. From these results the authors concluded that preseason hamstring: quadriceps peak torque ratio assessments may be useful in identifying
sprinters, or other similar athletes, susceptibility to having a hamstring injury. One limitation to this study is that not all sports medicine teams have access to the equipment necessary to get the hamstring: quadriceps ratio and try and predict the chance of injury. The ratio value of less than 0.6 at 180 degrees per second many not apply to other athletic activities. Also, clinicians’ have to keep in mind that an athlete’s strength and flexibility profile may changes during the season. Also, isokinetic testing has also been noted to have a lack of dynamic characteristics that are needed to specifically analyze activity specific to athletic participation.

2.7 Conclusion

The reviewed literature has shown core stability deficits, flexibility or ROM deficits, and muscle imbalance deficits to be strong risk factors for injury. The research has also made it clear that pre-season screening should be used to measure for these deficits. One consideration that these articles did not cover is that most sports medicine teams do not have access to the equipment needed to measure these values. Also, many of the measurements taken, while applicable, were not done in a functional matter that is prevalent to athletic participation. The FMS™ attempts to screen for these deficits in a more functional matter and with little equipment.
Chapter 3

Methodology

3.1 Experimental design

Prospective cohort design

3.2 Subjects

Intercollegiate Division I basketball players (Males: 19.07 yrs ± 0.83yrs, 194.36 lbs ± 31.42lbs, 75.64” ± 4.05”; females: 19.67yrs ± 1.11yrs,162.13lbs ± 19.63 lbs, 69.73” ± 2.22”) participating for the University of Toledo will be enrolled in this study. All subjects were required to sign consent forms as distributed by The University of Toledo. We included all those who were members of the 2009-2010 Men’s or Women’s University of Toledo basketball team and were uninjured during pre-season screening. Exclusion criteria included any injury or condition that prevented them from participating during the 2009-2010 season during the time of testing.
3.3 Instrumentation

Two functional movement kits, each comprised of a 2x4 foot board with half-inch increments written on the top, and plastic piping and elastic tubing that create a hurdle, and finally a single straight 4 foot long plastic PVC pipe.

3.4 Protocol

Subjects performed all seven exercises that comprise the FMS\textsuperscript{TM}. A simple three to zero scoring system was used.\textsuperscript{28, 29} A score of three is given if the subject is able to complete the movement perfectly, a score of two is given if the subject can complete the movement but with compensatory movement, a score of one is given if the subject is not able to complete the movement, and a score of zero is given if there was pain with the movement at any point\textsuperscript{28, 29}. After the pre-season scores are taken the athletes will continue with their normal competitive season. Any acute lower extremity injuries involving the knees or ankles will then be documented on a standardized tracking sheet by the certified athletic trainer assigned to the team.
3.5 Statistical Analysis

Separate independent t-tests were performed with the significance set at $p \leq 0.05$ to compare the pre-season total FMS$^{TM}$ score between the males and females, and also between the athletes that did or did not suffer a traumatic ankle or knee injury during the competition season. The primary dependent variable used was the scores on the FMS$^{TM}$ and the independent variables used were group (injured versus non-injured) and sex (male versus female). For secondary analysis, we created two modified FMS$^{TM}$ scores by eliminating some of the FMS$^{TM}$ tests that have more emphasis on function of the upper extremity. The first modified FMS$^{TM}$ score did not include the shoulder mobility test. The second modified FMS$^{TM}$ score did not include the shoulder mobility test or the core stability push-up test.

A receiver-operator characteristic (ROC) curve was created to determine the FMS$^{TM}$ value that maximized specificity and sensitivity. The ROC curve is a plot of the sensitivity (true positives) versus specificity (false positives). The different points on the curve correspond to different cut off points used to determine at what value the test is considered positive. The upper left portion of the curve is considered the point which maximizes both true positives and controls for false positives. Once the cutoff point was identified a 2x2 contingency table was created dichotomizing those who had an injury and those who did not. This was done so the FMS$^{TM}$ could be treated as an evaluation tool. From the table, odds ratios, likelihood ratios, sensitivity and specificity were calculated. This process was repeated for the total FMS$^{TM}$ score and the two modified FMS$^{TM}$ scores.
To estimate the amount of influence an athlete’s FMS™ score has on the probability of suffering an injury, post-test odds and post-test probability were calculated according to the formula provided. A 3-step calculation process was used to determine how much the probability of injury increased from pre-test to post-test when an athlete’s score fell below the cut-off score. For the likelihood ratio, the positive LR value is negative for an athlete when their score is above the cut-off score and positive when their score is equal to or below the cut-off score determined by the ROC curve. Calculation of the increase in probability is as follows:

1) Convert the pre-test probability to odds:
   \[ \text{Pre-test odds} = \frac{\text{pre-test probability}}{1 - \text{pre-test probability}} \]

2) Multiply the odds by the appropriate +LR value:
   \[ \text{Pre-test odds} \times +LR = \text{post-test odds} \]

3) Convert the post-test odds back to probability:
   \[ \frac{\text{Post-test odds}}{\text{post-test odds} + 1} = \text{Post-test probability} \]
Chapter 4:

Results

4.1 Total FMS score

The full female FMS™ score (15.87±2.79) was not statistically different from the males (14.85±1.95, p=0.27, Figure 4.1).

Figure 4.1: Total FMS scores between Male and Females
During the season, 4 athletes suffered a lower extremity injury. The total FMS\textsuperscript{TM} score of the injured group (16.25± 2.21) was actually slightly higher than the non-injured group (15.24±2.49), but this difference was not statistically different (p=0.45, Figure 4.2).

Figure 4.2: Total FMS\textsuperscript{TM} Score Between Injured and Non-Injured Groups

From the ROC curve analysis, a total FMS\textsuperscript{TM} score of 15.5 maximized sensitivity (0.50) and specificity (0.52). The resultant 2x2 contingency table is found in Table 4.1.

Table 4.1: 2x2 contingency for Total FMS\textsuperscript{TM} score

<table>
<thead>
<tr>
<th></th>
<th>injured</th>
<th>Non-injured</th>
</tr>
</thead>
<tbody>
<tr>
<td>+ test</td>
<td>2</td>
<td>12</td>
</tr>
<tr>
<td>- test</td>
<td>2</td>
<td>13</td>
</tr>
</tbody>
</table>
4.2 Modified to Exclude Shoulder mobility

When modifying the FMS™ to exclude the shoulder mobility test, again the males (13.80±2.51) and females (13.14±1.91) were not statistically different (p=0.44, Figure 4.3).

Figure 4.3: FMS™ (No Shoulder Mobility) between Males and Females

The total FMS™ score of the injured group (14.75±22.06) was again slightly higher than the non-injured group (13.28±2.23), but this difference was not statistically different (p=0.23, Figure 4.4).
From the ROC curve analysis, a FMS$^{\text{TM}}$ (No Shoulder Mobility) score of 13.5, out of the possible score of 18 points, maximized sensitivity (0.50) and specificity (0.48). The resultant 2x2 contingency table is found in Table 4.2.

Table 4.2: 2x2 contingency for FMS$^{\text{TM}}$ (No Shoulder Mobility) score

<table>
<thead>
<tr>
<th></th>
<th>injured</th>
<th>Non-injured</th>
</tr>
</thead>
<tbody>
<tr>
<td>+ test</td>
<td>2</td>
<td>13</td>
</tr>
<tr>
<td>- test</td>
<td>2</td>
<td>12</td>
</tr>
</tbody>
</table>
4.3 Modified FMS\textsuperscript{TM} to exclude Shoulder Mobility and Stability Push-Up

The final modification involved removing all tests that may involve the upper extremity (shoulder mobility and trunk stability push up) leaving a total score of 15 possible for the athletes to obtain. For the male group the mean was 10.57±1.65 and the female group was 11.33±1.87, which was not statistically different (p=0.26) (Figure 4.5).

Figure 4.5: FMS\textsuperscript{TM} (No Shoulder Mobility or Trunk Stability) Between Males and Females

For this final modification the mean score for the injured group was 12.00± 1.82 and for the non-injured group was (10.80 ±1.75), but again was not statistically different (p=0.22, Figure 4.6).
Figure 4.6: FMS$^{TM}$ (No Shoulder Mobility or Trunk Stability) Between the Injured and Non-Injured Subjects

From the ROC curve analysis, a FMS$^{TM}$ (No Shoulder Mobility or Trunk Stability) score of 10.5 maximized sensitivity (0.25) and specificity (0.64). The resultant 2x2 contingency table is found in Table 4.3.

Table 4.3: 2x2 contingency for FMS$^{TM}$ (No Shoulder Mobility or Trunk Stability) score

<table>
<thead>
<tr>
<th></th>
<th>injured</th>
<th>Non-injured</th>
</tr>
</thead>
<tbody>
<tr>
<td>+ test</td>
<td>1</td>
<td>9</td>
</tr>
<tr>
<td>- test</td>
<td>3</td>
<td>16</td>
</tr>
</tbody>
</table>
Chapter 5

Discussion

5.1 FMS Results

There were no significant differences in the total FMS™ score between male and female subjects, as well as between injured and non-injured groups. However, while not statistically different, it should be noted that the females did score marginally higher than the males and injured subjects scored marginally higher than the non-injured subjects, disproving the original hypotheses. While this is true, it should be kept in mind that this difference was very small. With a sensitivity = 0.50 and specificity = 0.52 these results show the chances of having a true positive or a false positive is essentially a fifty-fifty chance either way, which also did not support one of our hypotheses that a score on the FMS™ could demonstrate sensitivity and specificity scores about 0.70.

Because we were interested in lower extremity injuries in this study, we felt it may be interesting and relevant to eliminate upper extremity assessment tests from the FMS™ score in an effort to determine how well this series of assessments can predict male versus female differences and injured versus non-injured differences. In the first modified FMS™ again there was no significant difference between the two groups, in
either case. The sensitivity =0.50 and the specificity =0.48 were very weak, showing that again there is about a fifty-fifty chance of either getting a true positive or a false positive.

In the second modification of the FMS™ score that excluded the shoulder mobility and the trunk stability push up, once again there were no significant differences between the males and females or between the injured and non-injured groups. While specificity was the highest in any of the comparisons (0.64), it was still below the hypothesized level, and sensitivity was very low (0.25).

These results indicate that the FMS™ or a modified version of it was not a strong predictor of lower extremity injury among collegiate basketball players. This contradicts previous work that demonstrated effective injury prediction among professional football players. It is unknown if the differences between the two studies is due to a different level of athlete and sport demand (i.e professional players participating in a contact sport) used in the Kiesel paper, or because of a low sample size in our current study. An additional investigation comparing athletes from different sports may be needed.

Additionally, our results suggest no differences between male and female collegiate basketball players. While this is a surprising result, it may be beneficial to clinicians to know that sex differences may not be a factor that needs to be considered when using the FMS™.

5.2 Limitations

There are some limitations to our study. When looking at the methods it is important to note that when doing the full FMS™ some modifications are made to increase the ease and speed of the test. Since this study is interested in lower extremity injuries the clearing tests that are traditionally included in the FMS™ were
excluded from this study. While we do not suspect that excluding these clearing tests would have influenced the results, it is unknown clearing tests inclusion could have lowered scores and made the results of this study different.

Also, the exclusion of tracking of chronic lower extremity injuries could have inhibited the predictive quality of the FMS\textsuperscript{TM}. By limiting our interest to acute lower extremities only the number of injuries that could be included is limited. This could have been done by changing the definition of injury. Instead of just documenting acute lower extremity injuries this study could have changed its definition of injury to the same used by Kiesel et al\textsuperscript{33}, which could have increased the number of injuries by including persistent problems lasting for many days or weeks, which may have been more relevant to the group of athletes that was analyzed in this study.

The small sample size of this study is also a limiting factor. By limiting only to the basketball athletes of the University of Toledo there were fewer exposures that could result in injury as opposed to looking at multiple teams or even across multiple universities. The real limiting factor is the number of injuries that occurred in the season. This could be changed by following the team for more than one competitive season as well as changing the definition of injury to include a wider variety of lower extremity injuries.

Finally, while the research has shown consistently that core stability, flexibility, and muscle imbalances are linked to predicting injury in an athletic population\textsuperscript{6-18} no research has been conducted to compare the FMS\textsuperscript{TM} scores ability to measure these factors when compared to the more subjective measures that exist. The equipment needed to measure these factors imperially are expensive and time consuming. To have the
research available to show that the FMS\textsuperscript{TM} can measure these predictive factors could prove to be very useful in the clinical setting.

5.3 Future Research

Future research should focus on changing the definition of injury as well as increasing the sample size to see if a significant number of injuries and a significant score between injured and non-injured group occurs. Also research should be done comparing the tests in the FMS\textsuperscript{TM} that measure each factor individually (muscle imbalances, flexibility, and core stability) and compare performance on those tests to a proven measure of these factors. Also, inclusion of the clearing tests may change the scores of the groups making the injured groups score lower than that of the non-injured. It may show potential injury where excluding such tests may not. Future research also could focus on the bilateral deficits that have been suggested to predict injury. A comparison of side to side scores and injury side could attempt to answer this unanswered question. Also, changing the sport population may result in different injury rates. While basketball involves the lower extremity it may be interesting to investigate more predominately lower extremity intensive sports such as soccer, track, and cross country.

5.4 Conclusion

In conclusion, this study shows that there are no significant differences in mean FMS\textsuperscript{TM} score between injured versus non-injured or between males and females among collegiate basketball players. Therefore, the FMS\textsuperscript{TM} may not be a useful tool in predicting lower extremity injuries in collegiate basketball players.
REFERENCES


Appendix A

Performing and Scoring the FMS™

<table>
<thead>
<tr>
<th>Test</th>
<th>Performance of Test</th>
<th>Score of 3</th>
<th>Score of 2</th>
<th>Score of 1</th>
<th>Score of 0</th>
</tr>
</thead>
<tbody>
<tr>
<td>Deep squat</td>
<td>The athlete placed the feet slightly farther than shoulder width apart and places the hands on the dowel as to form a ninety degree angle at the elbows with the hands overhead. The athlete the presses the dowel overhead with the shoulders flexed and abducted with the elbows extended, then descends slowly into a squat position with the heels on the floor, the head and chest facing forward, and the dowel maximally pressed overhead.</td>
<td>A score of three is achieved if: the upper torso is parallel with the tibia or toward vertical, femur is below horizontal (the hip joint is below the knee joint), knees aligned over the feet, and Dowel is aligned over the feet.</td>
<td>If the athlete does not achieve the criteria of a score of three he or she then performs the test with a 2x6 under the heels. Two points are given if: upper torso is parallel with the tibia or toward the vertical, femur is below horizontal, knees are not aligned over the feet.</td>
<td>A score of one is given if: tibia and upper torso are not parallel, femur is not below horizontal, knees are not aligned over the feet. A score of zero is given if pain is noted with the exercise.</td>
<td>A score of zero is given if pain is noted with the exercise.</td>
</tr>
<tr>
<td><strong>Hurdle step</strong></td>
<td>Three points will be given if: ankle, hips and knee motion remaining primarily in the sagittal plane, minimal movement is noted in the lumbar spine, and the dowel remains parallel to the hurdle&lt;sup&gt;28, 29, 31&lt;/sup&gt;.</td>
<td>A score of two will be given if: the alignment is not maintained between the ankles, hips, and knees, movement is seen in the lumbar spine, and the dowel is not parallel to the hurdle&lt;sup&gt;28, 29, 31&lt;/sup&gt;.</td>
<td>One point will be given if: excessive side bending or flexion of the trunk, excessive rotation or abduction of the hip to compensate, inability to maintain balance&lt;sup&gt;28, 29, 31&lt;/sup&gt;.</td>
<td>a score of zero is given if pain is noted with the exercise&lt;sup&gt;28, 29, 31&lt;/sup&gt;.</td>
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<td>performed by placing both feet together and aligned with the toes directly beneath the hurdle; the height of the hurdle is adjusted to match that of the tibial tuberosity of the person in question, this measure is taken in centimeters&lt;sup&gt;28, 29, 31&lt;/sup&gt;. The dowel is placed just below the neck and it is held horizontally across the shoulders, the subject then steps slowly over the hurdle and touches their heel to the floor, keeping the supporting leg in an extended position the weight of the body should remain on the stance leg&lt;sup&gt;28, 29, 31&lt;/sup&gt;. The subject is then to return slowly to the starting position. This test is repeated three times and a grade given for each one&lt;sup&gt;28, 29, 31&lt;/sup&gt;. The test is then repeated on the subjects opposite leg&lt;sup&gt;28, 29, 31&lt;/sup&gt;.</td>
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<tr>
<td>In-line lunge</td>
<td>The length of the subject’s tibia will be measured from the floor to the tibial tuberosity, the subject will then be instructed to place the end of their heel on the end of the 2x6 board, using the tibia length a mark is made on the board from the end of the subject’s toes. The dowel is held behind the back in contact with the head, thoracic spine, and sacrum. The hand that is opposite the front foot should be held at the cervical spine and the other at the lumbar spine. The heel of the opposite foot then goes to the mark on the board and the back knee will be lowered enough to touch the board behind the heel of the front foot.</td>
<td></td>
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<tr>
<td>Three points given if the athlete stays in the sagittal plane, and the back knee does not touch the ground.</td>
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<tr>
<td>Two points are given for lateral compensation and the back knee not touching the ground.</td>
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<tr>
<td>One point is given if the athlete loses their balance or cannot complete the requirements for three or two points.</td>
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<tr>
<td>A score of zero is given if pain is experienced during the test.</td>
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</table>

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28, 29, 31

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<table>
<thead>
<tr>
<th>Shoulder mobility</th>
<th>First determine athletes hand length, measuring from distal wrist crease to the tip of third digit $^{28,29,31}$. Instruct the athlete to make a fist with thumbs inside the fist $^{28,29,31}$. The athlete should assume a maximally adducted, extended and internally rotated position with one shoulder, and a maximally ab ducted, flexed and externally rotated position with the other $^{28,29,31}$. During the test the hands should remain in a fist and they should be placed on the back in one smooth motion (no ballistic motion) $^{28,29,31}$. The tester then measures the distance between the two fists at the closest point. This test is done for both arms.</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>three points if the fists are within one hand length</td>
</tr>
<tr>
<td></td>
<td>two points if the fists are within one and a half hands length</td>
</tr>
<tr>
<td></td>
<td>one point if the fist falls outside one and a half hand lengths $^{28,29,31}$.</td>
</tr>
<tr>
<td></td>
<td>score of zero is given if pain is noted with the exercise $^{28,29,31}$</td>
</tr>
</tbody>
</table>
| **Straight leg raise** | Athlete assumes the starting position by lying supine with the arms in an anatomical position and head flat on the floor, the board is placed under the knees, the tester then identifies the anterior superior iliac spine and midpoint of the patella, between these two landmarks, the mid point of the thigh is found. The dowel is then placed at this position perpendicular to the ground. The individual is instructed to lift the test leg with a dorsiflexed ankle and an extended knee. The opposite knee should remain in contact with the board, the toes should remain pointed upward, and the head must remain flat on the floor.

This test is done for both the left and right leg. | Athlete receives three points if they successfully reach the end range position with the malleolus located past the dowel. Two points if the malleolus does not pass the dowel, but does not drop below sixty degrees of hip flexion. | One point is given if the malleolus does not pass the dowel, then the dowel is aligned along the medial malleolus of the test leg, perpendicular to the floor. The point is below the knee of down leg.

A score of zero is given if pain is noted with the exercise.

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| **Stability push-up** | This exercise begins by having the athlete assume a prone position with both feet together. The hands are then placed shoulder width apart, (forehead height for males, chin height for females) the knees are full extended and the ankles dorsiflexed. Have the athlete perform one push up in this position.

| Three points is given if the athlete’s body is lifted as one unit; there is no “lag” in the lumbar spine when performing the push up. | A score of two results if they are unable to complete this motion and the hands are moved to a lower point (chin for males, clavicle for females), and the push up is attempted again. If this is successful then a two is given. | If the athlete cannot complete the motion without lag in the score for two the athlete receives a score of one. A score of zero is given if pain is noted with the exercise. |
| Rotational stability | The athlete should be positioned in quadruped with the shoulders and hips at ninety degrees and the ankles should remain dorsiflexed. A board (2" x 6") is placed between the knees and hands so they are in contact with the board. Have the athlete flex his or her shoulder and extend the same side hip and knee. The leg and hand should only raise enough to clear the floor by about six inches. The elbow, hand, and knee that are lifted should all remain in line with the board and the athlete’s torso should also remain in the same plane as the board. The same shoulder and knee are then flexed enough for the elbow and knee to touch. A score is given for left and right side with the test side being that of the forward flexed arm. | A score of three points is given if the athlete completes the test with the same side arm and leg. Two points is given if the individual performs a diagonal pattern using the opposite shoulder and hip in the same manner as described above. One point is given if the athlete’s balance is lost or the athlete cannot perform the movement. A score of zero is given if pain is noted with the exercise. |