MOHLER, MARA LEE, M.S. The Ability of the FMS to Predict Knee Injury in Female Collegiate Athletes. (2014)
Directed by Dr. Sandra J. Shultz. 94 pp.

Non-contact knee injuries are one of the most common injuries among athletes that participate in sports that require cutting, quick deceleration and jumping actions. Researchers and clinicians have attempted to develop screening tools to identify those at increased risk for knee injury. The primary purpose of this study was to determine the extent to which the Functional Movement Screen (FMS) can predict non-contact knee and lower extremity injuries. The secondary purpose was to identify if certain lower extremity components of the FMS were more predictive of increased risk for these lower extremity injuries than the total score (which includes upper body movement dysfunctions). Female athletes from UNCG's division I basketball, cheer, soccer, softball, tennis, and volleyball teams comprised the sample.

The subjects were scored live and video recorded as they completed the entire FMS, and non-contact knee and lower extremity injury data were collected throughout their seasons. Intra-rater reliability of FMS screening was determined using percent agreement. Receiver operating characteristic (ROC) curves were used to determine if there was a particular score that was best able to distinguish between those who were injured and those who were not. Chi-square analyses determined if lower scores on specific lower extremity components of the FMS or the total FMS score were more likely to be found in injured subjects.

Four subjects sustained non-contact knee injuries and twenty-four subjects sustained other non-contact lower extremity injuries. The mean FMS score for all

subjects (n=72) was 16.33± 1.59. Percent agreement from live to video scoring for the final score was 60%. Percent agreement between day one and day two video scoring was 100%. The primary findings were that neither the final score of the FMS nor the individual subcomponents scores of the FMS were able to distinguish between uninjured and those who sustained non-contact knee or lower extremity injury in the female population studied. However, there was a trend toward more asymmetries in uninjured compared to injured athletes.

Due to the small sample size and a low incidence of knee injury, all non-contact lower extremity injuries were included. Combining all types and severities of injuries together may have confounded the ability of specific components of the FMS to predict injury, as it is expected that different injuries may have different biomechanical faults as risk factors. Future studies should use a longitudinal design where a larger population can be followed over multiple sports seasons so that injury can be stratified by severity and type. Future studies may also benefit by tracking male and female athletes to better understand the gender comparisons in movement patterns and injury rates. Asymmetry should be examined to determine if it represents an injury risk factor versus a normal functional adaptation in certain sports.

THE ABILITY OF THE FMS TO PREDICT KNEE INJURY

IN FEMALE COLLEGIATE ATHLETES

by

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A Thesis Submitted to
the Faculty of The Graduate School at
The University of North Carolina at Greensboro
in Partial Fulfillment
of the Requirements for the Degree
Master of Science

Greensboro
2014

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CHAPTER I

INTRODUCTION

Statement of Problem

Injuries are a common and unavoidable risk when participation in athletics. Currently, there are over 450,000 student-athletes participating in NCAA collegiate athletics (NCAA, Irick, 2012). With many sports requiring cutting, jumping, and decelerating maneuvers, the knee joint is particularly vulnerable to injuries compared to other joints. Data from the NCAA Injury Surveillance System indicate that over 50% of all injuries reported were lower extremity, with knee and ankle injuries making up the majority of those injuries (Hootman, Dick, & Agel, 2007). Non-contact injury mechanisms are those injuries that occur without person-to-person contact (Myklebust et al., 2003). Particularly devastating are non-contact anterior cruciate ligament (ACL) injuries which represent 72% of all ACL injuries (Boden, Dean, Feagin, & Garrett, 2000). Moreover, female athletes who participate in cutting and jumping sports sustain these non-contact ACL injuries at a 4-6 fold greater rate than male athletes who participate in similar sports (E Arendt, Agel, & Dick, 1999; Elizabeth Arendt & Dick, 1995). While less severe, other non-contact knee injuries such as patellofemoral pain syndrome (PFPS), tendonitis, bursitis, iliotibial band (IT band) friction syndrome, and other chronic injuries can also lead to a very long and painful athletic season. Also of concern is that these knee injuries increase the likelihood of developing osteoarthritis later in life, causing long term pain and disability (Alentorn-Geli et al., 2009; Brouwer et al., 2007). Thus, given the common nature of knee injuries in sport, particularly in women, and the potential for more severe knee injuries that lead to long term pain and disability, much effort has been directed toward injury screening and prevention strategies in order to identify and intervene on those who may be at greater risk before the injury occurs.

Researchers and clinicians have attempted to develop screening tools to identify those at increased risk for knee injury. Screening tools have largely focused on identifying risk factors that are modifiable with proper diagnosis and training (Alentorn-Geli et al., 2009; Hewett, Stroupe, Nance, & Noyes, 1996; Kiesel, Plisky, & Butler, 2009; Myklebust et al., 2003; Wojtys, Huston, Taylor, & Bastian, 1996; Zazulak, Hewett, Reeves, Goldberg, & Cholewicki, 2006), and are largely designed to identify aberrant neuromuscular control patterns of the trunk/core and lower extremity that are thought to increase the potential for knee injury (Cichanowski, Schmitt, Johnson, & Niemuth, 2007; Esser, 2011; Leetun, Ireland, Willson, Ballantyne, & Davis, 2004; Okada, Huxel, & Nesser, 2011; Padua, Bell, & Clark, 2012; Peate, Bates, Lunda, Francis, & Bellamy, 2007; Powers, 2010; Shultz & Schmitz, 2010; Tyler, Nicholas, Mullaney, & McHugh, 2006; Zazulak et al., 2006; Zazulak, Hewett, Reeves, Goldberg, & Cholewicki, 2007). But while these screening tests have been found to be reliable and have shown some promising results in predicting future injury (Chorba, Chorba, Bouillon, Overmyer, & Landis, 2010; Cook, Burton, & Hoogenboom, 2006a, 2006b; Esser, 2011; Gribble, Brigle, Pietrosimone, Pfile, & Webster, 2013; McLean et al., 2005; Minick et al., 2010;

Onate et al., 2012; Padua et al., 2009; Schneiders, Davidsson, Hörman, & Sullivan, 2011; Smith, Chimera, Wright, & Warren, 2013; Teyhen et al., 2012), the efficacy of these screening tools in identifying specific lower extremity dysfunctions that are ultimately predictive of injury risk has not yet been firmly established.

One such tool is the Functional Movement Screen (FMS) by Gray Cook which has been designed to identify underlying risk factors through observation of common movement dysfunctions and asymmetries (Chorba et al., 2010; Esser, 2011; Gribble et al., 2013; Minick et al., 2010; Onate et al., 2012; Schneiders et al., 2011; Smith et al., 2013; Teyhen et al., 2012). Common dysfunctions identified using the FMS include decreased core/trunk stability, and decreased hip and ankle stability and mobility (Cook et al., 2006a, 2006b), all of which are thought to be dysfunctions associated with non-contact knee injuries. Specific factors that may contribute to poor movement patterns (thus non-contact knee injury) include weak hip abductors and external rotators (Hollman et al., 2009; Leetun et al., 2004; Powers, 2010), inadequate hip adductor strength and activation (Hewett, Ford, Myer, Wanstrath, & Scheper, 2006; Padua et al., 2012), trunk/core instability (Zazulak et al., 2007) and reduced proprioception (Zazulak et al., 2006), medial gastrocnemius weakness (Bell, Padua, & Clark, 2008), and increased co-activation of the gastrocnemius and tibialis anterior causing ankle stiffness (Padua et al., 2012). The FMS may be able to detect these factors because six of the seven movement screen components are designed to challenge core/trunk stability, hip mobility and stability, and/or ankle mobility and stability. Each test is designed to give the examiner a better understanding of where the dysfunction is coming from (Cook et al., 2006a, 2006b) and the Functional Movement Systems gives suggestions on how to correct the movement dysfunctions related to the individual tests (Functional Movement Systems, 2013).

But while examiners have demonstrated their ability to consistently identify these dysfunctions when scoring the FMS (Chorba et al., 2010; Esser, 2011; Gribble et al., 2013; Minick et al., 2010; Onate et al., 2012; Schneiders et al., 2011; Smith et al., 2013; Teyhen et al., 2012), it is intended to identify the types of movement asymmetries and dysfunctions that have been associated with lower extremity injuries (Cook et al., 2006a, 2006b), and subsequently has been shown to be generally predictive of injury risk (Chorba et al., 2010; Kiesel, Plisky, & Voight, 2007; O'Connor, Deuster, Davis, Pappas, & Knapik, 2011). However, the FMS has yet to be validated for its ability to identify movement dysfunctions that are predictive of non-contact knee injuries.

Purpose

1. The primary purpose of this study was to determine the extent to which the FMS could predict non-contact knee and lower extremity injuries in NCAA division I female athletes who participate in basketball, cheer, soccer, softball, tennis, and volleyball.
2. The secondary purpose was to identify if certain components of the FMS could be used to predict increased risk of injury to the knee and lower extremity in the population being studied.

Hypothesis

1. Those athletes who displayed any asymmetries or scored below the cut-off score determined by the ROC curve on the total FMS would be more likely to experience a non-contact knee and/or lower extremity injury during their respective season(s).
2. One or more components of the FMS that challenge the mobility and stability of the core, hips, knees, and ankles (i.e. Deep squat, in-line lunge, hurdle step, active straight leg raise, trunk stability push-up, and rotary stability) would be a stronger predictor of non-contact knee and/or lower extremity injury than the overall score.

Limitations and Assumptions

1. Results from this thesis cannot be generalized to populations other than the collegiate females athletes aged 18 to 22 studied, or to sports other than basketball, cheer, soccer, softball, tennis, and volleyball.
2. The researcher was not FMS certified, but used the FMS during day to day job tasks and demonstrated reliability in scoring the FMS.
3. All participants gave their best efforts during the FMS.
4. The FMS is a valid tool for identifying those at risk for lower extremity injury.
5. FMS measures taken during a single testing session was representative of the participants’ function throughout the season.
6. Data was collected using athletes from one school.

Delimitations

1. A single researcher conducted all of the FMS testing based on guidelines put forth by Gray Cook and the other co-developers of the FMS.
2. Only healthy female athletes from UNCG's women's basketball, cheer, soccer, softball, tennis, and volleyball teams who had no musculoskeletal injury to the lower extremities within 30 days of testing or had no recent surgery that restricted them from full participation in preseason training participated in this study.
3. Injury data only included non-contact musculoskeletal injuries sustained to the knee and lower extremity.
4. All athletes wore shorts and no shoes during the testing session, and were videotaped from the sagittal and frontal views to aid the researcher in accurate scoring.
5. The FMS was examined by a single researcher who was trained in the scoring of the FMS by a Certified FMS expert, and demonstrated inter-rater reliability.

Operational Definitions

Athlete: A female who was an active roster member of UNCG's female basketball, cheer, soccer, softball, tennis, or volleyball teams.

Knee Injury: Any non-contact musculoskeletal injury to the knee joint or surrounding tissues, which was an acute or chronic condition, that required a minimum of five rehabilitation sessions with the respective team's certified athletic trainer and/or required modified activity during at least one practice or strength and conditioning session.

Lower Extremity Injury: Any non-contact musculoskeletal injury to the lower extremity (hips and below), which was an acute or chronic condition, that required a minimum of five rehabilitation sessions with the respective team's certified athletic trainer and/or required modified activity during at least one practice or strength and conditioning session.

Asymmetry: A notable difference in a movement pattern when comparing the right side of the body to the left when scoring the FMS.

Acute: The sudden appearance of symptoms due to a single traumatic event during sports participation. Stages: acute (0-4 days), subacute (5-14 days), and postacute (after 14 days).

Chronic: Also referred to as overuse injuries, are those injuries with a more gradual onset that are caused by repetitive light trauma sustained over multiple days of practice or games. Chronic pain can last anywhere from 1-12 months. Common chronic injuries include tendonitis, bursitis, stress reactions and stress fractures.

Core/Trunk stability: The hip's ability to control the trunk in response to forces generated from distal body segments and from unexpected perturbations.

Functional Movement Screen (FMS): A ranking and grading system made up of seven functional tests that documents movement patterns that are considered ideal for normal function. By screening these patterns, the FMS is intended to identify functional limitations and asymmetries.

Preparticipation Physical Examination (PPE): A series of tests and health screens intended to identify clinically relevant, pre-existing abnormities to determine medical eligibility for student-athletes before competing in collegiate athletics. PPEs are intended to detect any cardiovascular or musculoskeletal condition that may increase the risk or injury or death.

CHAPTER II

LITERATURE REVIEW

Introduction

Knee injuries are common and can lead to considerable time lost from sport. In a study by Majewski et al. (2006) that tracked nearly 20,000 sports injuries in a 10 year period, 39.8% were related to the knee joint. Knee joint injuries are particularly prevalent in highly competitive female athletes where cutting, jumping, and decelerating quickly is part of their daily sport requirements (Arendt & Dick, 1995; Besier, Lloyd, Cochrane, & Ackland, 2001; Hewett et al., 2005; Tyler et al., 2006; Waryasz & McDermott, 2008). The anterior cruciate ligament (ACL) is one of the more common internal structures of the knee that are damaged during these types of sporting events, resulting in approximately 38,000 ACL injuries in girls and women annually in the U.S. and at a cost of $17,000 per injury (Hewett, Lindenfeld, Riccobene, & Noyes, 1999).

NCAA surveillance system data on injuries in women's volleyball players found that 14% of game injuries occurred to the knee joint. Of this number, 37.7% were meniscus tears, which was the most frequently injured structure in the knee joint (Agel, Palmieri-smith, Dick, Wojtys, & Marshall, 2007). In an injury surveillance study done on professional women's soccer players, the most commonly injury joint was the knee during a one season period. Of the 55 injuries sustained at the knee, 15 were strains, nine were ACL injury, seven were sprains not involving the ACL, seven were inflammation (chronic), and five were meniscal tears (Giza, Mithöfer, Farrell, Zarins, & Gill, 2005).

Another concern for athletes who sustain a knee injury is the associated financial and emotion burden of these injuries (Griffin et al., 2006; Hewett, Myer, & Ford, 2006) and the potential for developing osteoarthritis later in life (Alentorn-Geli et al., 2009; Brouwer et al., 2007). It is therefore imperative that sports medicine clinicians understand the risk factors that lead to non-contact knee injuries and apply valid screening tools to identify those at risk and implement appropriate prevention programs in attempt to decrease the risk of injury. As a result, much research has been devoted to the development of screening tools that can reliably identify movement dysfunctions that are predictive of knee injury risk. To that end, the following section focused on specific movement dysfunctions thought to be related to non-contact knee injury that are modifiable with proper training, and those proposed risk factors thought to cause these movement dysfunctions.

Proposed Risk Factors of Non-contact Knee Injuries

There are many underlying risk factors that may lead to non-contact knee injury. In a systematic review by Waryasz et al. (2008), all of the following were noted as possible risk factors of non-contact knee injury: gastrocnemius tightness (Piva, Goodnite, & Childs, 2005; Witvrouw, Lysens, Bellemans, Cambier, & Vanderstraeten, 2000), ligamentous and overall joint laxity (Witvrouw et al., 2000), foot abnormalities such as excessive pronation (Duffey, Martin, Cannon, Craven, & Messier, 2000; Lun, Meeuwisse, Stergiou, & Stefanyshyn, 2004; Macgregor, Gerlach, Mellor, & Hodges, 2005; Sacco et al., 2006), hamstring tightness (Piva et al., 2005; Smith, Stroud, & McQueen, 1991), hip muscle weakness (Cichanowski et al., 2007; Nicholas, Strizak, & Veras, 1964; Piva et al., 2005; Powers, 2003), quadriceps tightness (Post, 2005; Witvrouw et al., 2000), iliotibial band (IT band) tightness, quadriceps muscle imbalance such as vastus medialis weakness and vastus lateralus overpowering causing lateral displacement of the patella (Amis, 2007; Bennett & Stauber, 1986; Callaghan, 2004; McConnell, 2007), patellar tilting (Amis, 2007; Fredericson & Yoon, 2006; Haim, Yaniv, Dekel, & Amir, 2006), and neuromuscular firing patterns in the quadriceps and hamstring musculature (Cowan, Bennell, Hodges, Crossley, & McConnell, 2001; Cowan, Hodges, Bennell, & Crossley, 2002; Witvrouw et al., 2000).

While intrinsic risk factors are often considered non-modifiable due to structural/anatomical reasons, other risk factors such as flexibility, strength, neuromuscular firing patterns, and proprioception are thought to be modifiable with proper intervention programs (Alentorn-Geli et al., 2009; Cowen, 2010; Hewett et al., 1996; Kiesel et al., 2009; Myklebust et al., 2003; Wojtys et al., 1996). Hip and quadriceps weakness has also been implicated in patella femoral pain syndrome (PFPS) (Bolgla, 2011). Despite the myriad of risk factors noted above (many of which focus on muscle weakness, tightness or imbalance), screening and prevention research largely focuses on the movement patterns that result from these defects in an effort to reduce injury risk

(Hewett et al., 1996; Leetun et al., 2004; Myer, Ford, & Hewett, 2005; Padua et al., 2012; Tyler et al., 2006; Zazulak et al., 2006; Zazulak et al., 2007). Thus, while it is acknowledged that both non-modifiable and modifiable risk factors may contribute to movement dysfunctions that are thought to be associated with knee injury risk (Butler, Plisky, Southers, Scoma, & Kiesel, 2010; Cook et al., 2006a, 2006b; Peate et al., 2007), identifying the gross movement patterns that result from these risk factors (also considered to be modifiable) were the primary focus of this review.

Movement Dysfunctions Thought to be Associated with Non-contact Knee Injury

Movement dysfunctions in the sagittal, frontal and transverse plane have all been associated with an increased risk of knee injury, and in particularly ACL injury and PFPS (Bell et al., 2008; Hewett, Ford, et al., 2006; Hollman et al., 2009; Leetun et al., 2004; Padua et al., 2012; Powers, 2010; Tyler et al., 2006; Zazulak et al., 2006; Zazulak et al., 2007). Research suggests that high knee valgus angles and knee abduction moment (KAM) during landing are strong predictors of ACL and other knee injuries (Brouwer et al., 2007; Elias, Cech, Weinstein, & Cosgrea, n.d.; Hewett et al., 2005; Hull, Berns, Varma, & Patterson, 1996; Mizuno et al., 2001; Senter & Hame, 2006). Knee valgus motion has been linked to injuries including: ACL rupture (Hewett et al., 2005), patellofemoral pain (Elias et al., 2004; Mizuno et al., 2001), knee osteoarthritis (Brouwer et al., 2007), medial collateral ligament (MCL) strain (Hull et al., 1996), and knee cartilage and meniscus damage (Senter & Hame, 2006). Researchers have found that female subjects, when compared to males, had significantly increased knee valgus angles

(Malinzak, Colby, Kirkendall, Yu, & Garrett, 2001). These findings are consistent with previous research that found the load on the ACL could be up to six times greater when the knee is in 5° of valgus compared to when it is aligned in the frontal plane (Bendjaballah, Shirazi-Adl, & Zukor, 1997). Studies examining medial knee displacement (MKD), a two-dimensional planar measure intended to represent knee valgus motion, suggest that valgus knee motion may result from instability at the hips and trunk (Bendjaballah, Shirazi-Adl, & Zukor, 1997; Hewett, Zazulak, Myer, & Ford, 2005; Hewett et al., 2005; Markolf et al., 1995; Zazulak et al., 2005, 2007) and decreased mobility at the ankle joint (Padua et al., 2012; Sigward & Powers, 2006). It has been suggested that high KAM may arise from a transfer of altered hip kinematics during landing, and an increase in hip adduction angles (Myer, Ford, Khoury, Succop, & Hewett, 2012). Malalignment in the lower extremity has also been linked to a decrease in activation of the trunk and hip musculature (Hewett et al., 2005), specifically lower gluteal EMG activity during landing (Zazulak et al., 2005). Collectively these data suggest that malalignments in the frontal plane may contribute to dynamic movement dysfunctions that lead to injuries in sports in which these movements occur most often.

From the sagittal view, landing with a more extended hip and knee with high quadriceps activation has been suggested to increase the potential for anterior tibial shear forces (known to strain the ACL) (Shultz & Schmitz, 2009) and the risk of knee injury (Li et al., 1999). Increased activation of the quadriceps relative to timing of the antagonist hamstring musculature has been suggested to increase anterior shear force at low knee flexion angles that tend to occur during landing and pivoting maneuvers (Hewett et al., 2005). Malinzak et al. (2001) found that females' knee flexion angles were significantly smaller while performing two cutting tasks, which included running 8 meters and cutting 45° with the dominate leg to the left and 45° with the dominate leg to the right. These researchers also concluded that female athletes have increased quadriceps muscle activation and decreased hamstring muscle activation, which may cause increased anterior shear forces at the knee, placing females at greater risk of non-contact knee injury.

In the transverse plane, a combination of hip internal rotation, knee abduction and tibial external rotation is thought to contribute to valgus collapse of the knee (Krosshaug et al., 2007). Other studies, however, have shown that tibial internal rotation may be a greater risk to knee injury (Markolf et al., 1995) and that external tibial rotation may occur after ligament failure (Meyer & Haut, 2008). In cadaveric studies, researchers have found that a combination of internal tibial rotation and anterior tibial shear applied to an extended knee joint, produce the greatest force on the ACL (Markolf et al., 1995). Some of the challenges with this research are the ability to accurately assessing rotational variables at the time of injury, due to errors in the gross kinematic estimates caused by external loads, muscle loads, and internal knee ligament force (Krosshaug et al., 2007). Still, these data suggest that excessive tibial rotation (whether internal or external) may increase the potential for ligament strain and injury.

Screening and Evaluation Tools

There have been many attempts at creating a screening tool to detect these proposed high risk movement patterns. However, no one screening tool to date has been able to detect the risk factors that are directly related to knee injury in sporting activities (Boling et al., 2009; Chappell, Yu, Kirkendall, & Garrett, 2002; Ford, Myer, & Hewett, 2003; Mclean, Lipfert, & Van Den Bogert, 2004; Padua et al., 2009, 2011). Clinicians are in need of a screening tool that is reliable, valid, and practical to use in their sports medicine setting so that it may be used to identify those at risk so that appropriate intervention programs can be established for those at increased risk of injury.

Two and Three Dimensional Motion Capture

It is well accepted that three dimensional (3D) motion capture is an accurate and reliable measurement for assessing lower limb joint motion of dynamic sports movements (Chappell et al., 2002; Ford et al., 2003; Malinzak et al., 2001; Mclean et al., 2004). However, due to the financial, spatial, and time restrictions, it is considered impractical in the clinical setting to assess joint motion and dynamic movement patterns that may increase an individual’s risk of injury (Myklebust et al., 2003). Two dimensional (2D) video recording, on the other hand, is considered relatively inexpensive and has been demonstrated as a successful method of screening people at risk of non-contact ACL injury by detecting a large valgus motion at the knee (McLean et al., 2005). The downfall to 2D screening is that it is time consuming when attempting to analyze the videos for joint centers in order to get an accurate measurement of joint angles (McLean et al., 2005). While 2D and 3D motion capture and videos may be accurate and reliable, they are impractical in the clinical sports setting if one wishes to screen a large number of patients in a limited period of time (e.g. as part of the pre-participation physical examination).

Landing Error Scoring System

The Landing Error Scoring System (LESS) is a screening tool used to identify potentially high-risk movement patterns associated with non-contact ACL risk and PFPS, and requires participants to jump off a 30cm box with both feet, land on both feet, and immediately complete a vertical jump (Boling et al., 2009; Padua et al., 2009). This screening tool uses a dynamic task that is a common mechanism of ACL injury and is a potential mechanism for chronic injuries such as PFPS and requires the use of two camcorders so that video analysis may be completed from the frontal and sagittal views. While the reliability of this screening tool has been reported (Padua et al., 2009), the need for two camcorders is somewhat a disadvantage for clinicians given the cost and time associated with the off line analysis of the data. To address this concern, Padua et al. (2011) developed a modified version of the LESS to be utilized in real time (LESS-RT). The researchers found that the LESS-RT demonstrated good inter-rater reliability and when compared to the original LESS, it appeared to detect similar risks of knee injury (Padua et al., 2011). However, it's ability to detect those at increased risk for injury is limited (Padua et al., 2011). Specifically, a more recent prospective study was unable to predict non-contact ACL injuries in high school and college athletes using the LESS (Smith et al., 2012).

Functional Movement Screen

The Functional Movement Screen (FMS) is another screening tool that is commonly used by sports medicine clinicians to identify movement dysfunctions that can predispose active or athletic populations to injury (Cook et al., 2006b), and requires little time and equipment. But while the FMS is currently being used by a number of clinicians to develop intervention programs to help correct any imbalances or deficiencies in the musculoskeletal system, its validity in detecting movement dysfunctions that are predictive of non-contact knee injury has not been well established.

The FMS is comprised of seven movement tests and three clearing exams designed to identify compensatory movement patterns throughout the kinetic chain. These poor movement patterns can be identified by observing left and right side imbalances and weaknesses in mobility and stability (Cook et al., 2006a, 2006b). Each individual test of the FMS is used to identify specific movement dysfunctions or asymmetries in specific areas of the musculoskeletal system. When put together, the FMS is intended as a holistic way to look at the fundamental movement patterns that correspond to an everyday active lifestyle. To better understand what each test of the FMS is capable of detecting, the following section provides a brief description of the purpose and clinical implications for the seven movement screens. A full description on how to perform each test and scoring is included in the methods section.

Deep Squat (DS)

The deep squat assesses bilateral, symmetrical and functional mobility of the hips, knees and ankles in the lower extremity and the shoulders and thoracic spine in the upper extremity (Cook et al., 2006a). The ability to assume a deep squat requires ankle dorsiflexion, knee and hip flexion, thoracic spine extension, and flexion and abduction of the shoulders (Cook et al., 2006a). This means that performance on this test can be affected by a number of factors. Specific to the lower extremity, limited mobility could stem from a decrease in dorsiflexion of the ankles or decreased flexion at the hip joints (Cook et al., 2006a). Dynamic stability of the lower extremity may also be compromised by poor neuromuscular control of the body's trunk/core musculature, which may result in an increased abduction torque at the knee causing increased strain and possible injury to the knee ligaments (Bendjaballah et al., 1997; Hewett et al., 2005; Markolf et al., 1995; Zazulak et al., 2005). Research has shown that an increase in gastrocnemius and tibialis anterior activation causes stiffness in the ankle joint during a double leg squatting task, and thus leads to decreased dorsiflexion (Padua et al., 2012). These researchers theorized that the increase in ankle joint stiffness may limit ankle dorsiflexion, and lead to increased foot pronation, tibial internal rotation, and MKD as a compensatory response during a squatting task (Padua et al., 2012). This was based on the work by Bell et al. (2008) who reported a 20% decrease in ankle dorsiflexion range of motion during a double leg squatting task in a group with medial knee displacement when compared to the control group, which supports the theory that restricted ankle dorsiflexion influences dynamic knee-valgus alignment. Other work also found that individuals with less dorsiflexion range of motion had a greater incidence of medial knee displacement (Sigward & Powers, 2006). Joint stiffness in the ankle causing foot pronation and tibial internal rotation may place individuals at a greater degree of medial knee displacement (Padua et al., 2012), however, more research needs to be done to determine if ankle stiffness is present during high risk tasks such cutting and jumping that may cause injury to the knee joint.

Hurdle Step (HS)

The purpose of the hurdle step is to test the body's proper stride mechanics of a stepping motion, while maintaining the opposite leg's single leg stance stability and overall balance (Cook et al., 2006a). This test assesses the bilateral mobility and stability function of the hips, knees, and ankles (Cook et al., 2006a). The HS requires open-kinetic chain dorsiflexion at the ankle, as well as flexion at the knee and hip joints of the step leg (Cook et al., 2006a). A poor score on the HS could be related to poor stability while maintaining hip extension with the stance leg and/or poor mobility while performing maximal hip flexion with the step leg (Cook et al., 2006a). Poor scores on the HS may also be contributed to minor limitations in ankle dorsiflexion and hip flexion of the step leg, or major limitations related to asymmetric hip immobility caused by an anterior pelvic tilt or poor trunk/core stability (Cook et al., 2006a). The HS may be able to reveal imbalances in hip and trunk/core stability if a loss of balance is noted during testing.

Trunk stability is related to the hip's ability to control the trunk in response to forces generated from distal body segments and from unexpected perturbations

(Bohdanna T Zazulak et al., 2007). In a study by Zazulak et al. (2007), researchers found that factors relating to core stability were predictive of knee, ligament, and ACL injury risk. This suggests that a decrease in neuromuscular control of the trunk influences dynamic stability at the knee joint (Bendjaballah et al., 1997; Hewett et al., 2005; Markolf et al., 1995; Zazulak et al., 2007). In support of this premise, Hewett et al. (2009) analyzed videos of trunk and knee motion during non-contact ACL injuries and found that the injured females demonstrated greater lateral trunk and greater knee abduction motion at landing when compared to male subjects and female controls. The potential consequences of these movement dysfunctions is a greater overall knee abduction motion and medial knee displacement resulting in an increased risk of non-contact knee injury (Bendjaballah et al., 1997; Hewett, Torg, & Boden, 2009; Hewett et al., 2005; Markolf et al., 1995; Padua et al., 2012).

In-line Lunge (ILL)

The purpose of the ILL is to assess the body's trunk and extremities ability to resist rotation, while maintaining proper alignment. This challenges the hip and ankle mobility and stability, along with quadriceps flexibility and knee stability (Cook et al., 2006a). Poor performance during the ILL may be due to inadequate hip mobility in either leg, knee and ankle stability in the stance leg, and/or an imbalance between adductor weakness and abductor tightness in either the stance or step leg's hip that could result in hip and knee rotations (Cook et al., 2006a). Minor limitations have been shown to exist with the mobility of one or both hips and serious limitations may be attributed to asymmetry between stability and mobility of one or both hips (Cook et al., 2006a). The inability to resist hip and trunk rotation and maintain proper alignment is thought to increase the amount of hip adduction and internal rotation of the femur that results in a valgus alignment and external rotation at the knee (Bell et al., 2008; Padua et al., 2012; Powers, 2010; Tyler et al., 2006). Trunk/core stability may also be attributed to the ILL if balance issues are noted during this test. Decreased neuromuscular control of the trunk influences dynamic stability at the knee joint (Bendjaballah et al., 1997; Hewett et al., 2005; Markolf et al., 1995; Zazulak et al., 2007), which may be predictive of severe acute knee injury risk (Hewett et al., 2005; Zazulak et al., 2007).

Shoulder Mobility (SM)

This screen combines internal rotation with adduction in one shoulder and external rotation with abduction in the other. Normal scapular mobility and thoracic spine extension are also required to perform this screen properly (Cook et al., 2006b). Poor scores during the SM test may be attributed to muscle imbalances or tightness in the anterior and/or posterior shoulder complex, scapulothoracic dysfunction causing decrease glenohumeral mobility and poor scapulothoracic mobility or stability (Cook et al., 2006b). This test is directly related to shoulder issues and has no implications for lower extremity injuries. As such, poor scores on this test (and its contribution to overall scores) may not be relevant when predicting knee injury specifically.

Clearing Exam: Shoulder Impingement

At the end of the SM test, a clearing exam should be performed to rule out a pain response that could be caused by shoulder impingement (Cook et al., 2006b). If pain exists in the clearing exam, a thorough shoulder evaluation should be completed by a certified sports medicine specialist.

Active Straight Leg Raise (ASLR)

This screening tool assesses the active flexibility of the hamstring and gastroc-soleus complex of the leg being tested (Cook et al., 2006b). Poor performance on this test, like the HS, may be attributed to relative hip mobility; however, the ASLR is focused more on hamstring and/or iliopsoas tightness (Cook et al., 2006b). There are discrepancies in the literature on whether or not increased hamstring tightness is related to PFPS. Piva et al. (2005) found a significant correlation between decreased hamstring flexibility and those subjects with PFPS using a straight leg raise test comparable to the ASLR. Using similar measures to test hamstring flexibility, researchers found no significant difference in hamstring flexibility in subjects who developed PFPS compared to those who did not (Witvrouw, Bellemans, & Lysens, 2001). In a two year prospective study by Witvrouw et al. (2001), researchers found a significant relationship between decreased hamstring and quadriceps flexibility and the development of patellar tendonitis when compared to healthy controls. Hamstring tightness has been theorized to cause a slight knee flexion during dynamic activities (Piva et al., 2005), which could potentially increase a person's risk of sustaining a non-contact knee injury (Krosshaug et al., 2007; Malinzak et al., 2001).

Trunk Stability Push-Up (TSPU)

This particular screen tests the ability of the trunk/core muscles to stabilize the spine in the sagittal plane, while the upper-extremity performs a closed-chain task. Poor performance on the TSPU can be simply related to lack of stability in the trunk/core (Cook et al., 2006b). Core stability is considered critical to lower extremity function because a decrease in core neuromuscular control may contribute to an increased valgus position at the knee, which may predispose an individual to an increased risk of knee (Hewett, Ford, et al., 2006; Zazulak et al., 2005, 2007). Specifically, insufficiency in neuromuscular control of the trunk during cutting and landing may cause uncontrolled lateral trunk motion predisposing the knee to abduction motions that lead to injury (Hewett et al., 2009; Hewett et al., 2005). While this task does not require cutting or landing, it is still plausible that if a lack of stability in the trunk/core is present during this test, it may be reasonable to relate poor scores to an increased risk of knee injury.

Clearing Exam: Spinal Extension

Following the TSPU, a clearing exam must be performed to rule out a pain response that might not be observed during the TSPU (Cook et al., 2006b).

Rotary Stability (RS)

The purpose of this test is to challenge the stability of the trunk/core while requiring proper neuromuscular coordination and energy transfer through the motions in the upper and lower extremity (Cook et al., 2006b). The motions performed during this test require trunk/core stability in the sagittal and transverse planes. Poor performance may be related to poor asymmetric stability of the trunk/core muscles (Cook et al., 2006b). As previously noted, a lack of core/trunk stability is thought to increase risk of lower extremity injury by causing a valgus position in the lower extremity (Hewett, Ford, et al., 2006; Zazulak et al., 2005, 2007). Impaired trunk proprioception and deficits in trunk control may be revealed by this test, which may be a predictor of knee injury, specifically in female athletes (Zazulak et al., 2006). This test may be a good predictor of knee injury because it necessitates stability of the trunk/core while performing a dynamic task with both the upper and lower extremities. Therefore, if the trunk/core is unable to stabilize throughout the movement of this test, it is possible that it may be unable to stabilize during complex athletic tasks.

Clearing Exam: Spinal Flexion

A spinal flexion clearing exam must be performed after the rotary stability test to rule out back pain that might go unnoticed during the movement screen (Cook et al., 2006b).

Reliability and Validity of the FMS

As the FMS gains popularity in the clinical world, establishing the reliability and validity of this testing system is critical if it is to be used for evidence based practice. Reliability of the FMS has been established for both interrater and intra-rater in multiple studies over the past few years (Chorba et al., 2010; Esser, 2011; Gribble et al., 2013; Minick et al., 2010; Onate et al., 2012; Schneiders et al., 2011; Smith et al., 2013; Teyhen et al., 2012). However, validity of the FMS in predicting injury risk is still under investigation.

Limited studies have reported promising results in identifying cutoff scores and asymmetries that are thought to be associated with an increased risk of injury (Kiesel et al., 2007; O'Connor et al., 2011). Additionally, in a study by Chorba et al. (2010), the researchers studied the ability of the FMS to predict injury in female collegiate athletes who participated in high risk sports. The results of the Chorba et al. (2010) study indicated greater lower extremity injury risk in those female athletes who scored below the cutoff score of 14 based off of the study by Kiesel et al. (2007). This is a particularly important finding for the current study because Chorba et al. (2010) found that when the shoulder mobility test was taken out of the analysis, the six other tests were highly predictive of lower extremity injury, meaning that tests specific to lower extremity function may be more sensitive in predicting lower extremity injury. This suggests a promising future in the early detection of female collegiate athletes that are at increased risk of lower extremity injury based on the use of the FMS on the particular population studied (Chorba et al., 2010). If the current study can determine that a subset of FMS tests are better predictors than others, it may be possible that clinicians can use a modified and more streamline version of the FMS, especially for lower extremity dominate sports, to determine those athletes at risk during PPEs. This is important because it could give clinicians a more efficient way to screen athletes, which would decrease screening time and could give a more direct approach to corrective exercise programs for those athletes who are thought to be at an increased risk of injury.

Research has also shown that FMS scores can be improved with a proper intervention program (Cowen, 2010; Kiesel et al., 2009). Kiesel et al. (2009) examined 62 subjects prior to an intervention, where only 7 scored above 14 on the entire FMS. After the intervention, which consisted of a 7-week program including a stretching component and self-administered trigger point release treatment, and a corrective exercise component, 39 of the 62 subjects scored above 14. Additionally, they reported that the number of subjects free of asymmetries increased from 31 before the intervention, to 42 after the intervention (Kiesel et al., 2009). The Kiesel et al. (2009) study did not, however, determine if injury risk decreased after the subjects' scores were improved above the 14 point cutoff or once asymmetries were resolved. Further research is necessary to determine if improvement in FMS scores following an intervention program actually reduces injury risk. Trunk and hip stability has been shown to play an important role in decreasing injury risk in firefighters (Peate et al., 2007). However, more research needs to be completed in the collegiate athletics population to determine if intervention programs using core stability exercises are able to decrease lower extremity, specifically knee, injury risk, or if assessment of core stability can reliably identify those at increased risk for injury. Thus, one would expect that evidence of a loss of balance or core/trunk stability during a movement screen test, such as the deep squat, hurdle step, in-line lunge, trunk stability push-up, and rotary stability tests of the FMS, may be good predictors of lower extremity injury risk.

Conclusion

Athletic related injuries can be a burden psychologically and financially. Knee joint injures, in particular, are prevalent in athletic populations and represented as many as 40% of all injuries (Majewski, Susanne, & Klaus, 2006). Over 50% of all injuries reported in the NCAA Injury Surveillance System were sustained to the lower extremity, with knee and ankle injuries making up the majority of those injuries (Hootman et al., 2007). Knee injury risk in athletics, therefore, is a problem worth studying. Researchers have discovered that female athletes who participate in cutting and jumping sports are at greater risk for sustaining non-contact knee injuries, when compared to males who participate in similar sports (Arendt, Agel, & Dick, 1999; Arendt & Dick, 1995; Besier et al., 2001; Boling et al., 2009; Hewett, Myer, et al., 2006). Research has also identified potential risk factors for non-contact knee injuries, with recent focus on poor movement patterns that may be modifiable with proper intervention programs (Bendjaballah et al., 1997; Hewett et al., 2005; Hewett et al., 2005; Macrum, Bell, Boling, Lewek, & Padua, 2012; Markolf et al., 1995; McConnell, 2007; Padua et al., 2012; Sigward & Powers, 2006; Zazulak et al., 2005, 2007). While screening tools have been developed over the years in attempt to identify poor movement patterns that increase injury risk in active populations (Cook et al., 2006a, 2006b; McLean et al., 2005; Padua et al., 2009), a valid and reliable tool has yet to be established. The Functional Movement Screen (FMS), is one screening tool used to detect poor movement patterns in active populations (Cook et al., 2006b), such as dynamic knee valgus and high knee abduction moment resulting from poor core/trunk stability, weakness in the hip adductors and external rotators, stiffness in the gastroc-soleus complex and tightness in the hamstring muscles (Alentorn-Geli et al., 2009; Bell et al., 2008; Hollman et al., 2009; Padua et al., 2012; Piva et al., 2005; Powers, 2010; Tyler et al., 2006; Willson, Mspt, & Pain, 2003). Because these same dysfunctions are thought to be associated with higher risk movement patterns that may place female athletes at greater risk for knee trauma (Bell et al., 2008; Boling et al., 2009; Hewett et al., 2005; Hewett, Ford, et al., 2006; Hewett, Myer, et al., 2006; Padua et al., 2012; Powers, 2010; Zazulak et al., 2006; Zazulak et al., 2007), the FMS may prove useful in identifying females at higher risk for knee injury. Other potential strengths of the FMS are that it is relatively low in cost, and can be efficiently completed in real time by a clinician. However, research has yet to examine whether the movement dysfunctions identified by the FMS are truly predictive of non-contact knee injuries. This information is critical if this is to be an evidence based tool used to identify those at risk and prescribe intervention programs accordingly. Based on the previous research of non-contact knee injury risk, particularly in female athletes (Arendt & Dick, 1995; Hewett, Myer, et al., 2006; Hewett et al., 2005; Krosshaug et al., 2007; Myklebust et al., 2003), and the ability of the FMS to reliably predict poor movement patterns and asymmetries (Chorba et al., 2010; Gribble et al., 2013; Minick et al., 2010; Onate et al., 2012; Schneiders et al., 2011;

Smith et al., 2013; Teyhen et al., 2012), it is plausible that we can use this screening system for the purposes of identifying those at risk for non-contact knee injury.

CHAPTER III

METHODS

Participants

Female student-athletes (n=99) that play basketball, cheer, soccer, softball, tennis and volleyball at one NCAA Division I institution were asked to volunteer for this study. The data collection took place prior to the start of their respective Fall seasons, and injury data was documented until the end of each team's season. Female student-athletes from these seven specific sports were chosen because of their increased risk of sustaining non-contact knee injuries (Arendt & Dick, 1995; Besier et al., 2001; Hewett, Myer, et al., 2006; Tyler et al., 2006; Waryasz & McDermott, 2008). Student-athletes were recruited via email and through team meetings with permission from the head coach and team Certified Athletic Trainer. Data collection included their age, height, weight, sport, position, previous injury history, injury history during the course of the season, and the performance of all seven tests of the Functional Movement Screen. Participants were excluded if they sustained a musculoskeletal injury within 30 days of testing that held them from full participation in pre-season events, or if they had a recent surgery that was restricting them from full participation. Of the 99 student-athletes, 72 agreed to participate in this study, 16 were excluded due to injury, and11 chose not to participate for other reasons. Approval from the UNCG Institutional Review Board and a signed consent form by the participants were required prior to data collection.

Materials

The Functional Movement Screen Test Kit (Functional Movement Systems, Inc., Chatham, VA) by Cook et al. (2006) was used to conduct the seven tests of the FMS. A Sony digital video camcorder and a Flip camera were used for video recording and subsequent scoring and data reduction to establish intra-rater reliability. Video cameras were set up at a distance of 5 meters away and at an 80 centimeter lens height in the sagittal and frontal planes in relation to the subject during testing. Videos were stored on a password protected external hard drive owned by the tester. Scores for each individual athlete were placed in a password protected Microsoft Excel spread sheet, identified only by code number.

Injuries were tracked and recorded by each team's Certified Athletic Trainer (ATC) and placed in the Athletic Trainer System (ATS) by Keffer Development Services, LLC (Grove City, PA). ATS is a FERPA certified system for keeping secure medical records. Each ATC has an individual username and password to access the system.

Procedures

Before data collection began, participants were asked to review and sign an informed consent (**Appendix A)**, and were asked to fill out a health and injury history questionnaire (**Appendix B)**. The health and injury history questionnaire was examined by the tester to ensure completeness and that the participants met the inclusion criteria for the study.

All injury communication with the participants was through their respective certified athletic trainers if they sustained a qualifying knee or lower extremity injury during each team's respective season(s). Injury was defined as any non-contact knee or lower extremity injury that was an acute or chronic condition that required a minimum of five rehabilitation sessions with the respective team's certified athletic trainer and/or required modified activity during at least one practice or strength and conditioning session. Acute was defined as the sudden appearance of symptoms due to a single traumatic event during sports participation, with stages classified as acute (0-4 days), subacute (5-14 days), and postacute (after 14 days) (Knight, Draper, 2008). Chronic, also referred to as overuse injuries, was defined as those injuries with a more gradual onset that are caused by repetitive light trauma sustained over a long duration (Knight, Draper, 2008). Injuries to the following structures were considered under the category of a knee injury: bone (proximal tibia and fibula, distal femur, and patella), ligament (anterior cruciate, medial collateral, lateral collateral, and posterior cruciate), muscles and tendons that cross or attach to bones that make up the knee joint, and other soft tissue injuries involved in the knee (menisci, bursa, plica, etc.). The final injury list was placed in a password protected Microsoft Excel spreadsheet for later analysis.

Each participant was tested individually using the FMS as part of their pre-season physical examination and prior to their first official competition. Testing was conducted in the Health and Human Performance building on UNCG's campus. The participants were asked to wear athletic clothes to the testing session. The procedures for the FMS followed the guidelines put forth by Cook et al. (2006) described at the conclusion of this section. FMS training of the tester was completed with an FMS certified UNCG Strength and Conditioning staff member. The FMS training included scoring of 10 pilot participants to demonstrate inter-rater reliability of tester with trainer. The tester and FMS certified trainer scored the 10 subjects, blinded to each other's scores while testing, and compared scores to insure good agreement (90%) before proceeding with the study.

Each participant was allowed three attempts at each test, and the best out of three was recorded. Scoring for each test was from zero to three, three being the best possible score. If the participant had pain with any of the movements or clearing exams, they received a zero for that test. An asymmetry was noted if the participant scored differently from side to side on the same test. For example, a participant may score a three on the right side and a two on the left side for the hurdle step test. If asymmetries were noted during testing, the lower of the two scores were recorded. Additionally, the number of asymmetries (maximum 3) was tallied for later analysis. The order of tests were as follows: 1) Deep squat; 2) Hurdle step; 3) In-line lunge; 4) Shoulder mobility; 5) Active straight leg raise; 6) Trunk stability push up; 7) Rotary stability. The PI videotaped and examined each participant performing the tests from the sagittal and frontal views. The participants were filmed from the beginning to the end of the entire FMS. Each screening took less than 15 minutes to complete all seven tests. Video scoring was used for the data analysis in which injury results were compared to the FMS scores. Twenty random subjects were chosen to be scored via video recording, which were scored on two separate occasions (spaced at least 2 weeks apart) to establish the examiners intra-rater consistency. All subjects were scored once during the live screening, and again using the video recordings.

Description of the FMS Tests

Deep Squat: The starting position for the deep squat was as follows: feet placed shoulder width apart in the sagittal plane; the dowel was placed on the crown of the head with the hands placed so that the elbows were at a 90° angle, extending the arms once the hands were place. The individual was then asked to slowly lower into a squat position with heels on the floor, head and chest facing forward, and the dowel being maximally pressed above the head (**Figures 1** and **2)**. This movement was performed up to three times. If a score of three was not achieved, the test was re-evaluated with the individual's heels on a 2x6 inch block. The highest score possible at that point was a two. Scoring criteria is explained in **Table 1.**

Table 1. FMS Scoring Rubric (Cook et al., 2006a,b)

	III	II	I
Deep Squat	• Upper torso is parallel with tibia or towards vertical • Femur below horizontal • Knees aligned with the feet • Dowel aligned with the feet	• Upper torso is parallel with tibia or towards vertical • Femur below horizontal • Knees aligned with the feet • Dowel aligned with the feet • 2x6 in. board required under heels	• Upper torso and tibia are not parallel • Femur is above horizontal • Knees are not aligned with feet • Flexion in lumbar spine is noted • 2x6 in. board required under heels
Hurdle Step	• Hips, knees, and ankles remain in sagittal plane • Little to no movement is noted in the lumbar spine • The dowel and hurdle remain parallel	• Hips, knees, and ankles become misaligned • Lumbar spine movement noted • Dowel and hurdle do not remain parallel	• Foot makes contact with hurdle band • Loss of balance is noted
In-line Lunge	• No torso movement noted • Dowel remains in contact with lumbar spine • Dowel and feet stay in the sagittal plane • Knee touches the board behind the heel of the opposite foot	• Movement in torso is noted • Dowel does not remain in contact with lumbar spine • Dowel and feet to not stay in sagittal plane • Knee does not touch board behind the heel of the opposite foot	• Loss of balance is noted
Shoulder Mobility	• Fists are measured within one hand length	• Fists are measured within one and a half hand lengths	• Distance between fists is greater than one and a half hand lengths
Active Straight Leg Raise	• Ankle/dowel reach between mid-thigh and ASIS	• Ankle/dowel reach between mid-patella and mid-thigh	• Ankle/dowel reach below mid-patella
Trunk Stability Push-up	• Males perform 1 repetition with thumbs aligned with top of forehead • Females perform 1 repetition with thumbs aligned with chin	• Males perform 1 repetition with thumbs aligned with the chin • Females perform 1 repetition with thumbs aligned with the clavicle	• Males are unable to perform 1 repetition with thumbs at chin • Females are unable to perform 1 repetition with thumbs at clavicle
Rotary Stability	• Performs 1 unilateral repetition while the spine stays parallel to surface • Knee and elbow touch	• Performs 1 diagonal repetition while spine says parallel to surface • Knee and elbow touch	• Unable to perform diagonal repetition

*****A score of zero is given if pain is associated with any test or clearing exams. Note any asymmetries on tests that are performed unilaterally.

Figure 1. Deep Squat Frontal View

Figure 2. Deep Squat Sagittal View

<u>Hurdle Step:</u> The individual started with their feet together and their toes touching the base of the hurdle. The height of the tibial tuberosity was measured and was used to position the height of the hurdle. The subject held the dowel across the back of the shoulders, as seen in **Figure 3**. The subject was then asked to step over the hurdle, touch their heel on the opposite side and return their step leg to the starting position. This maneuver was repeated as many as three times on each side. If the individual completed one repetition bilaterally meeting the criteria, a score of three was given. Asymmetries were noted on this exam. Scoring criteria is explained in **Table 1.**

Figure 3. Hurdle Step Frontal View

<u>In-line Lunge:</u> The length of the tibia was first measured from the floor to the tibial tuberosity. The individual then placed the toe of one foot on the zero mark standing on the FMS kit, and placed the heel of the opposite foot at the number representing the length of the tibia. The individual then placed the dowel on their back so that it touched the sacrum, thoracic spine and the head. The hand that was opposite of the front foot grasped the dowel at the cervical spine, and the other hand at the lumbar spine. Once the subject was in place, they were to lower the back knee and touch the surface of the board behind the heel of the front foot and then return to the starting position **(Figures 4** and **5)**. The in-line lunge was performed up to three times bilaterally. Asymmetries were noted on this exam. If the individual completed one repetition successfully, they received a three for that extremity. This test was measured on both sides. Scoring criteria is explained in **Table 1**.

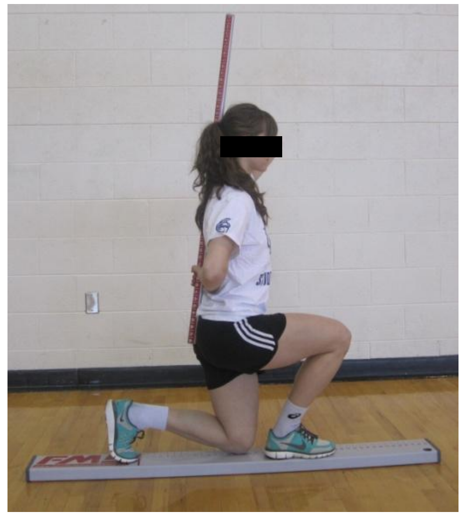

Figure 4. In-line Lunge Frontal View **Figure 5. In-line Lunge Sagittal View**

<u>**Shoulder Mobility:**</u> Hand length was measured from the distal wrist crease to the tip of the third digit using the inch markings on the dowel. The individual was then instructed to make a fist with each hand, with the thumb inside the fingers. One shoulder was maximally adducted, extended, and internally rotated and the other shoulder was maximally abducted, flexed, and externally rotated. These positions were achieved in one smooth motion and held in place while the tester measures the distance between the two fists **(Figure 6)**. This test was performed up to three times bilaterally. If the fists were within a hand length, the individual scored a three on that side. Asymmetries were noted on this exam. Scoring is explained in **Table 1**.

<u>**Clearing Exam:**</u> The subject placed the palm of one hand on the opposite shoulder and lifted the elbow as high as possible while keeping the palm touching the shoulder **(Figure**

7). This exam was performed on both sides. If there was pain while performing this exam, a score of zero was given for the shoulder mobility screen.

Figure 6. Shoulder Mobility Test

Figure 7. Shoulder Clearing Exam

<u>Active Straight Leg Raise:</u> The individual was supine in the anatomical position while the examiner identified the mid-point between the anterior superior iliac spine and the mid-point of the patella. The dowel was placed at this point, perpendicular to the ground. The individual was then asked to raise one leg with the ankle in dorsiflexion and the knee in full extension **(Figure 8)**. The opposite knee remained in contact with the ground throughout the test. If the medial malleolus reaches past the dowel, then the individual receives a score of three for that side. This test is performed on both sides. Note asymmetries on this exam. Scoring is explained in **Table 1**.

Figure 8. Active Straight Leg Raise

<u>Trunk Stability Push-Up:</u> The subject was in a prone position. Females were to perform one repetition with the thumbs aligned with the chin. The hands were placed shoulder width apart at the previously described positions. The individual was then asked to extend their knees and dorsiflex their ankles and perform one push-up from this position. The body should have lifted as a unit with no dip in the hips or lumbar spine to gain a score of three **(Figure 9)**. If the individual could not perform this movement from this position, they were asked to lower their hands to the next appropriate position as described in **Table 1**.

<u>Extension Clearing Exam:</u> The subject was prone and performed a press-up by pushing the upper body off the ground and keeping the lower extremities on the ground **(Figure 10)**. If this motion caused pain, a score of zero was given for the entire test.

Figure 9. Trunk Stability Push-up **Figure 10. Extension Clearing Exam**

<u>Rotary Stability:</u> The 2x6 board of the FMS kit was placed between the hands, knees, and toes while the individual was in a quadruped position. The shoulders, hips, knees, and ankles were all at 90 degrees for the starting position. The individual was asked to flex the shoulder and extend the same side hip and knee **(Figure 11)**. The same shoulder was then extended and the knee flexed so that the elbow and knee touched before returning to the starting position **(Figure 12)**. If a score of three was not obtained within three repetitions, the individual tried the same pattern with an opposite shoulder and hip technique. Asymmetries were noted on this exam. Scoring is explained in **Table 1**.

<u>Flexion Clearing Exam:</u> The subject started on their hands and knees and slowly rocked back so that the heels were touching the buttocks, and the chest was touching the thighs. The hands were stretched out in front of the body and arms fully extended **(Figure 13)**. If pain was present, the subject scored a zero on the rotary stability test.

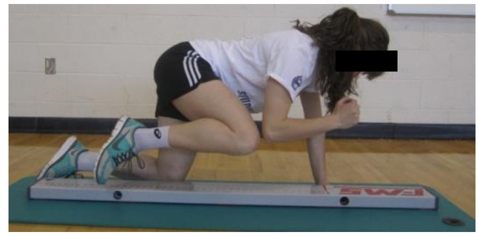

Figure 11. Rotary Stability Extended Position

Figure 12. Rotary Stability Flexed Position

Figure 13. Flexion Clearing Exam

Statistical Analysis

All of the participants' data was assigned a code number and data was kept in a password protected computer and maintained confidential at all times. The independent variables of this study (predictor variables) were the total FMS score and the score for each test subcomponent. The dependent variable was the number of knee and lower extremity injuries sustained throughout the season (total, acute and chronic), that was extracted and recorded from the Athletic Trainer System injury tracking database. The injury data included the structures involved, whether it was acute or chronic in nature, and the sport played. To maintain confidentiality, all data were assigned a code number and entered into a password protected Microsoft Excel file.

To confirm the PI's ability to consistently score the FMS in the study population, 20 randomly selected subjects were measured in real time, and twice again (spaced 2 weeks apart) from digital video recordings obtained during the real time measurement. Percent agreement was used to determine scoring consistency across the three measurements.

Means and standard deviations were computed for each independent and dependent variables for all subjects and when subjects were stratified by sport. Independent t-tests compared each FMS subcomponent, final scores and asymmetry between subjects who sustained a knee injury or lower extremity injury to subjects who did not sustain an injury.

To test the primary hypothesis, ROC curves were constructed to determine if there was a specific cutoff score that best distinguished between the injured and uninjured athletes and these results were qualitatively compared to the ≤14 cut off score determined by Kiesel et al. (2007). Each ROC curve was a plot of the true positive (sensitivity) rate against the false positive (1-specificity) rate for the different possible cutoff points of the FMS. The area under the curve was a measure of how well each FMS test could distinguish between the injured and uninjured groups. A Chi-square 2x2 contingency table then determined if those who sustained a knee injury or lower extremity injury were more likely to have low (≤14 or the score determined by the ROC curve) versus high (≥15 or the score determined by the ROC curve) FMS scores. ROC curves and chi-square analyses were also used to determine if athletes with one or more asymmetries were more likely to sustain a knee or lower extremity injury. To test the secondary hypothesis, ROC curves and Chi-square analyses determined whether a lower score on one or more of the FMS lower extremity subcomponents was more sensitive in identifying those who sustained a knee or lower extremity injury.

CHAPTER IV

RESULTS

Descriptive subject data including age, height, weight, and sport participation are included in **Table 2**. Four subjects sustained qualifying non-contact knee injuries during the season. Due to the low incidence of knee injury, secondary analyses were also run that included all non-contact lower extremity injuries. For these analyses, twenty-four subjects sustained non-contact lower extremity injuries, making a total of 28 injuries. Injuries by type and sport are described in (**Table 3).** The mean FMS score for all subjects (n=72) was 16.33 ± 1.59 (maximum score of 21).

Table 4 describes the percent agreement of the investigator when scoring the FMS live versus video on two separate occasions. When comparing FMS total score between live and video, the investigator's scores agreed 60% of the time. For the 40% where there was not agreement on the final score, 5% were disagreed by 1 point, 25% by 2 points, and 5% by 3 points. Percent agreement between day one and day two of video scoring was 100% for every test and the final score of the FMS. Based on the consistency of video scoring, the remainder of the analyses were based on the scores derived from day one video scoring.

Table 2. Summary of Subject Descriptive Data

	# Subjects (n)	Age (yrs)	Ht (cm)	Wt (kg)
All Subjects	72	19.5 (± 1.2)	65.8 (± 2.8)	65.4 (± 8.9)
Soccer	24	19.5 (± 1.2)	65.6 (± 2.2)	63.6 (± 7.5)
Volleyball	7	19.4 (± 1.4)	67.5 (± 4.2)	63.6 (± 10.3)
Tennis	6	19.3 (± 0.8)	65.0 (± 2.5)	60.6 (± 3.4)
Softball	12	19.5 (± 1.0)	65.3 (± 2.1)	70.7 (± 9.8)
Cheerleading	12	19.8 (± 1.5)	65.4 (± 2.4)	61.4 (± 6.9)
Basketball	11	19.3 (± 1.4)	68.3 (± 2.5)	71.3 (± 9.5)

Table 3. Injury by Type, Body Region and Sport

Structure Involved	Type	Area	Sport
Distal hamstring partial tear	acute	Knee	Soccer
Knee pain	acute	Knee	Basketball
Patellar Subluxation	acute	Knee	Basketball
patellar tendonitis	chronic	Knee	Tennis
Hamstring partial tear	acute	other LE	Soccer
Quadriceps partial tear	acute	other LE	Soccer
Adductor (groin) partial tear	acute	other LE	Soccer
Gastrocnemius partial tear	acute	other LE	Soccer
Achilles tendon strain	acute	other LE	Soccer
Lateral ankle sprain	acute	other LE	Soccer
Lateral ankle sprain	acute	other LE	Soccer
ankle impingement	chronic	other LE	Soccer
ankle synovitis	chronic	other LE	Soccer
iliopsoas bursitis	chronic	other LE	Soccer
Compartment Syndrome	acute	other LE	Basketball
Adductor (groin) partial tear	acute	other LE	Basketball
Hamstring partial tear	acute	other LE	Basketball
Midfoot sprain	acute	other LE	Basketball
Tendonopathy	chronic	other LE	Basketball
Capsular injury, joint sprain foot	acute	other LE	Cheer
Lateral ankle sprain	acute	other LE	Cheer
Hamstring partial tear	acute	other LE	Softball
Hamstring partial tear	acute	other LE	Softball
MTSS	chronic	other LE	Tennis
Gastrocnemius partial tear	acute	other LE	Volleyball
Iliopsoas partial tear	acute	other LE	Volleyball
Low leg stress reaction	chronic	other LE	Volleyball

Table 4. Agreement from Live Scoring to Video Scoring

Test	% Agreement
Deep squat	0.70
Hurdle Step Left	0.95
Hurdle Step Right	0.80
In-Line Lunge Left	0.75
In-Line Lunge Right	0.85
Shoulder Mobility Left	0.95
Shoulder Mobility Right	0.95
ASLR Left	0.85
ASLR Right	0.85
Trunk Stability Push-Up	0.85
Rotary stability Left	0.85
Rotary Stability Right	0.95
Final Score	0.60

Independent *t*-tests

Independent *t*-tests were used to initially compare the means and standard deviations of the FMS subcomponents, final scores, and evidence of asymmetries for those subjects who sustained a knee or lower extremity injury compared to those who did not. No significant difference was found in scores between those who sustained an injury and those who did not (**Tables 5 and 6)**.

Table 5. Independent t-test of FMS Tests, Final Score, and Asymmetry Comparing Uninjured Subjects and Injured Subjects with Knee Injury

Test	Knee Injury (N=4)		No Injury (N=68)		*P*-value
	Mean	SD	Mean	SD	
Deep Squat	2.3	0.5	2.0	0.5	0.367
Hurdle Step	2.0	0.8	2.2	0.5	0.599
In-Line Lunge	2.5	0.6	2.6	0.6	0.838
ASLR	2.5	0.6	2.7	0.5	0.433
TSPU	2.3	0.5	2.2	0.9	0.925
Rotary Stability	2.0	0	2.0	0.3	0.928
Final Score	16.0	1.4	16.3	1.8	0.751
Asymmetry	0.0	0.0	0.5	0.5	0.067

Table 6. Independent t-test of FMS Tests, Final Score, and Asymmetry Comparing Uninjured Subjects and Injured Subjects with Lower Extremity Injury

Test	LE Injury (N=28)		No Injury (N=44)		*P*-value
	Mean	SD	Mean	SD	
Deep Squat	2.1	0.4	2.0	0.5	0.122
Hurdle Step	2.2	0.5	2.1	0.5	0.622
In-Line Lunge	2.6	0.5	2.6	0.6	0.848
ASLR	2.7	0.5	2.7	0.5	0.977
TSPU	2.0	1.0	2.3	0.8	0.119
Rotary Stability	2.0	0.2	2.0	0.4	0.288
Final Score	16.3	1.6	16.3	1.9	0.870
Asymmetry	0.3	0.5	0.5	0.5	0.096

ROC Curves

Receiver operating characteristic (ROC) curves revealed area scores close to 0.5, and were unable to identify a score for each FMS subcomponent or the total score that was sensitive in predicting injury status. An example of the ROC curve output for the FMS test compared to knee injury is located in **Figure 14** and statistical output can be found in **Table 7.** The ROC curve for the asymmetry score indicated that an asymmetry score of ≥ 0.5 (someone with at least one asymmetry) was the most sensitive in identifying those without knee injuries (area=0.735) (**Figure 15, Table 8**).

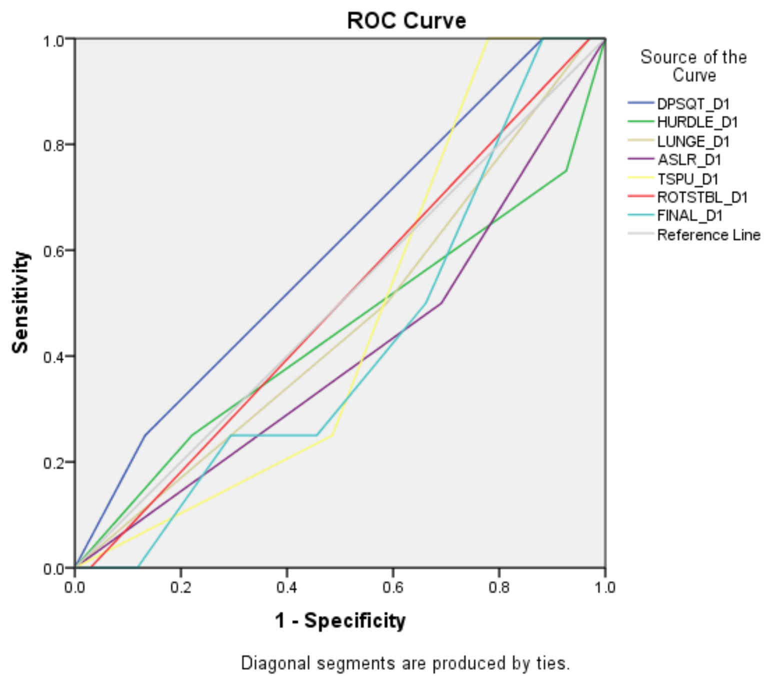

Figure 14. ROC Curve Output of FMS Subcomponents and Final Score in Comparison to Knee Injury

Table 7. ROC Curve Statistics from Output in Figure 14

Area Under the Curve

Test Result Variable(s)	Area	Std. Error[a]	Asymptotic Sig.[b]	Asymptotic 95% Confidence Interval	
				Lower Bound	Upper Bound
DPSQT_D1	.603	.140	.491	.329	.877
HURDLE_D1	.445	.171	.712	.109	.781
LUNGE_D1	.463	.146	.806	.176	.750
ASLR_D1	.404	.152	.523	.107	.702
TSPU_D1	.465	.110	.815	.250	.680
ROTSTBL_D1	.500	.142	1.000	.222	.778
FINAL_D1	.423	.127	.606	.173	.672

The test result variable(s): DPSQT_D1, HURDLE_D1, LUNGE_D1, ASLR_D1, TSPU_D1, ROTSTBL_D1, FINAL_D1 has at least one tie between the positive actual state group and the negative actual state group. Statistics may be biased.

a. Under the nonparametric assumption

b. Null hypothesis: true area = 0.5

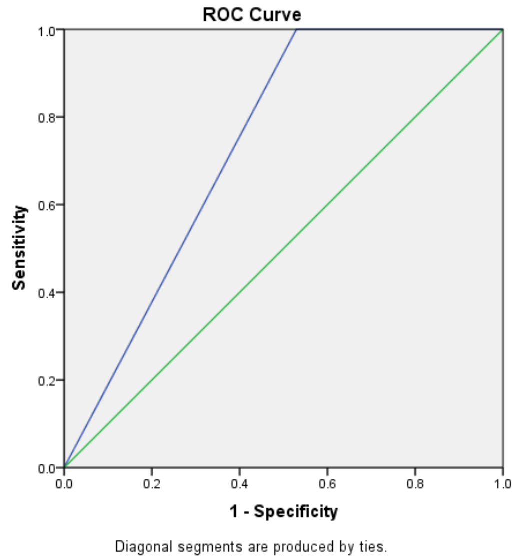

Figure 15. ROC Curve When Plotting Knee Injury Status Against Asymmetry Score

Table 8. ROC Curve Statistics from Output in Figure 15

Area Under the Curve

Test Result Variable(s): ASYMMETRY_D1

Area	Std. Error[a]	Asymptotic Sig.[b]	Asymptotic 95% Confidence Interval	
			Lower Bound	Upper Bound
.735	.087	.116	.564	.907

The test result variable(s): ASYMMETRY_D1 has at least one tie between the positive actual state group and the negative actual state group. Statistics may be biased.
a. Under the nonparametric assumption
b. Null hypothesis: true area = 0.5

Chi-square Analyses

Chi-square analyses were used to determine whether the proportion of subjects who sustained a knee injury (**Table 9)** and those who sustained a lower extremity injury

(**Table 10)** were more likely to score ≤14 as found by the Kiesel et al. (2007) and Chorba et al. (2010) studies. This cutoff score was used since the ROC curves were not able to identify a specific score in the current sample that was better able to distinguish between injured and uninjured. Similar analyses were performed to determine if those with knee injury (**Table 11)** and lower extremity injury (**Table 12)** were more likely to have asymmetries on the hurdle step, in-line lunge, active straight leg raise, and/or rotary stability tests**.** In each case, there was no significant difference in the proportion of high versus low scores between injured and uninjured subjects. Results of the chi-square analyses comparing FMS individual component scores to injury status are reported in **Tables 13** and **14**.

Table 9. Chi-square Analysis of Total FMS Score and Knee Injury Status

	Knee Injured		**P-Value**
	Yes	**No**	
FMS Score ≤14	0 (0.0%)	8 (11.8%)	0.467
FMS Score ≥15	4 (100.0%)	60 (88.2%)	

Table 10. Chi-square Analysis of Total FMS Score and Lower Extremity Injury Status

	LE Injured		P-Value
	Yes	No	
FMS Score ≤14	4 (14.3%)	4 (9.1%)	0.494
FMS Score ≥15	24 (85.7%)	40 (90.9%)	

Table 11. Chi-square Analysis of Asymmetry and Knee Injury Status

		Knee Injury		P-value
		Yes	No	
Asymmetry	Yes	0 (0.0%)	32 (47.1%)	0.066
	No	4 (100.0%)	36 (52.9%)	

Table 12. Chi-square Analysis of Asymmetry and Lower Extremity Injury Status

		LE Injury		P-value
		Yes	No	
Asymmetry	Yes	9 (32.1%)	23 (52.3%)	0.094
	No	19 (67.9%)	21 (47.7%)	

Table 13. Chi-square Analysis of FMS Subcomponents and Knee Injury Status

Test	Score	Knee Injury		Total	P-value
		No (n=68)	Yes (n=4)		
Deep Squat	1	11.8%	0.0%	11.1%	0.655
	2	75.0%	75.0%	75.0%	
	3	13.2%	25.0%	13.9%	
Hurdle Step	1	7.4%	25.0%	8.3%	0.437
	2	70.6%	50.0%	69.4%	
	3	22.1%	25.0%	22.2%	
In-Line Lunge	1	2.9%	0.0%	2.8%	0.86
	2	38.2%	50.0%	38.9%	
	3	58.8%	50.0%	58.3%	
ASLR	2	30.9%	50.0%	31.9%	0.425
	3	69.1%	50.0%	68.1%	
TSPU	0	5.9%	0.0%	5.6%	0.286
	1	16.2%	0.0%	15.3%	
	2	29.4%	75.0%	31.9%	
	3	48.5%	25.0%	47.2%	
Rotary Stability	0	1.5%	0.0%	1.4%	0.969
	1	1.5%	0.0%	1.4%	
	2	94.1%	100.0%	94.4%	
	3	2.9%	0.0%	2.8%	

Table 14. Chi-Square Analysis of FMS Subcomponents and Lower Extremity Injury Status

Test	Score	LE Injury No (n=44)	LE Injury Yes (n=28)	Total	P-value
Deep Squat	1	15.9%	3.6%	11.1%	0.23
	2	72.7%	78.6%	75.0%	
	3	11.4%	17.8%	13.9%	
Hurdle Step	1	9.1%	7.1%	8.3%	0.881
	2	70.5%	67.9%	69.4%	
	3	20.5%	25.0%	22.2%	
In-Line Lunge	1	4.5%	0.0%	2.8%	0.48
	2	36.4%	42.9%	38.9%	
	3	59.1%	57.1%	58.3%	
ASLR	2	31.8%	32.1%	31.9%	0.977
	3	68.2%	67.9%	68.1%	
TSPU	0	4.5%	7.1%	5.6%	0.282
	1	9.1%	25.0%	15.3%	
	2	34.1%	28.6%	31.9%	
	3	52.3%	39.3%	47.2%	
Rotary Stability	0	2.3%	0.0%	1.4%	0.707
	1	2.3%	0.0%	1.4%	
	2	93.2%	96.4%	94.4%	
	3	2.3%	3.6%	2.8%	

CHAPTER V

DISCUSSION

The purpose of the study was to determine the extent to which the Functional Movement Screen could predict non-contact knee injury in the female collegiate athlete population. The secondary purpose was to determine if specific lower extremity components of the FMS were stronger predictors of non-contact knee injury risk than the total score. However, because of the low number of knee injuries sustained, the study question was expanded to all non-contact injuries to the lower extremity. Our primary findings were that the total score of the FMS was not sensitive in determining non-contact knee or lower extremity injuries in the population studied, and that none of the subcomponents of the lower extremity FMS subcomponents were able to individually predict non-contact knee or lower extremity injury. Thus, our hypotheses were not supported. The following discussion compares these findings to previous literature and explores potential explanations for our finding and their clinical implications.

Reliability

The reliability between live and video scoring of the FMS identified video scoring to be the most consistent way to score the FMS. We believe that the video scoring was more accurate and precise due to the ability of the PI to watch the videos in slow motion and multiple times as needed. Previous research has shown excellent reliability (ICC= 0.92) when comparing live and video scores indicating that the two types of scoring are compatible (Shultz, Anderson, Matheson, Marcello, & Besier, 2013). Thus, while live scoring is more realistic to how the actual test is performed in the clinical setting, video scoring may be utilized in the future so that a more accurate assessment can be made and thus a better corrective exercise program can be put in place. However, while video scoring may allow the clinician to look back over each test as many times as desired, video equipment may not be readily available to all clinicians due to cost. It is also more time consuming to set up the cameras and to later score off-line. However, if time and equipment restriction are not an issue, video scoring may be the better option in order to obtain the most accurate and consistent score over time.

Hypothesis I

Because we were unable to identify a cutoff score for the total FMS that could distinguish between injured and uninjured subjects, we analyzed the data using the cutoff score of $\leq$14 from previous literature (Kiesel et al., 2007; Chorba et al. 2010). Contrary to these prior studies, a score of $\leq$14 was no more likely to be found in injured versus non-injured females in this study. However, there was considerable variability in the type and severity of injuries across the 3 studies, as well as how injury was defined. Additionally, in each of these studies there were a small number of participants and a relatively low number of injuries sustained. Thus, the difference in type and gender of athletes studied and differences in how injury was defined may have contributed to different results across studies. For example, Kiesel et al. (2007) studied 46 professional male football athletes over one season. Injury was defined as any injury that placed a player on injury reserve for at least three weeks, suggesting that only moderate to severe injuries were examined. Chorba et al. (2010) studied 38 NCAA division II female athletes who played soccer, volleyball and basketball over one season. Injury was defined as a musculoskeletal injury that was sustained during participation in their respective sporting activities and required medical attention by an athletic trainer, athletic training student or physician. For the current study, 72 female athletes were studied from six different NCAA division I sports over at least one competitive season during the 2013-2014 school year. Injury was defined as any non-contact musculoskeletal injury to the knee joint or lower extremity that was an acute or chronic condition that required a minimum of five rehabilitation sessions with the respective team's certified athletic trainer and/or required modified activity during at least one practice or strength and conditioning session. We felt that the injury definition used by Chorba et al. (2010) may have concluded very minor injuries that would not limit playing time in practice, strength and conditioning sessions, or games. Therefore, for our study, we developed an operational definition of an injury based on clinical experience and the NCAA's definition from the Injury Surveillance System. This allowed our study to retain the inclusion of chronic injuries, and also reduce the potential of acquiring minor, inconsequential injuries throughout data collection.

Based on these study differences, we considered possible reason for our lack of significant findings. Kiesel et al. (2007) looked at any injury that placed someone on injured reserve for three weeks, which is assumed to be a fairly severe injury and would not include many chronic injuries. However, Kiesel et al. (2007) did not include a list of the injuries sustained in order to protect the identity of the professional athletes, so the specific injuries sustained by these athletes are unknown. Still, these data may suggest that the FMS may be more predictive of acute severe injuries, rather than chronic overuse injuries. However, because chronic injuries are thought to be caused by repetitive microtrauma that could be related to dysfunctional movement patterns which may predispose an individual to injury, it would seem reasonable that the FMS would be predictive of chronic injury as well. To that end, Chorba et al. (2010) included both chronic and acute injuries, however, they provided no final list of the injuries collected. Therefore, it is unknown how the injuries sustained by athletes in this study compared to those sustained in previous studies in regards to type, severity or acute/chronic status. Further, our study's short data collection time may have limited our ability to generate sufficient long standing chronic injuries or severe acute injuries. Additionally collapsing so many different types and severities of injury together may have added more variability to the data, making it difficult to predict injury status from single FMS scores. This may be particularly true of the individual lower extremity subcomponent scores, since different movement dysfunctions are more likely to be associated with the risk and mechanisms of different lower extremity injuries.

Our findings are however consistent with two other larger studies where the FMS was not predictive of injury risk in 874 male Officer candidates in the Marine Corps (O'Connor et al., 2011) and 112 male and female high school basketball athletes (Sorenson, 2009). In the large prospective study by O'Connor et al. (2011), injury was defined as physical damage to the body secondary to physical training and the individual sought medical care one or more times during the study period. Injuries were grouped by type including: overuse, traumatic, any injury, and serious injury. There were a total of 270 injuries sustained throughout the study period. Sorenson (2009) defined injury in the high school basketball population studied, as neuromusculoskeletal impairments reported to and/or recognized by the school's coaching staff or Certified Athletic Trainer that occurred during sport related training or competition. They recorded type of injury, diagnosis, occurrence of previous injury, cause of injury, time of injury, whether it was non-contact versus contact, and the type of contact involved. Their injury findings reported 27 non-contact lower extremity injuries, only two upper extremity, and three trunk injures. Of the 60 girls included in the study, 19 sustained injuries, including 13 chronic and six acute. While the subject pools in these two studies are quite different than the female athletes and sports examined in the current study, the inconsistent results suggest the predictive ability of the FMS in identifying those at risk for lower extremity injury may be questionable, or at minimum may be highly dependent on population studied, and the type and severity of injuries examined.

The current study also examined whether asymmetries were predictive of knee and lower extremity injuries. Our findings revealed a trend towards one or more asymmetry distinguishing between knee injury statuses. However, this trend was opposite than what we expected because those participants who had one or more asymmetries were more likely to be uninjured than injured. While clinicians often think of asymmetry as a negative factor, our findings may suggest that it may not necessarily be a negative finding. Certain athletes, such as softball, soccer, and tennis players, may have to move asymmetrically in their sport to be successful, thus making their asymmetry on certain movement tasks a natural phenomenon of their training. Asymmetry in gait has been studied and determined to be a naturally occurring phenomenon (Haddad et al., 2010; Haddad et al., 2006; Herzog et al., 1989), and O'Connor et al. (2011) found that in a population of 874 male Officer candidates in the Marine Corps, no statistical evidence supported asymmetry to be a risk factor of injury. Clinicians may need to take the type of sport into consideration before attempting to correct movement patterns that result in asymmetry on the FMS tests. However, it is important to note that these results are based on a total of four knee injuries in our study, and it is difficult to draw firm conclusions based on this very small sample size. Previous research has made note of asymmetries (Kiesel et al., 2007; O'Connor et al., 2011; Teyhen et al., 2012), but have not examined these asymmetries relative to knee or lower extremity injury risk. More research needs to be completed to determine how asymmetry impacts injury with specific sports in mind. For example, sports that require a stance leg and a dominate leg, or a dominate arm may see more asymmetries on certain movement patterns because of the requirement of the sport, but may not see a pattern of injury related to asymmetry in this population. More work with larger samples and number of injuries are needed to fully address this question.

Hypothesis II

We expected that one or more components of the FMS that challenge the mobility and stability of the system would be stronger predictors of non-contact knee injury. Chorba et al. (2010) and Kiesel et al. (2007) only used the final FMS score to predict injury risk. Chorba et al. (2010) stated in future directions that certain components of the FMS may be more predictive of injury in specific populations. The investigators of the current study thought that the deep squat would be the most predictive of injury because of the complex nature of the task and the sport like attributes of the movement that is somewhat consistent with injury mechanisms. However, the current study did not find any of the subcomponents of the FMS to be predictive of knee or lower extremity injury. Again, the low number of subjects and the short duration of the data collection may have made it difficult to identify clear trends in data based on a single subcomponent of the FMS, as individual components may be better at identifying some injuries versus others. While our original intent was to look specifically at non-contact knee injuries for this reason, it was necessary to include all lower extremity injuries due to the low number of knee injuries. Because the intention of the FMS is to use multiple functional movements to challenge the entire kinetic chain, the total FMS score may be more relevant in this case given the variety of injuries sustained. Since previous research has not looked at individual subcomponents of the FMS, it was difficult to compare the current findings to previous literature.

Clinical Implications

Evidence based medicine (EBM) is a way to make decisions on the care of patients by integrating clinical expertise with the best and most recent external clinical evidence available from systematic research (Sackett et al., 1996). Evidence based practice (EBP) is the act of implementing what we learn from the systematic research and incorporating it into our clinical practice and decision making. It is important to note that the patient is also a very integral part of the decision making process in EBP. Clinicians' must consider what is best for the individual patient, their own clinical experience with what has worked for them in the past, and what the current evidence is saying about a particular technique or tool when treating or working with a patient. The FMS poses a few problems in EBM from the patient, clinical, and evidence standpoints. Some patients may consider the FMS to be confusing when the tests are being described, they may consider the motions to be unnatural and wonder how the movements are functional and relate to their sport, and some motions may even seem impossible to complete perfectly. On the other hand, the FMS does exploit the competitive nature of the athlete, in that they strive to get a really good score and improve their score every time they perform the test which may increasing the effort put forth by the athletes. From a clinical standpoint, the FMS poses a problem because it is popular and easy to use, however the cost of certification and applicability of the test does not warrant use in a clinical setting based on the current lack of evidence of its ability to predict future injury risk. The evidence on the FMS is inconsistent at best, with the majority of research reporting it is not predictive of future injury risk (O'Connor et al., 2011; Sorenson, 2009).

Thus while the FMS can be reliably scored by clinicians (Chorba et al., 2010; Esser, 2011; Gribble et al., 2013; Minick et al., 2010; Onate et al., 2012; Schneiders et al., 2011; Smith et al., 2013; Teyhen et al., 2012), it does not appear to be a valid test of injury risk. Additionally, although one study has shown that FMS scores can be improved with proper intervention programs, improved FMS scores has not been shown to decrease injury rates (Kiesel et al., 2009). Such issues should raise concerns for practicing clinicians. Clinicians implementing the FMS should carefully consider the lack of supportive evidence, especially in large scale applications such as PPEs, given the time, money, and effort necessary to implement this screen. The two studies that have seen significance in predicting injury (Kiesel et al., 2007; Chorba et al., 2010) had two very different definitions of injury, small sample sizes, and very specific athlete populations. Thus, a consistent definition of injury, larger sample sizes, and a broader population type is needed in future studies before clinicians can consider the FMS to be a valid screening tool for injury prediction. Therefore, clinicians who implement these corrective exercise programs to improve FMS scores are only assuming that this will decrease the subject's risk of injury and increase their function. In summary, many clinicians use the FMS to screen athletes in the off season in hopes of implementing a corrective exercise program to improve movement dysfunctions. However, many clinicians are still unsure of how to use and interpret the data extracted by the FMS. Additionally, our study is in agreement other literature suggesting the lack of injury predictability of this tool. Given our sample size, a wide variety of sports, and the target age population studied, and the lack of evidence of its injury predictability, we conclude that too much is still unknown about the FMS to be used confidently as evidence based injury risk screening tool in clinical practice. As clinicians across the country continue to become certified in this screening and evaluation system, there is also a need for these clinicians to stay abreast of the current evidence and the true limitations of it's application.

Limitations

As previously noted, the study was limited to a small sample size and a short data collection time frame, which caused us to group all lower extremity injures together, regardless of type or severity. Because of the low number of injuries, we were not able to look at knee injury specifically and criteria for injury had to be altered to include all non-contact lower extremity injuries. Combining all types and severities of injuries may have limited the sensitivity of the FMS in predicting knee and lower extremity injury status. In order to fully understand the role of the FMS in predicting injury, a longitudinal study is needed so that a larger number of subjects can be studied and allow stratification by sport and injury type and severity to determine if the FMS may be more sensitive in predicting some injuries more than others.

Future Directions

Future studies may benefit from following an incoming freshman class in a longitudinal study throughout their collegiate career. This would allow researchers to answer many questions regarding structural and functional changes of maturing athletes, and this would also allow researchers to track how FMS scores and injuries change over time. Future studies should also consider tracking all injuries that effect practice and game playing time. Additionally, a consistent definition of injury should be adopted to allow comparisons between studies. Tracking male and female athletes in the same study would also allow for gender comparisons to be made. Tracking asymmetries may be worth studying in certain populations to determine if this represents an injury risk factor versus a normal functional adaptation in some sports. Because it is appreciated that multiple risk factors likely contribute to injury, future studies may also consider adding and combining results from other functional and/or strength tests such as the vertical jump, standing broad jump, shuttle run, and etcetera relative to height, weight and sporting position to determine if a battery of tests may be more predictive of injury. Athletic trainers and clinicians may also be interested in using the FMS as a baseline measurement for when athletes get injured to show how the individual was functioning before injury, right after injury, and during the return to play portion of rehabilitation. There is currently no evidence on the FMS being used as a return to play guideline from injury, however previous research on improving test scores using corrective exercises (Kiesel et al., 2009; Peate et al., 2010) may be a very relatable and a promising future for the FMS.

Conclusion

This investigation utilized a widely known clinical measure for the assessment of functional movement to determine the relationship between the screening tool and non-contact knee and lower extremity injury risk in highly functioning female collegiate athletes. The Functional Movement Screen was chosen because it has been recognized as a standardized screening tool to determine those at risk for injury by previous research (Kiesel et al., 2007; Chorba et al., 2010). The FMS, however, had not been used to specifically screen for an increased risk of non-contact knee or lower extremity injuries in a female population. However, despite the intended use of the FMS, the current study was unable to find any predictive value in the FMS score in identifying those at risk for future knee or lower extremity injury. The only trends noted were with asymmetry scores, but these findings suggested that asymmetries were protective rather than risk factors for injury. The relationship found between injury and asymmetry may also indicate that some athletes function at a higher level with sport specific asymmetries.

Thus, it appears that dysfunctional movement patterns that have previously been thought to increase risk of injury during sport participation cannot solely attribute to injury risk in all female collegiate athletes. There have only been a few studies that have shown the FMS to be predictive of injury in the small body of EBP that is currently available. Based off of the current findings and previous research in other populations (O’Connor et al., 2011; Sorenson, 2009), we suggest that the FMS may not be the best tool to use at this time to predict injury risk as the preponderance of evidence suggest there appears to be no difference in scores between the injured and uninjured population.

The FMS has also been used to create corrective exercise programs, but if asymmetry and low scores on the FMS tests do not indicate a greater risk of injury, should clinicians be taking the time to create and implement these programs? Clinicians should consider the amount of EBM available before choosing to use the FMS in PPEs. The FMS is often used in PPEs, however if it is not predicting injury consistently, clinicians may be relying too heavily on the FMS in their decision making. The FMS does not account for strength, gender, sport participation, player position, fatigue, or environment during sport participation. Future studies should attempt to account for some if not all of these factors to better understand the risk factors for injury that may occur during sport participation, especially in the female collegiate athlete population.

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APPENDIX A

INSTITUTIONAL REVIEW BOARD CONSENT FORM

UNIVERSITY OF NORTH CAROLINA AT GREENSBORO
CONSENT TO ACT AS A HUMAN PARTICIPANT

Project Title: Use of the FMS During PPEs to Determine Knee Injury Risk in Female Collegiate Athletes

Principal Investigator and Faculty Advisor (if applicable): Mara L. Mohler, Sandra J. Schultz

Participant's Name: ______________________________

What is the study about?
This is a research project. Your participation is voluntary. The purpose of this study is to see if the scores on one or a combination of the seven movement tests that make up the Functional Movement Screen are able to predict future knee injury in female collegiate athletes.

Why are you asking me?
You are being asked because you are a current active roster member of the UNCG's female soccer, softball, tennis, or volleyball teams and are at least 18 years of age or older. You may not participate in this study if you have sustained an injury to your lower extremities within 30 days of testing that held you from full participation in pre-season events, or if you have had a recent surgery that is restricting you from full participation. Also, you will be excluded if you have any vestibular or balance disorders that could cause you to lose your balance during the functional tasks.

What will you ask me to do if I agree to be in the study?
You will be asked to fill out a health and injury history questionnaire. You will then be asked to perform a movement screening test that include 7 motions: 1) Deep squat- standing feet shoulder width apart and dowel held above head, you will perform a squat as low as you can and return to the starting position. 2) Hurdle step- standing with feet together, toes touching the board, you will lift one leg over the rubber band and touch the opposite side and return to the starting position. This is performed on both sides. 3) In-line lunge- standing on the board with one foot in front of the other and dowel held against the back, you will lunge down and touch the back knee behind the front heel and return to the starting position. 4) Shoulder mobility- You will reach one hand in a fist over the head and the other behind the back attempting to touch your hands together. Perform this test on both sides. 5) Active straight leg raise- You will lay on your back keeping one leg on the ground and raising the other towards your head. The leg on the ground should not bend. This is performed on both sides. 6) Trunk stability push up- You will lay on your stomach with your hands at chin level. From this position, you will push your body off the ground in one smooth motion. 7) Rotary stability- you will start on all four limbs and slowly reach the same side's arm and leg into full extension and then bring the elbow and knee together, then moves back to the starting position without losing balance. This test is performed on both sides. We will watch and video tape you performing each test from the front and side views. Each test will be scored from 0 to 3. It should take no more than 15 minutes to complete all seven tests. As part of your participation in athletics, your injuries will be tracked in the Athletic Trainer System that the Athletic Training Department uses on a daily basis. I will be accessing your medical records to record any knee injury you sustain during the course of the season. Only the injury data will be recorded and will be assigned a code number. No other personal health history information will be collected.

Is there any audio/video recording?
You will be videotaped during the FMS screen to assist the investigator in accurately scoring each test.

What are the risks to me?
The Institutional Review Board at the University of North Carolina at Greensboro has determined that participation in this study poses minimal risk to participants. The data we are collecting for this study is

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injury screening and documentation that is routinely collected in the Athletic Training Room and poses no additional risks to the participants. This study will be using a movement screen that requires physical movements to be done by the subjects. There is a very infrequent to rare risk of pain, discomfort or injury, however some underlying factors that the you may have, could lead to some pain or discomfort during the movement patterns being performed. If you have pain at any time during a test, you are given a score of zero and will move on to the next movement test.
If you have questions, want more information or have suggestions, please contact Mara Mohler at (574) 297-1259 (mlmohler@uncg.edu) or Dr. Sandra J. Shultz who may be contacted at (336) 334-3027 (sjshultz@uncg.edu).

If you have any concerns about your rights, how you are being treated, concerns or complaints about this project or benefits or risks associated with being in this study please contact the Office of Research Integrity at UNCG toll-free at (855)-251-2351.

Are there any benefits to society as a result of me taking part in this research?
There are no direct benefits to society as a result of this study, though results from this study may help us to better understand what tools may be appropriate to use during pre-participation evaluations to determine those athletes that may be at increased risk of knee injury.

Are there any benefits to *me* for taking part in this research study?
There are no direct benefits to participants in this study.

Will I get paid for being in the study? Will it cost me anything?
There are no costs to you or payments made for participating in this study.

How will you keep my information confidential?
All information obtained in this study is strictly confidential unless disclosure is required by law. All consent forms will be maintained in a locked file only accessible by the investigator for three years, at which time they will be destroyed by shredding. Videotapes will be stored on a password protected external harddrive and videos will be erased from the camera once downloaded onto the harddrive. After a period of three years, the videos will be deleted from the harddrive. Your information and data will be assigned a code number. The list connecting your name to this number will be kept in a locked file until the study has been completed and data analyzed, at which time the list will be destroyed. Your name will not be used in any report. All data will be stored on the principal investigators personal computer identified only by subject number. These data will be kept indefinitely. A photocopy of this original consent form will be provided to you for your records.

What if I want to leave the study?
You have the right to refuse to participate or to withdraw at any time, without penalty. If you do withdraw, it will not affect you in any way. If you choose to withdraw, you may request that any of your data which has been collected be destroyed unless it is in a de-identifiable state.

What about new information/changes in the study?
If significant new information relating to the study becomes available which may relate to your willingness to continue to participate, this information will be provided to you.

Voluntary Consent by Participant:
By signing this consent form you are agreeing that you read, or it has been read to you, and you fully understand the contents of this document and are openly willing consent to take part in this study. All of your questions concerning this study have been answered. By signing this form, you are agreeing that you are 18 years of age or older and are agreeing to participate, or have the individual specified above as a

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participant participate, in this study described to you by Mara Mohler.

Signature: ______________________________ Date: _______________

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APPENDIX B

HEALTH AND INJURY HISTORY QUESTIONNAIRE

PHYSICAL ACTIVITY AND HEALTH HISTORY

Do you have any General Health Problems or Illnesses? (e.g. diabetes, respiratory disease) Yes____ No____

Do you have any vestibular (inner ear) or balance disorders? Yes____ No____

Do you smoke? Yes____ No____

Do you drink alcohol? Yes____ No____ If yes, how often?_____________________________

Do you have any history of connective tissue disease or disorders? (e.g. Ehlers-Danlos, Marfan's Syndrome, Rheumatoid Arthritis) Yes____ No____

Has a family member of yours ever been diagnosed with breast cancer? Yes____ No____ (if no, please skip next question.)

If yes, please put a check next to the types of relatives that have been diagnosed. You may check more than one box:

Mother________ Sister________ Grandmother _________ Aunt _______.
Male relative (father, brother, grandfather, or uncle) ___________.
Other type of relative (please write in) _____________________________.

Please list any medications you take regularly: ____

____

Please list any previous injuries to your lower extremities. Please include a description of the injury (e.g. ligament sprain, muscle strain), severity of the injury, date of the injury, and whether it was on the left or right side.

Body Part	Description	Severity	Date of Injury	L or R
Hip				
Thigh				
Knee				

Lower Leg____

Ankle____

Foot____

Please list any previous surgery to your lower extremities (Include a description of the surgery, the date of the surgery, and whether it was on the left or right side)

Body Part	Description	Date of Surgery	L or R

Please list all physical activities that you are currently engaged in. For each activity, please indicate how much time you spend each week in this activity, the intensity of the activity (i.e. competitive or recreational) and for how long you have been regularly participating in the activity.

Activity	#Days/week	#Minutes/Day	Intensity	Activity Began When?

What time of day do you generally engage in the above activities?________________________

____

Please list other conditions / concerns that you feel we should be aware of:________________

____

____

____

____