EXAMINING THE RELATIONSHIP BETWEEN FUNCTIONAL MOVEMENT SCREEN (FMS) AND COMPUTERIZED BESS SCORES AND LOWER EXTREMITY INJURY RISK IN A COHORT OF FEMALE INTERCOLLEGIATE ATHLETES

by

Onazi O. Agbese

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SCORES AND LOWER EXTREMITY INJURY RISK

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Onazi O. Agbese

Approved: ____
Thomas W. Kaminski, Ph.D., ATC, FNATA, FACSM
Professor in charge of thesis on behalf of the Advisory Committee

Approved: ____
William B. Farquhar, Ph.D.
Chair of the Department of Kinesiology and Applied Physiology

Approved: ____
Kathleen S. Matt, Ph.D.
Dean of the College of Health Sciences

Approved: ____
Ann L. Ardis, Ph.D.
Senior Vice Provost for Graduate and Professional Education

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TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

ABSTRACT

The number of female athletes participating in sport has risen substantially over the past 30 years. The rise in participation has translated into a parallel rise in injuries, especially those associated with overuse. Injury prevention and improved performance are paramount in the minds of sports health care professionals and strength and conditioning specialists; so finding ways to identify injury risk has gained increased attention in recent years. The purpose of this study was to examine the relationship between lower extremity injury and performance on both the modified Functional Movement Screen, (FMS) Standard FMS, and computerized Balance Error Scoring System (BESS). Data from a large prospective study was extracted for this project. Specifically, data from a cohort of female student-athletes participating in 5 high risk sports of Basketball, Field Hockey, Lacrosse, Soccer, and Volleyball was derived and analyzed using Receiver Operant Characteristic (ROC). A modified-FMS score was developed from four of the seven FMS tests completed as a part of baseline testing. These 4 tests include the Deep Squat, Hurdle Step, In-Line Lunge, and the Active Straight Leg Raise, with a total possible score of 12. BESS scores were derived from the MobileMat™ BESS from Tekscan (Tekscan, South Boston, MA). The total BESS error score across all 6 testing conditions was used in the correlational analysis. Injuries occurring as a result of participation in their respective sport were monitored using SportsWare On-Line (SWOL) injury tracking software (Computer Sports Medicine, Inc. Stoughton, MA). Lower extremity injury served as the independent variable in this project, while the scores from the FMS methods along with the total BESS error score served as the dependent variables. Overall 20 athletes sustained an injury in our cohort, with the means between the injured and non-injured groups for the three dependent variables being FMS-4 (8.1±1.1 and 8.0±1.2), FMS-7 (15.4±1.3 and 15.0±1.6), and BESS (18.6±4.5 and 17.4±5.3) respectively. There were no significant findings in our ROC analysis. The area under the curve for our three methods was FMS-4 (.510), FMS-7 (.567), and BESS (.577), indicating no useful diagnostic capability for any of the three variables for lower extremity injury. Despite some previous reports indicating injury prediction capabilities for the FMS, our finding do not support the usefulness of such a tool in our cohort of female student-athletes. Although the BESS has demonstrated some utility in the management of sport-related concussions, its ability to predict lower extremity injury is minimal.

Chapter 1

INTRODUCTION

Sport performance relies on basic locomotor manipulative and stabilizing movements including optimal balance. In addition, optimizing these basic performance attributes can aid in attenuating the probability of incurring an injury. Injuries come at a cost, the University of Iowa reported that the average annual investment in a student-athlete was in excess of $34,000 per athlete with over 10% of that cost coming from medical expenses.[34] This points to the importance of keeping athletes injury free and having the capability of identifying individuals at risk for injury. Title IX legislation has created many more opportunities for female athletes over the past 43 years with some select sports experiencing increases to more than 16 times their 1980 participation rates.[27] Simultaneously there has been an associated increase in the number of female athletes experiencing participation-related injuries; with greater than 50% of these injuries in the lower extremity.[17,39] When combined, the increase in participation and injury rates in the female athlete population, an environment has been created whereby the need for continued research exists. To date research has been performed on female athletes involving a broad range of exercise science based topics including differences in performance, biomechanics, power output, and injuries; with many comparing to their male sport counterparts.[12,21,32] Despite advances in sport performance research, there still exists some areas of performance that lag behind that which has been done with male athletes. One such area includes balance performance and its relationship with sport injury. Static and dynamic balance can be defined as the ability to maintain a base of support with minimal movement and the ability to perform a task while maintaining a stable position.[38] Many sports involve upright posture, so optimal balance is important for success in these endeavors. The Balance Error Scoring System (BESS) was developed as a portable, cost effective, and objective way of measuring static balance[29] The BESS test has been used extensively in sport-related concussion as well as lower extremity injury research.[24,25] McGuine and colleagues even reported an increase in the incidence of ankle injuries in high school basketball players who demonstrated deficits in static balance performance.[25] While there have been some studies examining balance performance and injury in older adult populations,[23,35] there exists a void as it relates to studies involving athletes, especially females. Improvements in balance assessment technology have enabled researchers the opportunity to better quantify static balance using sophisticated mathematical algorithms to compute such balance measures as center of pressure velocity, entropy, and 95% area of center of pressure.

From a sport performance perspective, side-to-side symmetry in the execution of purposeful movements is important. Therefore, asymmetrical movements are a cause for concern because of their potential for injury.[19] There are a number of studies involving asymmetrical movement deficiencies associated with the Functional Movement Screen (FMS) involving football athletes,[18] military personnel,[22] and firefighters;[5] however research is lacking with regard to the female sport population. Asymmetries are of interest because they lead to compensations that may lead to larger problems such as overuse injuries which account for an injury rate of over three times other reported injuries.[30] These overuse injuries were greater in number in college as compared to high school athletes, and were higher in females than males in gender comparable sports.[39] Some believe that many overuse injuries in athletics are the result of side-to-side asymmetries, causing detrimental compensatory movement patterns.[7,19.] This is especially important because Roos et al. reported collegiate female athletes have a higher proportion of overuse injuries as compared to their male sport counterparts.[30] The FMS is a tool developed to expose movement limitations and asymmetries by placing the athlete in extreme positions where weaknesses and imbalances become noticeable; especially when mobility and motor control are not optimal.[6] Traditional ways of utilizing the FMS include (1) a tool to determine a starting point for lifting progressions, (2) assessing the return-to-play readiness of an athlete, [1] and (3) a screening tool for injury risk. The FMS consists of seven different tests that are scored on a 4 point scale (0,1,2,3) with composite scores ranging from 0 to 21. The specific tests of the FMS include the Deep Squat, Hurdle Step, In-Line Lunge, Active Straight-Leg Raise, Shoulder Mobility, Trunk Stability Push-Up, and Rotary Stability. The Deep Squat and the Trunk Stability Push-up are single measurements and do not measure asymmetries. The remaining 5 tests use unilateral scores for both the left and right sides and thus are useful in identifying asymmetries in those movements. Because lower extremity injuries are predominant in most sports, it seems plausible to parse out only those component parts of the FMS that involve evaluation of the lower extremities (Deep Squat, Hurdle Step, In-Line Lunge, Active Straight Leg Raise). A contemporary graduate thesis published online by Saul and colleagues introduced a modified lower extremity version of the FMS.[27] Their study involved collegiate football players and injury risk associated with the modified FMS scores. Use of the modified version of the FMS involving a female sport population has not been performed.

It is clear that participation by female athletes in sports is on the rise, in addition it is evident that lower extremity injuries in female athletes have increased, so access to performance assessment tools such as the FMS and computerized balance measures may prove beneficial in identifying injury risk in this population. In this investigation we examined three specific aims: (1) Examine the relationship between the modified FMS score and lower extremity injury in a cohort of female athletes and (2) Examine the relationship between BESS scores and lower extremity injury. (3) Examine the relationship between the standard FMS and injury. We hypothesized that (1) The modified FMS will have similar predictive power to a full FMS screen in that a composite score averaging less than 2 per test will predict injury. (2) The BESS will not be a good predictor of lower extremity injury due to its static balance nature. (3) The standard FMS will be a significant predictor of injury in our cohort.

Chapter 2

METHODS

2.1 Experimental Approach to the Problem

This study analyzed the relationship between the scores derived from the modified FMS (FMS-4) and lower extremity injury. The FMS-4 consists of the Deep Squat, Hurdle Step, Active Straight-Leg Raise and the In-Line Lunge and were included because of their strong connection with lower extremity movements. The three tests that were omitted from being included in the FMS-4 were the Shoulder Mobility, Trunk Stability Push-up, and the Rotary Stability due to their non-lower extremity focused nature however these tests are included in the FMS-7 analysis. In addition, the relationship between BESS error scores and lower extremity injury was examined.

2.2 Subjects

Subjects are all female NCAA Division-I athletes from the University of Delaware competing in the sports of, Basketball, Field Hockey, Lacrosse, Soccer, and Volleyball. Twenty-one of the fifty athletes in the study sustained 33 lower extremity injuries over the time period. Demographic information can be found in Table 2 BESS and FMS Composite Scores by Sport (Means± Standard Deviations). All subjects were at least 18 years of age or older at the time of testing and signed the appropriate informed consent documents (UDIRB- 131714-10). Injuries occurring as a result of participation in their respective sport were monitored using SportsWareOn-Line (SWOL) injury tracking software (Computer Sports Medicine, Inc. Stoughton, MA). We defined injury in this study as the athlete meeting both of the following criteria (1) the injury had to occur as a result of sport participation and (2) the injury required the attention of the athletic training or sports medicine staff. In the event that an athlete sustained more than one lower extremity injury that athlete was only counted once in the statistical analysis.

2.3 Procedures

All subjects participated in two separate baseline test sessions that included balance assessment and FMS testing. The balance portion of the baseline testing required about 15 minutes to complete while the FMS test session lasted 1 hour.

Balance Testing

The MobileMat™ BESS from Tekscan (Tekscan, South Boston, MA) was used to provide a computerized output of the Balance Error Scoring System (BESS). The BESS consists of six stances: double-leg firm, single-leg firm (non-dominant), tandem firm (non-dominant in back), double-leg foam, single-leg foam (non-dominant), and tandem foam (non-dominant in back); where the non-dominant leg is considered that opposite of which one would kick a ball. In the foam condition, an Airex Balance Pad (Power Systems Inc., Knoxville, TN. USA; 46.4 x 38.7 cm) was placed on top of the Tekscan MobileMat® BESS portable sensor. Each stance was maintained for 20 seconds with the hands on hips and eyes closed. If subjects deviated from the test position or lost control of balance they were instructed to return to the original test position as quickly as possible to resume the test. As with the traditional BESS, the MobileMat® BESS allows a maximum of ten errors for each trial. In addition, when using the MobileMat® BESS, if a subject cannot maintain the proper stance for at least 5 seconds, or does not otherwise complete the condition, they are given the maximum score of 10. The total BESS score will be used for the correlational analysis.

Functional Movement Screen

Functional Movement Screen testing was conducted by members of the strength and conditioning staff. All staff members conducting the screen are FMS Level-1 certified. All student-athletes participating in this study were screened using all seven components of the FMS, creating a composite score ranging from 0-21. For purposes of this study and similar to that used in the Saul et al. thesis,[27] the modified FMS (FMS-4) was created using the scores from the Deep Squat, Hurdle Step, In-Line Lunge, and the Active Straight-Leg Raise These tests are selected due to their close approximation to lower extremity movements. An FMS-4 composite score ranging from 0-12 was established, with individual scores ranging from 0-3. The standard FMS will use the scores from all seven tests, the four from the modified in addition to the Shoulder Mobility, Rotary Stability, and the Trunk Stability Push-Up. A detailed description of the four components of the FMS-4 is included here based on the work by Burton and Cook.[6]

(1) Deep Squat- The individual assumes the starting position by placing his/her feet approximately shoulder-width apart and the feet aligned in the sagittal plane. The individual then adjusts their hands on the dowel to assume a 90-degree angle of the elbows with the dowel overhead. Next, the dowel is pressed overhead with the shoulders flexed and abducted, and the elbows extended, so that the dowel is directly overhead. The individual is then instructed to descend as far as they can into a squat position while maintaining an upright torso, keeping the heels and the dowel in position. The athlete holds the descended position for a count of one, and then returns to the starting position. As many as three repetitions may be performed. If the criteria for a score of “3” is not achieved, the athlete is then asked to perform the test with a 2x6 block under the heels

(2) Hurdle Step-The individual assumes the starting position by first placing the feet together and aligning the toes touching the base of the hurdle. The hurdle is then adjusted to the height of the athlete's tibial tuberosity. The dowel is grasped with both hands and positioned behind the neck and across the shoulders. The individual is then asked to maintain an upright posture and step over the hurdle, raising the foot toward the shin, and maintaining alignment between the foot, knee, and hip, and touch their heel to the floor (without accepting weight) while maintaining the stance leg in an extended position. The moving leg is then returned to the starting position. The hurdle step should be performed slowly and as many as three times bilaterally. If one repetition is completed bilaterally a score of 3 is given

(3) In-Line-Lunge- The tester attains the individual's tibia length, by either measuring it from the floor to the tibial tuberosity or acquiring it from the height of the string during the hurdle step test. The individual is then asked to place the end of their heel on the end of the board or a tape measure taped to the floor. The previous tibial measurement is then applied from the end of the toes of the foot on the board and a mark is made. The dowel is placed behind the back touching the head, thoracic spine, and middle of the buttocks. The hand opposite to the front foot should be the hand grasping the dowel at the cervical spine. The other hand grasps the dowel at the lumbar spine. The individual then steps out on the board or tape measure on the floor placing the heel of the opposite foot at the indicated mark. Both toes must point forward, and feet must begin flat. The individual then lowers the back knee enough to touch the surface behind the heel of the front foot, while maintaining an upright posture, and then returns to the starting position. The lunge is performed up to three times bilaterally in a slow controlled fashion. If one repetition is completed successfully then a three is given for that extremity (right or left).

(4) Active Straight-Leg Raise The individual first assumes the starting position by lying supine with the arms in anatomical position, legs over the 2 × 6 board, and head flat on the floor. The tester then identifies the mid-point between the anterior superior iliac spine, and the midpoint of the patella of the leg on the floor, and a dowel is placed at this position, perpendicular to the ground. Next the individual is instructed to slowly lift the test leg with a dorsiflexed ankle and an extended knee. During the test the opposite knee (the down leg) must remain in contact with the ground and the

toes pointed upward, and the head in contact with the floor. Once the end-range position is achieved, note the position of the upward ankle relative to the non-moving limb. If the malleolus does not pass the dowel, move the dowel, much like a plumb line, to equal with the malleolus of the test leg, and score per the criteria

2.4 Statistical Analysis

Dependent variables for this study are (FMS-4 composite score, FMS-7 composite score, and BESS total errors) while the independent variables are whether or not an injury occurred in the lower extremity, all injuries will be considered. Because the variables being measured are on the interval and nominal scale respectively the statistical data will be analyzed using Receiver Operant Characteristic (ROC) curves. This type of analysis is useful in that sensitivity, or the ability to correctly identify the proportion of positives and specificity the proportion of negatives that are correctly identified can be readily analyzed from the readout allowing for a cut point to be established if one does indeed exist. One advantage of using ROC is that it does not require homogeneity of groups to be effective. An ROC that has its peak closer to the upper left hand corner of the graph (i.e. a larger area under the curve) is representative of a test with a better diagnostic capability. An area under the curve of .50 represents a test that has an equal true positive and false positive rate across all cut scores. An area under the curve of at least .639 represents a medium effect size while .566 represents a small effect size. Data were analyzed using the statistical package for the social sciences (SPSS Version 22.0 Armonk, NY IBM Corp).

Chapter 3

RESULTS

3.1 Introduction

In this study there were 50 total subjects that sustained a combined 33 injuries throughout the 8-month study period. The demographic data for the participants can be found in Table 1. Nine of the athletes suffered multiple lower extremity injuries. In the event of an athlete sustaining multiple injuries within the study period the athlete was not considered multiple times for the outcome variable for the purposes of the analysis.

Table 1 Demographic Information

Sport	Subjects	Age (Y)*	Height (cm)*	Mass (Kg)*
W. Basketball	8	18.1 ±.35	183.8 ±4.5	84.1 ±11.6
W. Field Hockey	7	18.1 ±.38	163.6 ±4.9	61.2 ±6.2
W. Lacrosse	14	18.3 ±.47	163.1 ±6.1	58.1 ±7.9
W. Soccer	14	18.2 ±.41	166.7 ±5.3	61.4 ±5.9
W. Volleyball	7	18.0 ±0	174.9 ±7.4	66.5 ±8.5
Total	50	18.2 ±.1	170.4±8.9	66.2±10.4

*Values are represented as means± standard deviations

3.2 BESS Scores and Injury Prediction Ability

BESS composite scores ranged from 16.2 to 20.9 across all subjects. The breakdown of BESS scores across individual sport athletes is located in Table 2. There were 49 total subjects in the BESS protocol with 20 of them incurring at least one of the 33 injuries. It is important to note that one of the women's soccer players did not have BESS data and was excluded from the analysis. Women's Volleyball had the worst average BESS score of all the sports studied and would be classified as having poor balance against normative values when compared to all healthy adults and women of their age range.[16] It is interesting to note that the traditionally taller sport athletes (Basketball and Volleyball) had more BESS errors than those in the other three sports (Lacrosse, Soccer, and Field Hockey) studied where height tends to emphasized less.

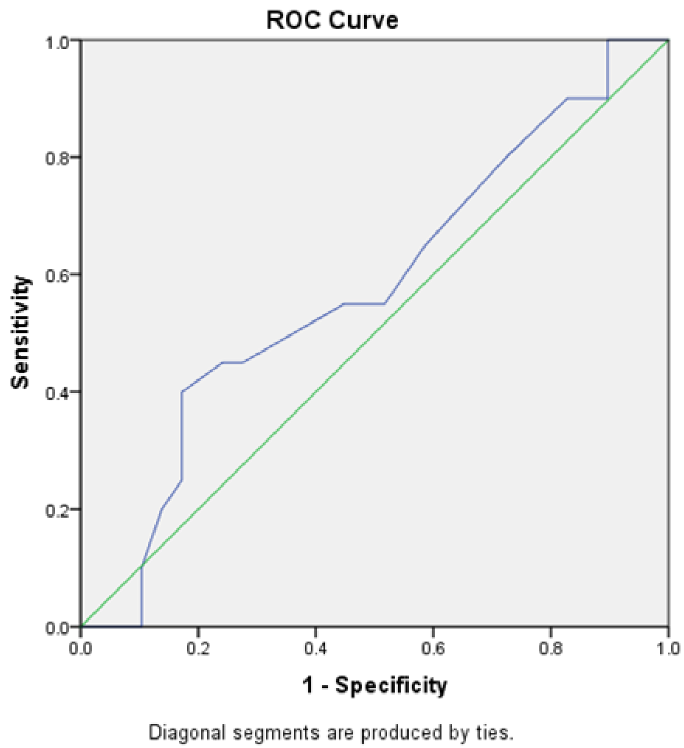
Table 2 BESS and FMS Composite Scores by Sport

Sport	BESS*	FMS-4*	FMS-7±*
W. Basketball	19.1 ±4.3	8.0 ±1.2	14.6 ±1.1
W. Lacrosse	16.2 ±3.2	8.4 ±.63	15.4 ±1.1
W. Soccer	17.5 ±6.1	8.5 ±1.2	16.3 ±1.2
W. Field Hockey	17.4 ±4.4	6.5 ±.54	12.8 ±0.8
W. Volleyball	20.9 ±5.8	7.6 ±.79	15.1 ±0.7
Total	18.2±1.8	7.8±.81	14.8±1.3

*Values are represented as Means and Standard Deviations

The results of the ROC analysis indicate that the BESS composite scores are not a good predictor of lower extremity injury in this cohort of female student athletes. Details of this ROC curve are shown in Figure 1. Analysis of the curve proved to be not significant (p=.365), while the area under the curve (AUC) revealed an effect size only slightly better than what could be predicted from random chance diagnostic (AUC=.577). When the BESS composite scores (Table 3) were compared between subjects in the injured group (18.6±4.5) errors to the non-injured group (17.4±4.3) errors it becomes apparent that these scores are closely matched.

Figure 1 BESS ROC Curve

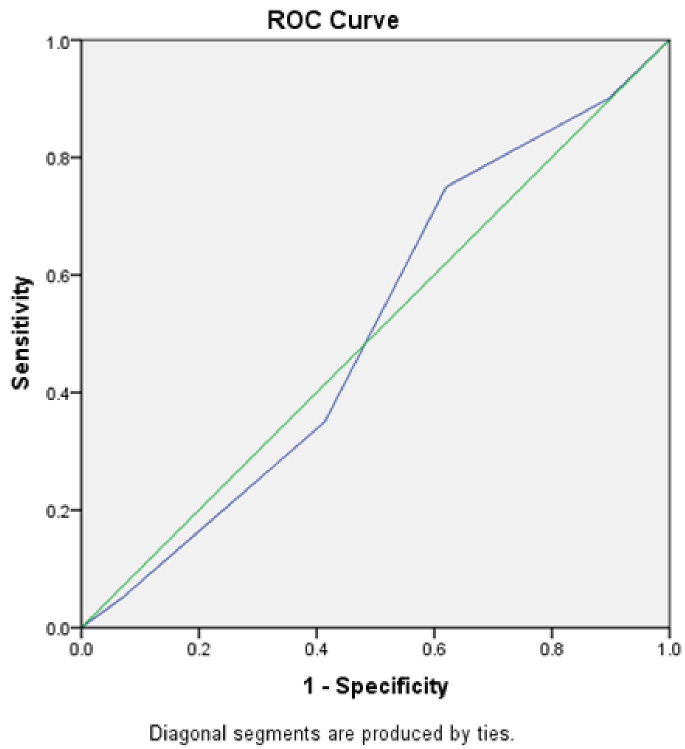


3.3 Modified FMS and Injury Prediction Ability

FMS-4 composite scores ranged from 6.5 to 8.5 across all subjects. The data for the FMS-4 is represented by sport in Table 2. Note that the scores across different sports are tightly matched with the exception of Field Hockey that had a score of 6.5 and are quite different from those reported by Saul et al. in his study of football players (11.09±.76) and (10.95±1.11) in the injured and non-injured groups respectively. The total number of subjects for the modified FMS was also 49 with 20 incurring at least one lower extremity injury. It is important to note that there was one women's basketball player that did not have FMS data and was excluded from this analysis.

The results of the ROC analysis indicate that the FMS-4 composite scores are not a good predictor of lower extremity injury in this cohort of female student athletes. Details of this ROC curve are shown in Figure 2. Analysis of the curve proved to be not significant (p=.903), while the area under the curve (AUC) revealed an effect size only slightly better than what could be predicted from random chance diagnostic (AUC=.510). When the FMS-4 composite scores (Table 3) were compared between subjects in the injured group (8.05±1.1) to the non-injured group (8.0±1.2) it becomes apparent that these scores are closely matched.

Figure 2 Modified FMS ROC curve



3.4 Standard FMS and Injury Prediction Ability

FMS-7 composite scores ranged from 12.8 to 16.3 across all subjects. The data for the FMS-7 is represented by sport Table 2. Note that the scores across different sports are tightly matched with the exception of Field Hockey that had a score of 12.8 and are quite different from those reported by Saul et al. in his study of football players (17.85±1.42) and (18.32±1.72) in the injured and non-injured groups respectively. The total number of subjects for the modified FMS was also 49 with 20 incurring at least one lower extremity injury. It is important to note that there was one women's basketball player that did not have FMS data and was excluded from this analysis.

The results of the ROC analysis indicate that the FMS-7 composite scores are not a good predictor of lower extremity injury in this cohort of female student athletes. Details of this ROC curve are shown in Figure 3. Analysis of the curve proved to be not significant (p=.428), while the area under the curve (AUC) revealed an effect size only slightly better than what could be predicted from random chance diagnostic (AUC=.567). When the FMS-7 composite scores (Table 3) were compared between subjects in the injured group (15.4±1.3) to the non-injured group (15.0±1.6) it becomes apparent that these scores are closely matched.

3.5 Results Summary

Asymptotic significance is the measure of statistical significance in an ROC analysis. To reach significance the value must be less than 0.05. The values for asymptotic significance can be found in Table 4. None of the data reached asymptotic significance therefore a cut score for optimal sensitivity and specificity could not be established. Consequently, with no cut score diagnostic odds ratios could not be calculated.

Figure 3 Standard FMS ROC Curve

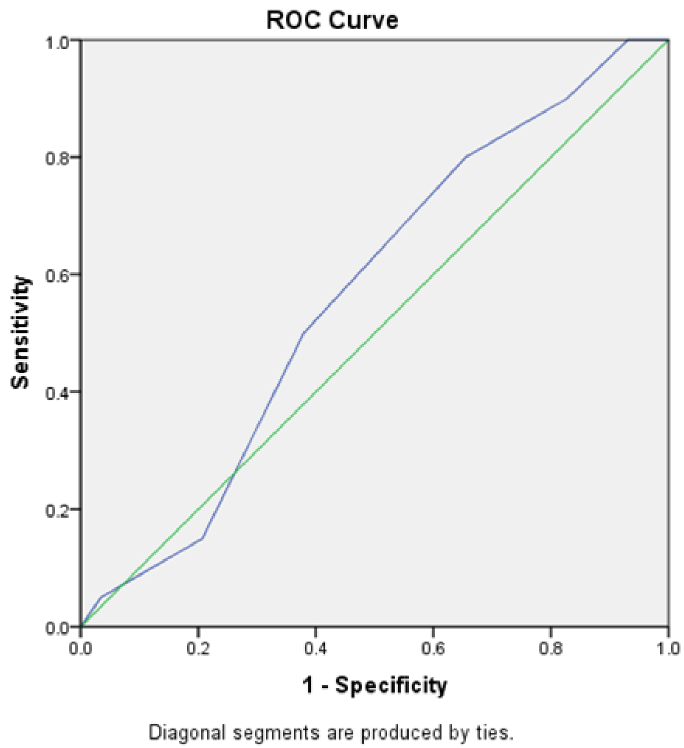


Table 3 Means and Standard Deviations by injury group for the independent variables

Variable	Injured Group*	Non Injured Group*
BESS Score	18.6 ±4.5	17.4 ±5.3
FMS-4	8.1 ±1.1	8.0 ±1.2
FMS-7	15.4 ±1.3	15.0 ±1.6

*Values are represented as Means with Standard Deviations in parentheses.

Table 4 ROC Analysis Asymptotic Significance and AUC

Variable	Overall *p* Values	AUC*
BESS Score	.365	.577
FMS-4	.903	.510
FMS-7	.428	.567

* AUC = Area Under the Curve.

Chapter 4

DISCUSSION

4.1 Introduction

The primary purpose of this study was to determine if a lower extremity focused, modified FMS composite score could be used to predict lower extremity injury in NCAA Division-I female athletes from the sports of basketball, field hockey, lacrosse, soccer, and volleyball. The secondary purpose was to examine how static balance as measured by the BESS and a traditional seven test FMS composite score could predict lower extremity injury in the same population. Athletes that suffered a lower extremity injury counter intuitively scored higher on both the modified and standard FMS. While they scored worse on the BESS when compared to the non-injured group.

4.2 BESS

We examined the utility of the BESS in predicting injury in our cohort of athletes using ROC curves to determine the diagnostic capability. We hypothesized that the BESS would not be a good predictor of lower extremity injury in our cohort due in large part to its measurement of errors in static balance. Our data suggests that the BESS has no significant predictive ability to determine a lower extremity injury in our cohort which confirms our hypothesis. Of note, however, is that of the three methods that we used to determine the predictive power of injury the BESS was the closest variable to obtaining significance and had the largest effect size (Table 4). To our knowledge this is the first study to use the BESS in an attempt to examine injury diagnostic capability for musculoskeletal injuries. Docherty et al. studied collegiate athletes with functional ankle instability (FAI) and determined that those with FAI had worse balance than those without. Although that study did not look at predictive power directly it was one that did examine the connection between poor balance and injury.[9] Balance assessments have been used for injury prediction before but much of the research deals with dynamic balance measures. One such study by Plisky et al. utilized male and female high school basketball players and reported that components of the Star Excursion Balance Test (SEBT) are able to predict lower extremity injury.[28] The SEBT differs from the BESS in that it requires dynamic movements, unlike the BESS which measures static balance.

For many years the BESS has been used for concussion-related research and clinical management dealing with balance deficits compared to baseline in athletes suspected of or diagnosed with a sport-related concussion. A study by Guskiewicz et al. using collegiate athletes as their subjects looked at BESS scores at baseline and across recovery times.[14] What is noteworthy about their baseline data is that the average BESS scores ranged from 12-15 in their cohort of collegiate athletes, while our average was 18.6 and 17.4 for the injured and non-injured groups respectively (Table 3). Also of note is that nearly all errors measured post-concussion in their study were lower than our averages for both the injured and non-injured groups.[14] We suspect the differences between studies involved BESS measurement techniques.

Specifically, we utilized the MobileMat™ BESS from Tekscan which may be more sensitive in detecting BESS errors than the clinician viewed scoring utilized by Guskiewicz et al. As the popularity of the the MobileMat™ BESS from Tekscan grows perhaps future comparisons can be made easier.

The BESS, however, is not without its own limitations. There are factors that can influence the errors that a participant accumulates in a test. Fatigue is one such example of an external factor. In a study conducted by Wilkins et al. subjects were put through either a 20 minute fatiguing protocol or rest. The subjects were pre and post tested in the study, those subjects put through the fatiguing protocol sustained significantly more errors than the control group.[37] This limitation to the BESS of having increased errors due to fatigue should not have had an affect our study because the athletes were not fatigued during the baseline testing protocol. Sport participation and fatigue is another factor that can influence BESS error accumulation. In a study conducted by Bressel et al. comparing static and dynamic balance in gymnasts, soccer, and basketball players. What is interesting about their study is that despite the various different body positions and enhanced need for proprioception that would be expected in a gymnast the gymnast did not score statistically better than the soccer players. However they did accumulate less errors than the basketball players the authors discuss the potential difference in footwear or lack thereof and playing surface as potential explanations as to why gymnasts performed better than basketball players.[2] This limitation has limited applicability to our study because we did not include any sports that are artistic performance sports where single-leg barefoot aerial proprioception are emphasized as task relevant cues. Learning effect is also an important consideration to the BESS. A study by Broglio et al. used 48 young healthy adults and put them through five BESS protocols to try to ascertain reliability associated with learning effects. Testing was clinically reliable in their study when either 3 tests were administered in a single day or when 2 trials were done at different time points.[3] This could be a reason why scores may have been poor in our groups because the athletes were only tested once on the BESS and Broglio et al. suggest averaging three trials for comparison to normative values.

We were also interested as to how our BESS scores were compared to normative values in the healthy adult population. Using results from Iverson and Koehle we noted that our scores were higher than those of similar age as reported by Iverson and Koehle and would have classified our subjects in both groups as having below average to poor scores.[16] We were also interested in comparing our sport averages to normative values and in doing so noted that surprisingly the women's volleyball team would rank in the poor category. Once again we attribute the differences in methodology most likely account for those differences. In addition the notion that dynamic balance may be of greater importance to these athletes than the static nature that is assessed by BESS is supported. Although a study by Clark et al. suggested that a modified BESS and a Modified Star Excursion Balance Test do have a significant correlation, the strength of the association is limited.[8] In other words the static balance quality measured by the BESS is not likely to be able to predict musculoskeletal injury.

4.3 FMS-4

We utilized a method similar to Saul et al.[31] to establish our modified, lower extremity focused version of the FMS by examining the composite scores of the Deep Squat, Hurdle Step, In-Line Lunge, and the Active Straight Leg Raise. Using their own data they were able to establish a cut-score of 11.5 that maximized sensitivity and specificity for their population. We hypothesized that the FMS-4 would have a similar predictive power for injury as the FMS-7 with average scores of 2 on each test yielding a cut score predictive of injury. Contrary to their findings the results of our ROC analysis did not yield any significant injury prediction capabilities and thus did not support our original hypothesis. When closely examining the FMS-4 data between our study and that of Saul et al. our non-injured group had a mean FMS-4 score of 8 while their non-injured mean was 10.9. There could be several reasons as to why this is the case. Uncertain to the number of different FMS raters that were used in the Saul et al., study we do know that 3-4 different raters were used in our study. As a result subtle differences in scoring between different raters may have influenced our lower FMS scores. However it is important to note that all were FMS certified and experienced. Additionally, the values reported by Saul et al. are very close to a perfect 12.0 score which in most instances is highly unlikely. Secondly differences in gender of the athletes tested in our study (female) vs those tested by Saul et al. (male) may help to explain some of the differences in FMS scores between studies. However a recent study by Chimera et al. that investigated composite FMS scores in NCAA Division-I athletes reported no significant differences between the genders. Women did have a tendency to score higher on the In-Line Lunge and the Active Straight Leg Raise but scores on the Deep Squat and Hurdle Step were nearly identical.[7] Based on this information we would have expected our scores to actually be higher than that reported by Saul et al. but this was not the case. Lastly differences in the total number of subjects between our study (N=50) and that of the Saul et al. study (N=70) could explain some of the differences.

4.4 FMS-7

The standard seven test FMS has been purported to be a good predictor of injury in athletes by multiple studies[5,9,18,19,20]. Based upon the work of these previous studies we hypothesized that the FMS-7 would be a good predictor of injury. However our results suggest that the FMS-7 is not a good predictor of lower extremity injury in our cohort of female athletes. One of the first studies to utilize the FMS was done by Kiesel et al. using professional football players; whereby they established a cut score of 14 as the point where injury likelihood increased. A more recent investigation by Saul et al. in collegiate football players suggested a much higher cut score of 18.5. Interestingly we did not find any significant cut score that maximized sensitivity and specificity in our population of female student athletes. Not surprising are these elevated FMS-7 scores considering our earlier comments about the FMS-4 score being higher than expected. We argue that the elevated scores are greatly influenced by many individual scores closer to a 3. Another comparison of interest was to examine the injured vs. non-injured means as reported by Kiesel et al. and Saul et al. to our own FMS-7 values. For the injured group Kiesel et al. reported an FMS-7 value of 14.3, while Saul et al. reported a value of 17.8. Our value seemed to fall between those two with an average of 15.4 for the injured group. However in the non-injured group our score was lower (15.0) as compared to the 17.4 and 18.4 scores reported by Kiesel et al. and Saul et al. respectively. We attribute the differences to the fact that Kiesel used a much more stringent definition of injury than either the Saul et al. paper or our own study with their professional football players needing to be held on the injured reserve list for a minimum of 3 weeks.[18] Despite using different levels of athletes, the fact that both Kiesel et al. and Saul et al. are using high level football players you would expect their scores to be more closely approximated for both their injured and non-injured group but their differences in injury definition could explain the differences in scores. Both of their injury definitions required the athlete to be held out for a certain period of time while ours did not. While our definition may capture more injuries, it effects the scores between the injured and non-injured groups making them more similar. Perhaps a better comparison to our study is the report from Warren et al. Using FMS-7 scores for injury prediction in a large cohort of NCAA Division-I student athletes.[36] The differences in FMS-7 scores they report for the injured and non-injured groups were (14.3) and (14.1) respectively, quite similar to ours in that the differences are small, while their injury definition mirrored that which we used. More recently a 2015 meta-analysis by Dorrel et al. examined the validity of the FMS to predict injury and establish a cut score.[11] Their analysis calls into question the validity of the FMS for multiple reasons, among which different authors used the cut score of Kiesel et al. to predict injury in spite of the fact that they had different definitions of injury. In addition the meta-analysis pointed to the fact that many authors failed to report AUC values.[11]

One of the inherent limitations to both the FMS-4 and FMS-7 is the fact that there are nuances in scoring a value of 2 in each of the component tests. The broad scope of deficiencies that can lead to a score of 2 makes it so there may be inconsistencies between athletes scoring a 2. The multi-joint nature of many of the component tests exposes the subject to a lower score, however the deficiencies may not be substantial enough to limit the athlete from doing the movement entirely and being scored as 1. This would lead to similar group scores across participants whether injured or not and would call into question the predictive power in all athletes.

4.5 Limitations

It is important to note some limitations associated with our study. We acknowledge the fact that not all FMS testing was performed by the same raters. Although multiple studies have shown the interrater reliability[13,26,31] of the FMS to be acceptable, the potential for error with multiple raters conducting the test is still something that needs to be considered. We used multiple raters because each strength and conditioning coach is responsible for the FMS testing of their own assigned teams. Secondly our timeline for injury reporting was very specific to ending mid-March 2016 which may have limited the number of reportable injuries from our WLAX team. Lastly no considerations were made for previous injury history in any of the subjects utilized in this study. This limitation is of importance based on some of the earlier work from Kiesel et al. that spoke to injury history and the potential for associated asymmetries affecting injury susceptibility.[19]

4.6 Future Research

The FMS scoring criteria has fallen under scrutiny by other researchers.[4,15] Based on our results we contend that future research involving the FMS should utilized a 100 point FMS scoring scale. With the current 4 point scoring scale (0,1,2,3) many scores fall in the 2 range because of the reasons mentioned above. With a 100 point scoring scale scores may be more precise and possibly aid in the stratification of injury risk and establishing a more valid cut score. Lastly with regard to balance assessments and injury prediction we recommend that dynamic measures of balance be considered versus the static measures of balance used in our study, because most sport activities combine both static and dynamic balance.

4.7 Conclusion

FMS and BESS scores are two contemporary measures to examine sport performance. The purpose of this study was to examine the injury prediction capabilities of both the FMS and BESS scores. Acknowledging the fact that our study was underpowered, nonetheless our results indicate little or no injury predictive qualities for the BESS, FMS-4, and FMS-7 scores. Sport performance professionals along with clinicians may need to look at other measures of performance appraisal to gain greater insight into injury prediction.

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Appendix A

LITERATURE REVIEW

A.1 Introduction

Title IX legislation went into effect over 40 years ago and since its inception the number of female athletes participating has increased. Subsequently this increase in the number of athletes has created a need for research to be done with female athletes as the primary focus. Institutions of higher education nationwide invest a great deal of time, money, and energy into athletics, so keeping student-athletes free from injury is a priority. Injury prediction research is gaining popularity among sports medicine and strength and conditioning researchers. There is some evidence that an individual with poor balance has an increased risk of injury.[18] More contemporary evidence indicates that asymmetries in performance variables such as balance, strength, proprioception, muscle endurance, flexibility, and mobility put athletes at risk for injury.[16] The ability to recognize and improve upon these deficiencies is of great importance in the sports medicine community. In spite of the available research there exists a gap concerning a joint approach involving balance and a Functional Movement Screen (FMS) to assist identifying female athletes that are at an increased risk of incurring injury.

A.2 Female Athletic Participation

Title IX legislation has had its greatest impact on athletics especially at the high school and collegiate level. Title IX paved the way for the number of female athletes in sport to explode over the past 30 years by several fold. According to the 2013 NCAA participation report from 1980-2012 the number of women's lacrosse players increased from 930 to 2784 and women's soccer increased from 530 to 8749 over that same time period.[20] Parallel to this participation has been an increase in injuries sustained by these student-athletes. Emphasis on the female athlete has created a need for strength and conditioning research to better guide techniques and protocols that have traditionally been based on male sport athletes. Research examining the 2003 NCAA injury report revealed a significant increase in the number of injuries that occurred in the lower extremity in female athletes over the 15 year period examined.[13] Interestingly the highest number of injuries that occurred per athlete exposure took place in the preseason practice period. Hootman et al. speculated that the primary cause of the injury increase was due to poor conditioning levels and an increased practice time during the pre-season period.[13]

Independent of studying the FMS a recent epidemiological study by Yang et al. on the nature of injuries in male and female intercollegiate athletes classified those injuries as either acute or overuse. Additionally over that same time period female athletes accounted for more than half of the total overuse injuries. When looking at the ratio of the reported injuries that were due to overuse, the female athletes accounted for 62% of the injuries. Interestingly, this study also reported that more than half of the injuries that occurred were in the lower extremity.[29] On close examination of the overuse injuries that occurred more than half of those *did not* result in time loss from participation. From a practical standpoint overuse injuries are especially concerning to strength and conditioning specialists because they limit optimal training ability and conditioning on the part of the athlete. Of equal importance is the fact that if an athlete becomes deconditioned their risk of sustaining an injury increases and that risk may be augmented by a longer period of restriction.

A.3 Balance

Adequate balance is a prerequisite to success in sport performance. There are a multitude of ways that balance can be assessed by sports medicine professionals. Static and dynamic balance can be defined, respectively, as the ability to maintain a base of support with minimal movement and the ability to perform a task while maintaining a stable position.[28] One clinical tool for measuring static balance is the Balance Error Scoring System (BESS). The BESS was developed as a portable, cost effective, and objective way of measuring static.[22] The BESS is evaluated by totaling errors in balance under three different stance conditions. (double-leg, single-leg, tandem) and is performed on two different surfaces (hard and foam), with the eyes closed, and the hands on the hips. An error is defined as the following: (1) moving the hands off of the iliac crests, (2) opening the eyes, (3) step stumble or fall, (4) abduction or flexion of the hip beyond 30^o, (5) lifting the forefoot or heel off of the testing surface, and (6) remaining out of the proper testing position for greater than 5 seconds. The maximum number of errors for any given testing condition is 10.[22] The BESS is a reliable measure of balance with the greatest generalizability coefficient occurring after the test is administered three times and averaging three test trials.[2]

Research examining balance as a predictor of lower extremity injury is limited. An early publication by McGuine et al. involving high school basketball players did report a connection between balance deficits and ankle injury incidence using amount postural sway as a measure of balance.[18] Additionally work by Plisky and colleagues utilized a Star Excursion Balance Test in a cohort of male and female high school basketball players to study injury risk. Interestingly they observed that females with a composite reach distance of less than 94.0% of their limb length were 6.5 times more likely to have a lower extremity.[23] Despite refinements in balance assessment technology over the last fifteen years we are unaware of any additional more contemporary studies that have examined balance and lower extremity injury risk especially in the female athlete.

TekScan (Tekscan Inc. South Boston, MA) has recently introduced The MobileMat™ BESS utilizing a portable mat to calculate the errors objectively using advanced mathematical algorithms. A recent study comparing the computer-derived versus human-derived scores on the BESS yielded fair to good agreement with all stances on both the solid and firm surfaces.[5] While BESS scores provide a crude and limited picture of balance there are several other more sophisticated measures that can be used. These variables include such measures as center of pressure (COP) velocity of sway, time to stabilization, 95% area of COP, and entropy.

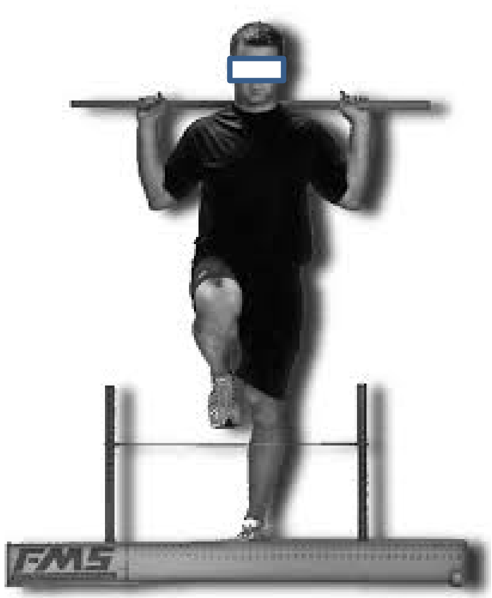
A.4 FMS

The Functional Movement Screen (FMS), developed in 1995 is one component in the larger battery of functional movement system tests. The FMS consists of a grading system that is used to observe movement patterns and expose movement deficiencies and asymmetries by putting a person in extreme positions where compensations will expose said deficiencies.[3] The movement patterns assessed are those that are considered to be essential to normal athletic function. The FMS was developed as a result of needing a way to identify whether athletes perform their skilled movements with or without compensations. For example two athletes that can perform well-above average on the partial curl-up test based on normative values; whereas one athlete initiates their reps using the head and neck the other athlete may primarily use the trunk musculature to achieve the movement. From a performance standpoint both athletes would appear to be equal but the performance test does not recognize the compensatory movement patterns that are elicited by the first athlete such as inappropriate movement initiation with the head or neck or being uncontrolled in the speed of the movement. The FMS is designed to expose these deficiencies and allow for a more comprehensive evaluation of the athlete from a strength and conditioning perspective. Use of the FMS as a screening tool is gaining popularity thanks in part to its use at the National Football League Scouting Combine.

The FMS consists of 7 component parts and three additional clearing tests:

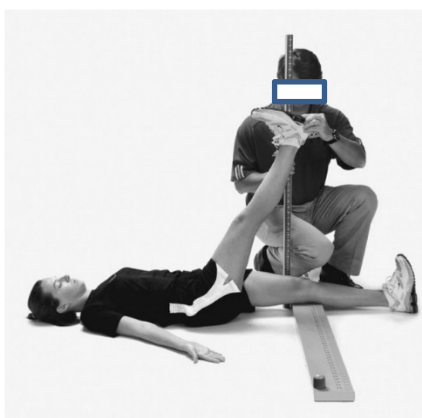
1) Deep Squat (DS)

2) Hurdle Step (HS)



3) In-Line Lunge (IL)

4) Active Straight Leg Raise (ASLR)



5) Shoulder Mobility (SM)

6) Trunk-Stability Push-up(TSPU)

7) Rotary Stability (RS)

The three additional clearing tests include the (1). shoulder impingement (2) spinal flexion (3) spinal extension.

Each component part is scored on a four point scale from 0-3 with a zero score assigned to subjects who report pain during the test or obtain a positive classification on the clearing test. A score of 1 is given if the subject is unable to perform the movement or if they fail to obtain the proper starting position. A score of 2 is earned if the movement is completed but there is a compensation made to complete the task. The compensations vary from test to test for a given movement and may include, for example, external rotation of the hip during the ASLR. A score of 3 is assigned to subjects who perform the movement completely without compensation. Functional Movement Screens composite scores can range from 0 (worst) to 21 (best).

In addition to its use as a screening tool the FMS has been examined as a diagnostic tool for injury risk. Several researchers[7,10,14] have suggested an FMS composite cut-off score for injury prediction; whereas scoring below the cut-off point would have a higher likelihood of injury. The aforementioned authors suggest that the cut off scores is 14. Chorba et al. used a cohort of NCAA Division-II female athletes across the three sports of soccer, volleyball, and basketball in their study. Their definition of injury was somewhat broad in that it included anything that had the athlete seek advice or attention from a sports medicine professional, likely inflating the total number of injuries.[7] More recently Garrison and colleagues (2015) used a population of NCAA Division-I athletes across both genders whereby the definition of injury was limited to that which kept the athlete from participating in their respective sports for a minimum of 24 hours and/or if a prophylactic (bracing or taping) intervention occurred.[10] Kiesel et al. examined FMS scores in a cohort of professional football players using a 14 cut-off score. Their definition of time-loss was very strict and narrow in that the football athletes had to have spent a minimum of 3 weeks on the injured reserve list. Despite the wide range of injury definitions among these researchers it is interesting to point out that the predictive value of a 14 cut-off score increased if athletes had a prior history of injury. Another interesting population that has been studied using the FMS as a pre-training screen has included military and firefighting personnel.[14] Studies by O'Connor et al. and Butler et al. also used a cut-off score of 14.[21,4] What is unique about both of these studies is that poor FMS performance in conjunction with core strength and conditioning levels were strong predictors for injury; which included both overuse and acute injuries.[21,14] While there appears to be a general consensus in the literature for a cut-off score of 14 a recent paper by Warren et al. examining 167 NCAA Division-I athletes with no previous history of injury counters that this cut-off score is non-universal. Their effort to closely examine individual FMS components and injury risk, for example, demonstrated that subjects scoring a two on the In-Line Lunge had a higher incidence of injury than those who scored a three; a finding that is in stark contrast to those studies that looked at FMS component parts a whole.[27] In addition to using FMS scores as being the sole predictor of injury one should also consider measures such as body mass index (BMI) and levels of physical activity, both of which are correlated with FMS scores. The efforts of Duncan and Stanley suggests that FMS scores are strongly correlated with BMI and physical activity (pedometers).[9]

Measurement techniques that are carefully scrutinized as being valid and reliable are best accepted. The FMS is purported to expose movement deficiencies and asymmetries that are essential to athletic performance. We carefully examined three previous reports whose purpose was to study the test-retest reliability of the FMS. Teyhen et al. monitored FMS scores in a group of soldiers using two novice raters in screening sessions separated by three days. They reported moderate to good intrarater ICC of .76 (95% CI: .63, .85) and interrater ICC .74 (95% CI .60, .83) reliability.[26] Another study by Gribble et al. evaluated the reliability of the FMS with different raters who had varying levels of knowledge and experience with the FMS and its component parts. As expected those individuals with prior exposure to the FMS testing process had better interrater reliability.[12] This points to the important fact that the FMS screen should be conducted by those with some level of familiarity with the process. An additional study by Minick et al. looked at the interrater reliability of scoring the FMS between novice and expert raters. They define *novice* raters as being those who had taken an FMS training course and *experts* as individuals that taught an FMS training course and had multiple years of experience with the screen.[19] While intra rater reliability was high in both the *novice* and *expert* groups, there was less agreement from an interrater perspective. This finding emphasizes the need that any follow up FMS screens be done by the same individual.

A.5 FMS and Athletic Performance

In addition to its usefulness as an injury prediction tool, the FMS has also been used to assess return-to-play readiness. Boyle et al. conducted research on adolescents and adults that had undergone anterior cruciate ligament reconstructive (ACLR) surgery a minimum of 9 months prior to the start of the study. They used the FMS and the Lower Quarter Y- Balance Test (LQYBT) to determine if their scores were indicative of injury risk (composite FMS score <14). It is important to note that all subjects had otherwise met return-to-participation criteria prior to enrolling in the study, passed other objective and subjective measures from their health care providers and/or sports medicine teams to return to participation. Interestingly, and despite medical clearance all three groups of the subjects tested had scores lower than 14 on the FMS composite. There was however no significant change in LQYBT scores, nor any indications of asymmetrical differences between the injured and non-injured sides.[1] The importance of this study in highlighting performance deficiencies in athletes who otherwise were cleared for full participation exposes the need for additional study. Furthermore, having pre-injury (baseline) FMS data, which is common in many collegiate settings, would further strengthen such research and provide an additional tool in determining return-to-play status post injury.

If FMS is looked at as part of the performance pyramid, one could argue that improvement in FMS scores would be important in evaluating effectiveness of corrective exercise programs in a non-injured population. Currently there are three contemporary research studies that collectively studied improvements in composite FMS scores over a 6 week training period involving corrective exercises focused on FMS improvement. In particular the Goss et al. used a military population of special-forces soldiers. According to FMS guidelines related to the corrective exercise hierarchy, the most important exercise to target is the Active Straight Leg Raise (ASLR) especially with scores of 1 or when asymmetries are present. In the special forces population the most significant improvement occurred with the ASLR post intervention. Another important component of the performance pyramid is skill and therefore having the ability to link FMS performance to this aspect of the pyramid is important to sport coaches.[8,11,15] A contemporary report by Lockie et al. set out to determine if there was a relationship between FMS scores and various other measures of sport performance (sit and reach, speed tests, agility test, and explosive power tests). While some tests did have a correlation to performance outcomes such as ASLR and unilateral sit and reach test; the varying correlations between most components of the FMS and most of the performance outcomes measured did not give any indication that scoring a certain way on the FMS could be predictive of an athletes on-field performance.[17] Additionally a recent study conducted by Parchman and

McBride looked at the correlation between FMS and 1RM squat performance in a cohort of NCAA Division I male and female golfers (n=9 and n=25 respectively), a negative correlation between improvement on the FMS and scores on the 1RM squat that had been previously established, similar results were discovered in a study involving a group of elite high school baseball players. [22,25] The authors also investigated whether the FMS correlated to other performance measures as well including agility, power, acceleration, and speed.[22] The FMS showed no correlation to any of the performance measures providing further evidence to the notion that the FMS has limitations in predicting athletic performance.

A.6 Conclusion

Thanks in part to Title IX legislation that went into effect over forty years ago there has been a rise in female athletic participation across all levels of competition. As a result there has been a concurrent increase in injuries in this population as well as an interest among many sports medicine professionals to enhance performance and prevent injury. Recent interest in the FMS as a tool for identifying injury risk has gained traction among sports medicine professionals. However the female athlete population is one group that has not been sufficiently studied. In addition recent interest in quantifiable balance measures as injury predictors has grown. The intent of this research investigation is to carefully examine injury risk in a cohort of female student athletes utilizing the FMS and measures of balance and determine if a relationship exists among these variables.

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Appendix B

IRB DOCUMENT

University of Delaware Human Subjects
Informed Consent Form

RESEARCH STUDY TITLE: Ankle Injury Assessment and Tracking in an Athletic Population

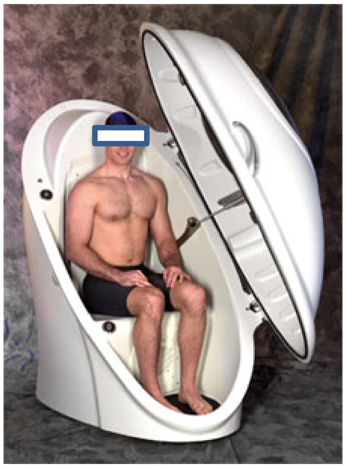
INVESTIGATORS: Thomas W. Kaminski, PhD (Dept. of Kinesiology & Applied Physiology); Geoff Gustavsen, MD (Team Physician - UD Sports Medicine)

PURPOSE OF STUDY AND INTRODUCTION
The purpose of this research project is to better understand factors that could lead to an ankle sprain. You are being asked to participate because you're a student-athlete at the University of Delaware. You must be 18 years or older to participate in this study. We will examine different aspects of ankle function (strength, balance, looseness, ligament status, etc…) and track any changes that may occur over your athletic career at the University of Delaware. Your participation is voluntary and you are in no way obligated to take part in this project.

PROCEDURES
The initial testing will take about 75 minutes to complete. You will be asked to complete a questionnaire and several tasks to evaluate your ankle. You will be asked wear workout clothing (e.g. shorts/sweatpants and t-shirt) for all testing and perform each task either barefoot or wearing running shoes. All testing will take place in the Human Performance Lab.

Questionnaire: You will be asked about your age, height, weight, and gender and will complete a questionnaire about physical activity. You will complete two questionnaires about your ankle health and past history of lower leg injuries.

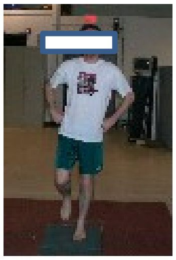
Body Composition Testing: Your Lean Body Mass (LBM) will be determined using a device called a Bod Pod®. Wearing a pair of shorts, you will sit in the device, which is a small egg shaped apparatus with a window. You will remain quiet, still and breathe normally for about 10 minutes. During this time, the device makes a series of calculations based on your weight.



Warm-up: You will be provided with a 5-minute warm-up on a stationary bike with lower body stretching activities before and after the tests.

Strength Testing: Ankle strength will be measured using an isokinetic dynamometer; a device that you will sit on that easily measures ankle force. Strength measurements will be performed on both ankles at a slow and fast speed for all four ankle motions (up, down, in, and out). You will wear running shoes during this test and will perform 3 warm-up reps followed by 3 maximal repetitions at each speed and motion (see image below).

Stability: You will be asked to perform hopping tasks onto a force platform built into the floor. The four hopping tasks will be from the left, right, backward, and forward directions. For the left, right, and backward hopping tasks, you will be standing next to the force platform, single-legged and barefoot, and have your hands on your waist. After you hear the command "go", you will hop over a 2" hurdle to the center of the force platform. Your task is to stabilize yourself as quickly as possible (see image below). You will hold the position for 5 sec. This procedure will be repeated using the other foot. For the forward hops, we will measure your leg length (from hip to ankle) and place a rubber hurdle 6" high between you and the force platform. We will demonstrate the "step-step-hop" method to hop over the rubber hurdle. You are to land one-footed on the force platform (barefoot), and again stabilize for 5 sec. You will perform this procedure separately on both the left and right foot. You will be asked to perform three trials of each hopping task.



Ankle Arthrometer: Ankle looseness will be measured using a device that is strapped to your foot and tests motion in an up, down, and rotary manner (see image below). This procedure will take about 5 minutes to complete.

Ultrasound Imaging: We will take ultrasound images of both of your ankles using some gel and an ultrasound wand (see image below). The gel will be applied directly to your skin and the wand will be slowly moved over the inside and outside of your ankle to capture an image on a computer screen. You will experience no pain with this test. A total of 6 images will be taken for each ankle: 1) outside ankle in neutral position, 2) inside ankle in neutral position, 3) outside ankle with your toes pointed all the way down, 4) inside ankle with your toes pointed all the way down, 5) outside ankle with your toes pointed all the way in, and 6) inside ankle with your toes pointed all the way out.

Follow-Up Questionnaire: At 1 year intervals you may be asked to complete the identical 2 survey questionnaires you've completed today at the baseline test session. The link to the "on-line" questionnaires will be sent to the e-mail address you have provided us today. The questionnaires require about 5 minutes to complete.

Functional Movement Screen (FMS) Scores: As part of your annual baseline evaluation/testing with the UD Strength and Conditioning staff, you have an FMS score that has been calculated as a result. We work closely with the UD Strength & Conditioning staff in scheduling participation for this project and so they will handle the transfer of those scores to us. We intend to compare that score with results of some of the testing performed in this battery of tests involving the ankle.

CONDITIONS OF SUBJECT PARTICIPATION

All of the data will be kept confidential. Aggregate (cumulative) data from this study will be shared with the sports medicine staff here at the University of Delaware. In addition, records of any athletic-related injuries that you experience while participating as an intercollegiate athlete will be shared with the research team. Your information will be assigned a code number. The list connecting your name to the code number will be kept in a locked file. When the study is completed and the data have been analyzed, that list will be destroyed, but the coded data will be kept indefinitely on a secured electronic file device. Your name will not be used in conjunction with this study. In the event of physical injury during participation, you will receive first aid. If you require additional medical treatment, you will be responsible for the cost. You will be removed from the study if you experience any injury that interferes with the results or prevents you from completing it. There are no consequences for withdrawing from the study and you can do so at any time.

RISKS AND BENEFITS
Potential risks in this project are minimal. As with any exercise or challenging movements, risks include fatigue, localized muscle soreness, and the potential for strains and sprains of muscles and joints of the lower leg. There is a slight risk to you

of suffering bone, muscle, or joint injuries during the exercise protocol. If you are injured during research procedures, you will be offered first aid at no cost to you. If you need additional medical treatment, the cost of this treatment will be your responsibility or that of your third-party payer (for example, your health insurance). By signing this document you are not waiving any rights that you may have if injury was the result of negligence of the university or its investigators. If you become too fatigued or uncomfortable, you may stop the test at any time. Potential benefits include the better understanding of why some people sprain their ankle more than others. In addition, this study can lead to identify predisposing factors to an ankle injury and therefore help prevent future ankle injuries.

CONTACTS

Questions regarding the research study can be directed to Dr. Thomas W. Kaminski (302) 831-6402 or kaminski@udel.edu. For questions of concerns about the rights to the individuals who agree to participate in the study: Human Subjects Review Board, University of Delaware (302) 831-2137.

ASSURANCE

Participation in this study is completely voluntary. You may stop at any time during the testing without penalty. Refusal or choosing to discontinue participation in this study is the right of the individual, with no loss of benefits to which the subject is otherwise entitled.

CONSENT SIGNATURES

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Subject Consent Signature Date

____

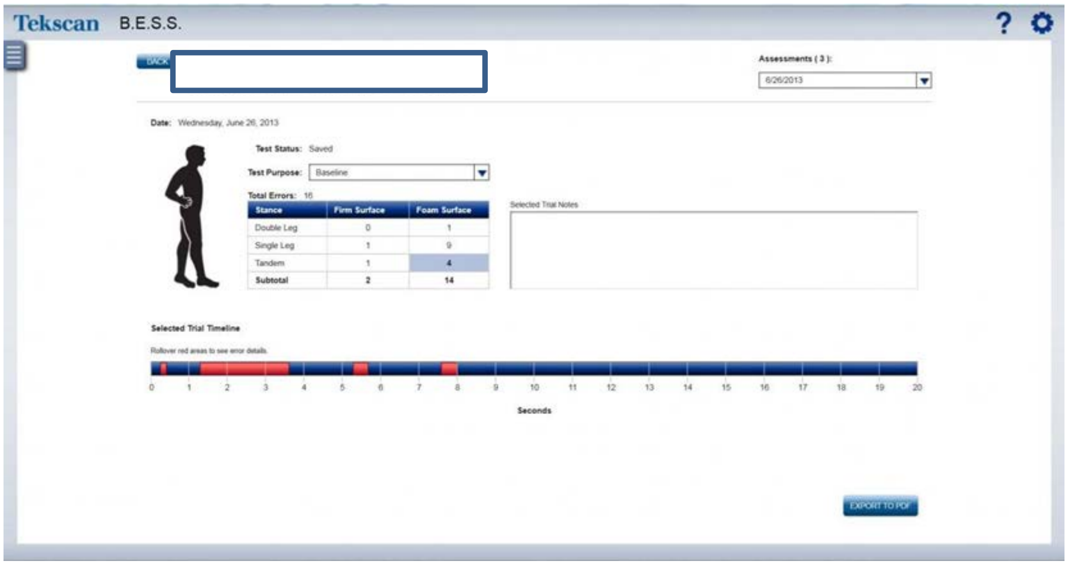
Principal Investigator Signature Date

Signed consent forms will be retained by the researcher for three years after completion of the research.

Appendix C

DATA COLLECTION SHEETS

C.1 BESS



C.2 FMS

THE FUNCTIONAL MOVEMENT SCREEN

SCORING SHEET

NAME: DATE: DOB:

ADDRESS:

CITY, STATE, ZIP: PHONE:

SCHOOL/AFFILIATION:

HT: WT: AGE: GENDER:

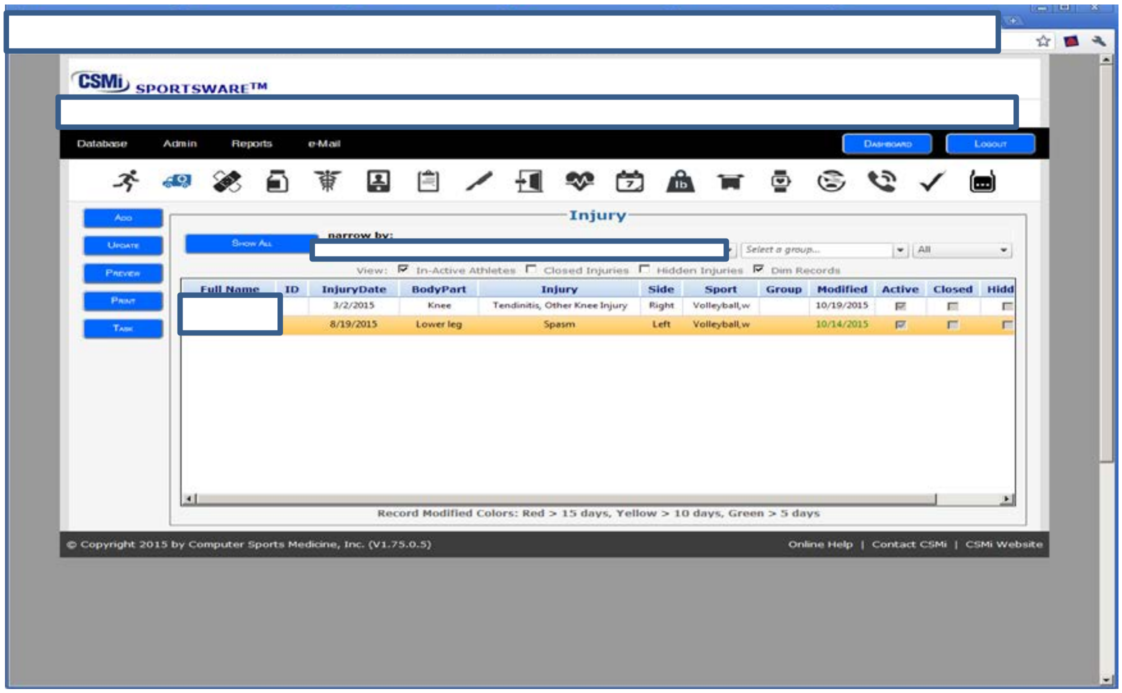
PRIMARY ACTIVITY: PRIMARY OBJECTIVE:

HAND/LEG DOMINANT: PREVIOUS TEST SCORE:

TEST	RAW SCORE		FINAL SCORE	COMMENTS
DEEP SQUAT				
HURDLE STEP	L			
	R			
INLINE LUNGE	L			
	R			
SHOULDER MOBILITY	L			
	R			
IMPINGEMENT CLEARING TEST	L +/-			
	R +/-			
ACTIVE STRAIGHT-LEG RAISE	L			
	R			
TRUNK STABILITY PUSHUP				
PRESS-UP CLEARING TEST	+/-			
ROTARY STABILITY	L			
	R			
POSTERIOR ROCKING CLEARING TEST	+/-			
		TOTAL		

 36

C.3 SWOL


CSMi SPORTSWARE™
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Admin
Reports
e-Mail
Dashboard
Logout
Add
Update
Preview
Print
Task
Injury
Show All
narrow by:
Select a group...
All
View: In-Active Athletes Closed Injuries Hidden Injuries Dim Records
Full Name ID InjuryDate BodyPart Injury Side Sport Group Modified Active Closed Hidd
3/2/2015 Knee Tendinitis, Other Knee Injury Right Volleyball,w 10/19/2015
8/19/2015 Lower leg Spasm Left Volleyball,w 10/14/2015
Record Modified Colors: Red > 15 days, Yellow > 10 days, Green > 5 days
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