

**EXAMINING THE FUNCTIONAL MOVEMENT SCREEN AND Y BALANCE
TEST SCORES IN A COHORT OF INTERCOLLEGIATE ATHLETES
BEFORE AND AFTER A TRAINING INTERVENTION**

by

Jenna E. Liljeberg

A thesis submitted to the Faculty of the University of Delaware in partial fulfillment of
the requirements for the degree of Master of Science in Exercise Science

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ABSTRACT

The number of lower extremity (LE) injuries in Division-I collegiate student-athletes has consistently increased over the past 10 years. Given these steady trends, a reliable screening tool is essential to predict an athlete's risk of injury in order to enhance the safety and performance of this population. Even though research surrounding the FMS and YBT have been mixed, very few studies have looked at the effect of these test scores over time and its effect on strength. The primary purpose of this study was to compare both YBT and FMS scores in NCAA Division-I student-athletes before and after a supervised strength and conditioning-based intervention. This prospective cohort study had 122 participants (42 males, 80 females) (age= 19.6 ± 1.1 , height 174.3 ± 8.2 , mass 70.4 ± 9.4). Each participant completed the FMS, YBT, squat max, and bench press max testing at three separate time periods over a 17-month span. Of the total number of participants, those that obtained a LE injury were classified as LE injured (n=50) and those that were not, were classified as healthy (n=72). A one-way analysis of variance was used to compare scores between the two screening tools; a Tukey post-hoc was used to determine where significant differences took place across time. A two-group growth curve was used for the study's second aim and third aim to determine if there was a difference between YBT and FMS scores of athletes who have or have not sustained LE injuries, as well as to compare maximum squat and bench press test results in student-

athletes before, during, and after a strength and conditioning-based intervention. The following variables showed a significant difference over time: anterior difference (ANT Diff) ($p < 0.004$), posteromedial difference (PM Diff) ($p < 0.011$), PL Diff ($p < 0.035$), YBT composite score difference (YBT COMP Diff) ($p < 0.001$), deep squat ($p < 0.025$), in-line lunge ($p < 0.001$), max bench press ($p < 0.001$), max squat ($p < 0.001$), and LE injury ($p < 0.001$). The following variables had a significant effect on maximum squat: ANT Diff ($p = 0.044$, $t = 2.022$), Deep Squat ($p = 0.029$, $t = 2.189$), Hurdle Step-Over ($p = 0.017$, $t = 2.401$), In-Line Lunge ($p = 0.006$, $t = 2.759$), and FMS COMP ($p < 0.001$, $t = 5.108$). Both PM Diff ($p = 0.02$, $t = 2.332$) and Deep Squat ($p = 0.002$, $t = -3.094$) had a significant effect on LE injury. While previous research has not been in support of the FMS as an injury predictor, we believe that certain components, specifically the deep squat, may improve over time through a strength and conditioning program. Athletic trainers and strength and conditioning coaches should consider using the YBT as a pre-participation screening tool and symmetry measure between limbs. We believe that when utilizing the FMS and YBT, strength gains over time may influence these test scores.

Chapter 1

INTRODUCTION

Participation in the National Collegiate Athletic Association (NCAA) has greatly risen over the years, with an 80% increase in female participation and a 20% increase in male participation.(21) More than 478,000 student-athletes were a part of NCAA organized collegiate sports from 2013-2014.(45) The Center for Disease Control and Prevention (CDC) sampled NCAA data over five academic years from 2009-2010 and 2013-2014, and projected 1,053,370 injuries to have occurred with an estimated 176.7 million athlete-exposures (i.e. one athlete's participation in one competition or one practice) to potential injury.(34,45) Previous research has found that 50% of collegiate injuries occur in the lower extremity (LE).(11,21) Due to steady injury rates and the prevalence of LE injuries, preventing these occurrences is essential for the safety and performance of student-athletes.

Many researchers have defined an injury as damage occurring during participation in an NCAA organized practice or competition that requires medical attention and results in time loss.(34,39,44) Plisky defined a LE injury as impairment to the lower body, including the hip but not the sacroiliac joint or lumbar spine, resulting in restriction from participation in a game or

practice.(33)

It is suggested LE injuries may be related to limb asymmetries, or the absolute difference between two legs, placing higher demand on a given limb making it vulnerable to injury.(32) Injury prevention has become a focal point of student-athlete welfare among sports health care and athlete performance specialists over the past 10 years. Many researchers have exaggerated the need for consistent pre-season screening tests that can identify asymmetries or other factors that put athletes at risk for LE injuries.(17,43)

The Y Balance Test (YBT) and Functional Movement Screen (FMS) are two common pre-participation screening tools used in today's athletic population. The YBT is a newly modified version of the Star Excursion Balance Test (SEBT) that evaluates single-leg balance, mobility, stability and overall coordination.(24) Maximal reach distances of the lower limbs are unilaterally recorded in eight different directions in the SEBT and in three different directions in the YBT.(9) The FMS is a series of seven tests that place a subject in positions where functional movement limitations and asymmetries can be identified.(2) It is thought that these tests provide the foundation for more complex athletic movements, and any weaknesses or asymmetries exposed may put the athlete at risk of injury.(2,23)

However, there is a lack of consistency in the research involving the YBT and FMS in detecting LE injuries in an injured versus uninjured population, thus,

the need for additional research examining the validity and reliability of these screening tests. For example, in one literature review on screening tools, it was determined that there is much conflicting evidence surrounding the FMS as an injury predictor.(6) On the other hand, the authors stated the YBT has more potential for injury prediction, specifically with anterior reach asymmetry.(6) No study to date has screened a collegiate athletic population before and after having completed a supervised strength and conditioning program. Results of a pre-test, post-test-based study may offer clinically relevant evidence to further support or disprove the use of the YBT and FMS in an injured collegiate population. The importance of improving both the YBT and FMS via a strength training programs seems logical to investigate the connection between these two variables. Findings may also be beneficial for team coaches, strength and conditioning specialists, certified athletic trainers, physicians and other sports health care professionals to improve the performance and safety of today's student-athletes.

The primary purpose of the current study was to compare both YBT and FMS scores in NCAA Division-I student-athletes before and after a supervised strength and conditioning-based intervention. We hypothesized that athletes' YBT and FMS scores would improve over time with a strength and conditioning-based intervention throughout the academic year.

The second aim of this study was to determine if there was a difference

between YBT and FMS scores of athletes who sustained LE injuries compared to non-injured athletes. We hypothesized that athletes who suffered a LE injury during the intervention period would have poorer scores when compared to student-athletes who remained injury free throughout the study.

As a mechanism of carefully monitoring athlete performance and providing a statistical co-variate, our third aim was to determine if strength variables (bench press and squat exercises) affect YBT and FMS scores. In conjunction with the predicted improvement in screening test scores over time, we hypothesized that athletes' maximum squat and bench press numbers would also increase throughout a strength and conditioning intervention, as well as affect FMS and YBT test scores.

Chapter 2

METHODS

2.1 Research Design

A prospective cohort design was used to investigate differences in:

- 1) YBT and FMS scores
- 2) YBT and FMS scores in a subset of student-athletes with LE injuries
- 3) Maximum squat and bench press test results

2.2 Subjects

One hundred twenty-two NCAA Division-I student-athletes (80 females, 42 males) participated in this study (Table 1). The student-athletes were from the following sports: men's and women's golf, tennis, swimming and diving, and women's rowing (Table 2). All 122 participants were cleared for physical activity by the University of Delaware's Sports Medicine Staff and signed a consent form with approval from the Institutional Review Board (#131714-12). Participants were excluded from the study if they failed to complete testing due to transferring in or out of the school, quitting or being cut from a team, or graduating.

Table 1. Participant Characteristics (Mean \pm SD)

| Participants | Age (years) | Height (cm) | Mass (kg) | Leg Length (cm) |
|---------------------|--------------------|--------------------|------------------|------------------------|
| Female (n=80) | 19.7 \pm 1.1 | 170.5 \pm 6.7 | 67.0 \pm 7.7 | 90.0 \pm 0.0 |
| Male (n=42) | 19.3 \pm 1.0 | 181.8 \pm 5.1 | 77.1 \pm 9.0 | 94.1 \pm 0.0 |
| Total (N=122) | 19.6 \pm 1 | 174.3 \pm 8.2 | 70.4 \pm 9.4 | 91.4 \pm 0.0 |

N, Number of subjects.

Table 2. Participant Breakdown by Sport

| Sport | Total Participants (n) | Total LE Injuries (n) |
|--------------|-------------------------------|------------------------------|
| Tennis | 18 | 14 |
| Rowing | 43 | 15 |
| Golf | 20 | 5 |
| Swimming | 41 | 16 |

N, Number of subjects.

2.3 Instrumentation

The FMS (Functional Movement Systems, Cleveland, Ohio, USA) and Y-Balance Test (YBT) (Functional Movement Systems, Cleveland, Ohio, USA) were used as measures of LE functional performance. Sorinex (Sorinex Exercise Equipment, Lexington, SC, USA) and Hammer Strength (Life Fitness, Rosemont, IL, USA) squat racks were used when testing the student-athletes in the squat and bench press exercises. SportsWareOnLine (SWOL) (Computer Sports Medicine Inc, Stoughton, Massachusetts, USA) was utilized to track LE injuries in each athlete. Student-athletes also completed a demographic and health-history questionnaire.

2.4 Procedure

The study period spanned from August 2016 through January 2018. The participants were tested with their respective teams in the 2016 fall semester upon beginning their sports-specific strength and conditioning program. The teams were FMS tested on the first day of training in the fall 2016 semester and

performed the YBT on a separate non-training day at the athlete’s convenience. One certified strength and conditioning coach designed and trained the four teams through a different training program specific to the sport. This same instructor, also FMS Level 1 and YBT certified, conducted all pre and post-testing on each subject with both screening tools. Another FMS Level 1 strength and conditioning coach assisted in the FMS testing of two teams. A reliability analysis was completed with ten random subjects who were consented and filmed during the testing session with both raters. Each rater independently scored the 10 subjects, and one week later watched their videos to re-score the subjects in a random order. This process was then repeated one week later for a total of three scores per subject per rater. An interclass correlation coefficient showed both raters had high intra-rater reliability (ICC=0.97, 95% CI: 0.93-0.99; ICC=0.96, 95% CI: 0.90-0.97). The inter-rater reliability between both raters was also high (ICC=0.97, 95% CI: 0.93-0.99). Measures of strength were taken at the beginning of the strength and conditioning intervention and multiple times throughout the study period. Testing frequency varied per team depending on in-season lifting schedules. This procedure is outlined in Figure 1.

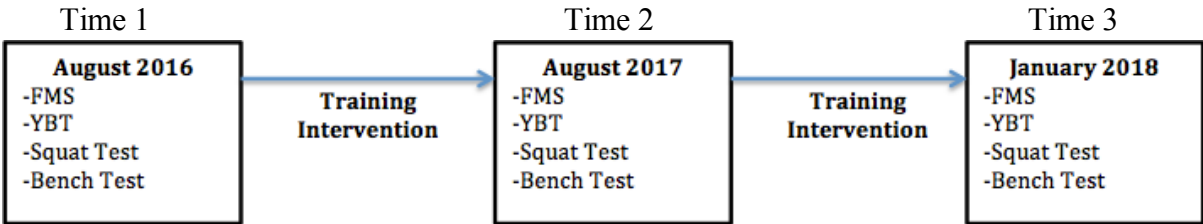


Figure 1. Testing Timeline

Functional Movement Screen

The FMS was composed of seven different functional movements in which subjects were scored on each test on an ordinal scale of zero to three.(25) The seven FMS evaluations included the deep squat, hurdle step, in-line lunge, shoulder mobility, active straight leg raise, trunk stability push-up, and rotary stability test.(8) During the team's allotted training time the athletes were evaluated on the FMS in the varsity weight room. The team was given instructions on the first test, and then each athlete one by one performed the evaluation. This process was repeated for each of the seven assessments. A score of three was given if the movement was performed correctly, a two was awarded if the movement was completed correctly with a modification, or a score of one was given if the subject was unable to complete the movement even with a modification.(25) A zero was scored if an athlete had pain at any point during the test. Five of the seven tests were performed unilaterally, with the left and right limbs scored individually. The lower score of the two sides was taken as the overall score for that specific test. The scores for each of the seven tests were added together for one overall composite score (COMP). After three of the tests (shoulder mobility, trunk stability push-up, rotary stability) a clearing test was performed to observe a pain response; these clearing tests were not scored, but recorded as positive for pain or negative for pain.(8) A detailed description for

each of the seven tests is shown below from the FMS manual.

- (1) Deep Squat-The individual assumes the starting position by placing his/her feet approximately shoulder width apart with 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. The individual is then instructed to descend slowly into a squat position. The squat position should be assumed with the heels on the floor, head and chest facing forward and the dowel maximally pressed overhead. The individual may repeat the movement up to three times. If the criteria for a score of III is not achieved, the athlete is then asked to perform the test with a 2 x 6 board under their 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 positioned across the shoulders below the neck. The individual is then asked to step over the hurdle and touch their heel to the floor 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 3 times bilaterally. If one

repetition is completed bilaterally meeting the criteria below a score of III is given.

- (3) In-Line Lunge- The tester attains the individual's tibia length, by either measuring it from the floor to the tibia 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. The previous tibia 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 sacrum. 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 placing the heel of the opposite foot at the indicated mark on the board. The individual then lowers the back knee enough to touch the board behind the heel of the front foot and then returns to 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.
- (4) Shoulder Mobility-The tester first determines the hand length by measuring the distance from the distal wrist crease to the tip of the third digit. The individual begins standing with feet together and remains in this position throughout the test. The individual is instructed

to make a fist with each hand, placing the thumb inside the fist. They are then asked to assume a maximally adducted, extended and internally rotated position with one shoulder, and a maximally abducted, flexed and externally rotated position with the other. During the test the hands should remain in a fist and they should be placed on the back in one smooth motion. The tester then measures the distance between the two closest bony prominences. Perform the shoulder mobility test as many as 3 times bilaterally.

- (5) Active Straight Leg Raise- The individual first assumes the starting position by lying supine with the arms in an anatomical position and head flat on the floor. The board is placed under the knees. The tester then identifies mid-point between the anterior superior iliac spine (ASIS) and mid-point of the patella, the dowel is then placed at this position perpendicular to the ground. Next, the individual is instructed to lift the test leg with a dorsiflexed ankle and an extended knee. During the test the opposite knee should remain in contact with the board, the toes should remain pointed upward, and the head remain flat on the floor. Once the end range position is achieved, and the malleolus is located past the dowel, then the score is recorded per the criteria. If the malleolus does not pass the dowel then the dowel, is aligned along the medial malleolus of the test leg, perpendicular to the floor and scored per the criteria. The active straight leg raise test

should be performed as many as 3 times bilaterally.

(6) Trunk Stability Push-Up-The individual assumes a prone position with the feet together. The hands are then placed shoulder width apart at the appropriate position per the criteria. The knees are then fully extended and the ankles are dorsiflexed. The individual is asked to perform one push-up in this position. The body should be lifted as a unit. There should be no lag in the lumbar spine when performing this push-up. If the individual cannot perform a push-up in this position, the hands are lowered to the appropriate position per the criteria.

(7) Rotary Stability- The individual assumes the starting position in quadruped with their shoulders and hips at 90 degrees relative to the torso. The knees are positioned at 90 degrees and the ankles should remain dorsiflexed. The board is then placed between the knees and hands so they are in contact with the board. The individual then flexes the shoulder and extends the same side hip and knee. The leg and hand are only raised enough to clear the floor by approximately 6 inches. The elbow, hand, and knee that are lifted should all remain in line with the board. The torso should also remain in the same plane as the board. The same shoulder is then extended and the knee flexed enough for the elbow and knee to touch. This is performed bilaterally for up to 3 repetitions. If a score of III is not attained, then the individual performs a diagonal pattern using the

opposite shoulder and hip in the same manner as described above.

Y Balance Test

The YBT was developed through researching injury prevention and post-injury motor control changes.(40) The Lower Quarter YBT (YBT-LQ) is dynamic test performed in a single leg stance requiring strength, flexibility, core control, and proprioception at the limit of one's stability and functional symmetry. It is a simplified version of the SEBT in which only three of the eight reach directions are performed.



a) Anterior (ANT) b) Posteromedial (PM) c) Posterolateral (PL)

Figure 2. YBT Reach Directions (www.functionalmovements.com)

The objective of the YBT was for the student-athletes to maintain single limb stance while reaching with the contralateral leg as far as possible.(40) Prior to the start of the test, limb length was measured on both the left and right sides, as it can play a small yet significant factor in how far one is able to reach. Limb

length was measured in centimeters from the distance from the athlete's palpated anterior superior iliac spine to the most distal part of the palpated medial malleolus.(35) Socks and shoes were removed before testing. The student-athletes were given testing instructions and practice repetitions prior to the start of the test. Athletes were instructed to stand in the center of the footplate with the distal part of their right foot at the start of the red line.(35,40) While maintaining balance on the right stance leg, the leg being measured, the free left foot was used to push the indicator box as far forward as possible in a specific direction. The subject pushed the indicator box from behind with their toes and maintained contact with the box at all times. Three consecutive trials were performed with the right limb in the anterior (ANT) direction and then with the left limb in the ANT direction; this procedure was followed in the posteromedial (PM) direction and then in the posterolateral (PL) direction. Attempts were rejected and repeated if the athlete failed to maintain unilateral stance on the platform, failed to maintain contact with the indicator box with the reach foot, placed the toes or foot on top of the indicator box, touched the ground or testing poles with the reach foot, or failed to return the reach foot back to the starting position under control without touching the ground. Athletes were given a maximum of six attempts to achieve three successful trials. If there were more than four failed attempts, a zero was recorded for that trial. Maximal reach distances were recorded by reading the measurement at the edge of the reach

indicator box to the nearest 0.5 cm. Composite scores (COMP) were calculated for each the right and left limbs in order to provide an overall performance rating relative to one's body.(40) This overall score took the sum of the greatest reach distances in all three directions divided by three times the limb length, and then multiplied by 100. The symmetry amongst limbs were compared in all three directions by taking the absolute value of the difference between the left and right reach distances (Diff).

Strength Testing

Throughout the strength and conditioning intervention period, measures of strength were taken to track changes in individual and team performance, observe the overall effect of the strength program in its ability to improve performance, and to provide specific intensity and load ranges for each individual during a workout. All student-athletes were tested in the front squat and bench press exercises multiple times throughout training by the same certified strength and conditioning coach. During a testing session student-athletes were assigned specific loads for the warm-up sets leading up to their testing set. A spotter was always used for the testing sets in case of failure to complete a repetition. A failed repetition was defined as an athlete's inability to successfully complete one full repetition from start to finish without assistance. The strength and conditioning coach observed and guided each athlete during testing. After a few weeks of starting the sports-specific strength and conditioning intervention, all student-athletes completed a three-rep maximum

(3RM) performance on the front squat and bench press. An estimated one-rep maximum (1RM) was calculated from the results of the 3RM tests. After another phase of training under loads and intensities specific to the athlete's 1RM, the participants were tested again in the two exercises. However, this time the athletes were instructed to burnout (hit as many reps as possible) the two exercises with their previous 1RMs. A new estimated 1RM was calculated and compared to previous testing results. The student-athletes were tested for a new 3RM before leaving for winter break in order to create and provide each athlete with a winter take-home exercise packet. Upon returning from winter break, the athletes were responsible for successfully hitting 90% of their previous 1RM for at least one rep before starting a new training phase. The purpose of this test was to safely observe if the athletes had maintained strength over winter break; programs were adjusted if athletes could not hit 90% of their previous 1RMs. Testing was not completed during a team's in-season period due to limited time in the weight room and a focus of injury prevention and maintaining current strength and conditioning levels. A new 3RM was taken before the student-athletes left for summer break in order to provide summer-take home workout packets with updated loads and intensities. Results for all testing were reported to the student-athletes and the team coach.

Training Interventions

Once testing was completed, athletes went about normal strength training

from August 2016 to January 2018 and were tracked for lower extremity injuries using SWOL. The strength and conditioning programs contained flexibility work, corrective exercises for rehabilitation and injury prevention, plyometric training, weight training, and speed and endurance conditioning. Periodization phases were altered monthly based on the training goals, metabolic demands, and competition status of the sport. The four sports trained two to three times per week, depending on the competition schedule, throughout the academic year. We acknowledge that training differences existed among the cohorts of student-athlete's participating. All teams followed a similar program in the off-season, in which plyometric activities, strength exercises, and conditioning were emphasized. While in-season exercises varied per sport, all teams followed a low-volume-high-intensity program focused on injury prevention and strength maintenance. For example, golfers performed more rotational core and hip and trunk mobility exercises, the women's rowing team performed exercises to mimic an erg movement, and the swimming/diving and tennis teams performed more power-emphasized exercises like the push press.

Injury Surveillance

A LE injury was defined as any injury occurring to the lower half of the body, including the hip joint, which required treatment from an athletic trainer or team physician and resulted in time loss from competition.(33) SWOL was used to determine injury type, severity, location, date of occurrence, and amount of

time loss from practices or games. This software database was used by the ATC for each sports team for injury tracking purposes. Athletes who obtained a LE injury during the study were placed into a second cohort for further statistical analysis. These athletes were then FMS and YBT tested again after having completed a training program in the 2017 fall semester; the same evaluator administered the tests using the procedures described above.

2.5 Statistical Analysis

The first aim of this study used a one-way analysis of variance to compare FMS and YBT scores at the beginning (August 2016) and end of an intervention (January 2018). A Tukey Post-Hoc analysis was used to determine where significant differences took place over time. The independent variable was time, while the dependent variables were the FMS and YBT component and cumulative scores. The study's second aim used a two-group growth curve to compare YBT scores, FMS scores, and strength measures in athletes who obtained a LE injury versus those that did not. The significant p-value was set at 0.05. The independent variables were those who obtained an injury versus those who did not and time. The dependent variables were also FMS and YBT component and composite scores. Both aim 1 and aim 2 used time, age, height, weight, gender, sport, squat 1RM, and bench press 1RM as co-variables. The study's third aim used a two-group growth curve to compare strength measures (bench press and squat) and YBT and FMS test results over time with a training

intervention. SPSS version 24.0 (IBM Corp, Armonk, NY, USA) was used to run these statistical analyses.

Chapter 3

RESULTS

3.1 FMS and YBT Scores Over Time

Tables 3 and 4 show the descriptive statistics for all variables. Over time, there was a decrease in the average ANT Diff, PM Diff, PL Diff, YBT COMP Diff with the YBT (Table 3). The average deep squat, hurdle-step over, in-line lunge, and FMS COMP scores stayed relatively constant with slight increases (Table 3).

Table 3. Descriptive Statistics Across Time for FMS & YBT Scores

| Variable | Time 1 | | Time 2 | | Time 3 | | Sign. |
|--------------------------|--------|------------|--------|------------|--------|------------|---------|
| | n | M ± SD | n | M ± SD | n | M ± SD | |
| ANT Diff (cm) | 121 | 3.4 ± 2.6 | 94 | 2.7 ± 2.2 | 84 | 2.8 ± 2.5 | 0.004* |
| PM Diff (cm) | 121 | 4.9 ± 4.2 | 94 | 4.2 ± 2.9 | 84 | 3.9 ± 2.9 | 0.011* |
| PL Diff (cm) | 121 | 4.9 ± 4.0 | 94 | 4.2 ± 3.4 | 84 | 4.1 ± 3.4 | 0.035* |
| YBT COMP Diff (%) | 121 | 3.6 ± 3.3 | 94 | 2.6 ± 2.3 | 84 | 2.0 ± 2.3 | <0.001* |
| Deep Squat | 121 | 2.0 ± 0.7 | 94 | 2.0 ± 0.7 | 84 | 1.8 ± 0.7 | 0.025* |
| Hurdle Step-Over | 121 | 2.0 ± 0.5 | 94 | 2.0 ± 0.7 | 84 | 2.1 ± 0.4 | 0.315 |
| In-Line Lunge | 121 | 2.0 ± 0.6 | 94 | 2.0 ± 0.7 | 84 | 2.3 ± 0.6 | <0.001* |
| FMS COMP | 121 | 15.5 ± 1.9 | 94 | 15.2 ± 2.5 | 84 | 16.0 ± 8.0 | 0.211 |

Sign, Significance; N, Number of subjects; M, Mean; SD, Standard Deviation; ANT, Anterior; Diff, Difference; PM, Posteromedial; PL, Posterolateral; COMP, Composite. * indicates statistically significant variables (p<0.05).

Table 4. Descriptive Statistics Across Time for Strength Measures (Mean \pm SD)

| Variable | Time 1 | | Time 2 | | Time 3 | | Sign. |
|-----------------------------|--------|-----------------|--------|-----------------|--------|-----------------|---------|
| | n | M \pm SD | n | M \pm SD | n | M \pm SD | |
| Max Front Squat (kg) | 106 | 60.0 \pm 23.7 | 80 | 68.1 \pm 20.1 | 79 | 70.0 \pm 19.6 | <0.001* |
| Max Bench (kg) | 107 | 49.7 \pm 22.1 | 55 | 61.1 \pm 21.6 | 55 | 63.3 \pm 22.2 | <0.001* |

Sign, Significance; N, Number of subjects; M, Mean; SD, Standard Deviation; Max, Maximum. * indicates statistically significant variables ($p < 0.05$).

There were significant differences between time points one and two with ANT Diff ($p=0.01$), YBT COMP Diff ($p=0.001$), maximum bench press ($p=0.001$), and maximum squat ($p=0.001$). There were significant differences between time points one and three with ANT Diff ($p=0.018$), PM Diff ($p=0.012$), YBT COMP Diff ($p=0.003$), in-line lunge ($p=0.001$), maximum bench press ($p=0.001$), maximum squat ($p=0.001$), LE injury ($p=0.001$), and trending significance with PL Diff ($p=0.058$). There were significant differences between time points two and three with deep squat ($p=0.019$), in-line lunge ($p=0.001$), and LE injury ($p=0.002$).

3.2 FMS and YBT Scores in Injured vs. Non-Injured Student-Athletes

A total of 122 student-athletes (80 females, 42 males) from four different sports teams at a NCAA Division-I university participated in this 17-month study. The 122

subjects sustained a combined 50 LE injuries (33 females, 17 males) throughout the course of the study, with 20 chronic injuries and 30 acute injuries. Twenty-seven LE injuries occurred in the 12 months between time points one and 2, while 23 injuries occurred in the five months between time points two and three. Swimming had the highest number of LE injuries, followed by rowing, tennis, and lastly golf (Table 2).

A mixed model analysis found the following variables had a significant effect on time: YBT COMP Diff ($p=0.011$, $t= -2.568$), ANT Diff ($p=0.005$, $t= -2.80$), deep squat ($p=0.037$, $t=2.092$), in-line lunge ($p<0.001$, $t= -3.636$), and FMS COMP ($p=0.012$, $t= -2.512$). The following variables had a significant effect on quadratic time: YBT COMP DIFF ($p=0.026$, $t= -2.229$), deep squat ($p=0.011$, $t= -2.541$), and in-line lunge ($p<0.001$, $t=4.098$). The following variables had a significant effect on maximum squat: ANT Diff ($p=0.044$, $t=2.022$), deep squat ($p=0.029$, $t=2.189$), hurdle step-over ($p=0.017$, $t=2.401$), in-line lunge ($p=0.006$, $t=2.759$), and FMS COMP ($p<0.001$, $t=5.108$). Only hurdle step-over had a significant effect on maximum bench press ($p=0.002$, $t=3.125$). The following variables had a significant effect on LE injury: PM Diff ($p=0.02$, $t=2.332$) and deep squat ($p=0.002$, $t= -3.094$). The following variables had a significant effect on age: deep squat ($p<0.001$, $t=5.01$), in-line lunge ($p<0.001$, $t=5.84$), and FMS COMP ($p<0.001$, $t=6.507$). The following variables had a significant effect on gender: YBT COMP Diff ($p=0.001$, $t=3.523$), PM Diff ($p<0.001$, $t=3.969$), PL Diff ($p=0.003$, $t=2.974$), hurdle step-over ($p<0.001$, $t= -5.521$), and FMS COMP ($p=0.007$, $t= -2.691$). The following variables had a significant effect on sport: ANT Diff ($p=0.036$, $t=2.107$), deep squat ($p=0.026$, $t=2.238$), and FMS COMP ($p=0.014$, $t=2.462$). While hurdle step-

over ($p < 0.001$, $t = -3.789$) and FMS COMP ($p < 0.001$, $t = -3.562$) had significant effects on weight, only hurdle step-over had a significant effect on height ($p = 0.042$, $t = 2.04$). YBT COMP Diff showed a significant interaction between quadratic time and sport ($p = 0.014$, $t = 2.495$). Both in-line lunge ($p = 0.02$, $t = -2.36$) and FMS COMP ($p = 0.004$, $t = -2.971$) showed a significant interaction between quadratic time and maximum squat.

Non-injured student-athletes had less average ANT Diff, PM Diff, PL Diff, and YBT COMP Diff than injured student-athletes (Table 5). Non-injured student-athletes had higher average deep squat, hurdle step-over, in-line lunge, and FMS COMP scores than injured student-athletes (Table 5). The non-injured cohort had a higher average bench 1RM, but a lower average squat 1RM compared to the injured cohort (Table 5). A separate compared means analysis was run to compare results between males and females. Males had larger average ANT Diff, PM Diff, PL Diff, and YBT COMP Diff compared to the female student-athletes (Table 6). While males had a higher average deep squat score, females had higher average scores on the hurdle-step over, in-line lunge, and FMS COMP (Table 6). The male student-athletes had larger 1RMs for both the squat and bench press exercises (Table 6).

Table 5. Results of Two-Group Growth Curve-Non-Injured vs. LE Injured (Mean \pm SD)

| Test | No Injury | LE Injury |
|---------------|-----------------|------------------|
| Ant Diff (cm) | 2.98 \pm 2.43 | 3.50 \pm 2.43* |
| PM Diff (cm) | 4.33 \pm 3.41 | 5.24 \pm 4.36* |
| PL Diff (cm) | 4.42 \pm 3.74 | 4.49 \pm 2.45* |

| | | |
|----------------------|-------------|--------------|
| YBT COMP Diff (%) | 3.01 ± 2.81 | 3.54 ± 2.79* |
| Deep Squat | 1.97 ± 0.68 | 1.70 ± 0.81* |
| Hurdle Step Over | 2.0 ± 0.52 | 1.94 ± 0.79 |
| In-Line Lunge | 2.11 ± 0.63 | 1.98 ± 0.85* |
| FMS COMP | 15.6 ± 4.77 | 14.88 ± 2.69 |
| Front Squat Max (kg) | 65.3 ± 21.7 | 66.9 ± 24.4* |
| Bench Max (kg) | 56.2 ± 22.9 | 53.8 ± 21.7* |

ANT, Anterior; Diff, Difference, PM, Posteromedial; PL, Posterolateral; COMP, Composite; Max, Maximum. * indicates statistically significant variables between no injury and LE injury (p<0.05).

Table 6. Results of Two-Group Growth Curve-Female vs. Male Athletes (Mean ± SD)

| Test | Female | Male |
|----------------------|--------------|--------------|
| Ant Diff (cm) | 2.83 ± 2.35* | 3.41 ± 2.57* |
| PM Diff (cm) | 4.09 ± 3.14* | 5.07 ± 4.08* |
| PL Diff (cm) | 4.15 ± 3.39* | 5.00 ± 4.10* |
| YBT COMP Diff (%) | 2.82 ± 2.64* | 3.54 ± 3.07* |
| Deep Squat | 1.94 ± 0.71* | 1.95 ± 0.67* |
| Hurdle Step Over | 2.04 ± 0.56 | 1.90 ± 0.50 |
| In-Line Lunge | 2.14 ± 0.65* | 2.03 ± 0.64* |
| FMS COMP | 15.75 ± 5.47 | 15.10 ± 2.03 |
| Front Squat Max (kg) | 52.3 ± 11.6* | 89.7 ± 14.5* |
| Bench Max (kg) | 39.1 ± 9.1* | 79.1 ± 13.9* |

ANT, Anterior; Diff, Difference, PM, Posteromedial; PL, Posterolateral; COMP, Composite; Max, Maximum. * indicates statistically significant variables between females and males (p<0.05).

3.3 Strength Performance and Screening Test Scores

The mean maximum squat and maximum bench press maxes increased throughout the study while controlling for a strength and conditioning intervention (Table 4). As stated above, five dependent variables had a significant effect on maximum squat: ANT Diff ($p=0.044$, $t=2.022$), deep squat ($p=0.029$, $t=2.189$), hurdle step-over ($p=0.017$, $t=2.401$), in-line lunge ($p=0.006$, $t=2.759$) with a significant interaction between maximum squat and quadratic time ($p=0.02$, $t= -2.36$), and FMS COMP ($p<0.001$, $t=5.108$) with a significant interaction between maximum squat and quadratic time ($p=0.004$, $t= -2.971$). Only hurdle-step over had a significant effect on maximum bench press ($p=0.002$, $t=3.125$). Males had a higher average squat and bench press maximums than females (Table 6). The injured cohort had a higher average squat maximum, while the non-injured cohort had a higher average bench press maximum (Table 5).

Chapter 4

DISCUSSION

4.1 FMS

Research surrounding the use and ability of the FMS is of much debate. While multiple studies have found the FMS to be an invalid screening tool(1,2,12), others have found a significant relationship between FMS scores and injury occurrence.(7,23) Authors continue to recommend future research on the FMS, yet the lack of a universal conclusion surrounding this tool should be enough to abandon its use as an injury prediction tool. Multiple systematic reviews on the FMS have determined this device cannot be supported as injury predictor.(6,30,43) A review by Whittaker et al. analyzed 15 studies using the FMS and its ability to make an association between poor movement and lower extremity injury in sport and military/first responder occupations. After evaluating the 15 studies, the author concluded the FMS lacks consistent, high-quality cohort evidence and validity to support the claim that insufficient movement is related to lower extremity injuries.(43) In a separate review with similar conclusions, Dorrel et al. suggest this instrument may be a sufficient movement quality assessor, but not a sufficient and valid injury prediction tool.(12) While some researchers have found the FMS to have moderate to excellent reliability, (6,29,41) others have found it to have poor reliability. (36) For example, one study reported good test-retest reliability (ICC=0.6, 95% CI:0.35, 0.77) but poor inter-rater reliability (K α =0.38, 95% CI:0.35, 0.41) between raters.(36) On the other hand, another study reported good inter-rater

reliability over two testing sessions (ICC=0.87-0.89; 95% CI: 0.74-0.95), and good intra-rater reliability between four testers (ICC=0.81-0.91).(6) Similar to other studies, we found high inter-rater (ICC=0.97, 95% CI: 0.93-0.99) reliability and high intra-rater reliability (ICC=0.97, 95% CI: 0.93-0.99; ICC=0.96, 95% CI: 0.90-0.97) for the two strength and conditioning coaches who tested the student-athletes on the FMS.

Even though the cohort of uninjured student-athletes had higher average FMS component and composite scores compared to the cohort of athletes who sustained a LE injury (Table 5), our results cannot support the FMS as an injury predictor. Female athletes had higher average component and composite scores on everything but deep squat (Table 6). Females may have better single-leg strength, balance, mobility, and control than males, which would explain their higher averages on the single leg tests that contribute to the composite score. Similarly, Chimera et al. found Division-I collegiate female athletes performed better on the in-line lunge test and active straight leg raise tests, both of which are single leg tests, than collegiate male athletes.(5) These authors, however, found no difference on the deep squat or hurdle step-over test. The male athletes in our study possessed higher average maximum squat values, which may relate to their better performance on the deep squat test. Our results indicate there may be a connection between lower body strength and FMS scores. Deep squat, hurdle-step over, in-line lunge, and FMS COMP all had a significant effect on an athlete's maximum squat, while in-line lunge and FMS COMP both showed a significant interaction between time and maximum squat. These results imply an athlete's lower body mechanics, whether it be unilateral or bilateral, may influence his or her current

strength and overall strength capability as measured by the FMS. Furthermore, we saw an increase in the average squat 1RM over time, while FMS component and composite scores had slight increases (Table 2). This implies as an athlete's lower body strength increases over time in conjunction with a strength and conditioning program, FMS scores may also increase.

4.2 YBT

Like the FMS, our results indicate that strength training may affect YBT scores. Just as strength measures improved over time with a strength and conditioning intervention, YBT scores also improved. Throughout the study period, we saw decreases in the average differences between limbs in component and composite YBT scores (Table 3). Similar to our results, previous research found a significant main effect of time for the YBT, with the significant increases of YBT performance occurring in basketball players who completed an eight-week balance and plyometric training intervention.(4) While student-athlete strength evaluations were improved throughout our study period, YBT scores may have also improved due to the sports-specific training. The training intervention aimed to better the coordination, neuromuscular control, balance, strength, and speed abilities of the study's participants, many abilities of which are essential and influential to performance on the YBT. The connection between YBT scores and strength measures can be further validated by the finding that ANT Diff had a significant effect on maximum squat. In order to perform the ANT reach direction of the YBT, one must mimic the movement of a single-leg squat. The

lower body mobility, strength, and coordination necessary to perform a technically sound squat are similar requirements of the body when reaching in the ANT direction of the YBT. Significant asymmetry seen between limbs in this direction may also be seen with a unilateral or bilateral squat.

Surprisingly, PM Diff was the only YBT variable to have a significant effect on LE injury. Lee et al. found hip extensor, hip abductor, and knee flexor strength was positively correlated with PM reach distances in a separate study on adult females.(26) This direction of the lower-limb test may require more flexibility and strength, specifically at the hip and knee, as the subject is required to push the indicator box as far out laterally as possible and then return back to the start position. An athlete's PM reach distance may be influenced by their strength and range of motion at the hip and knee, especially on the dominate limb. It's also possible that greater PM reach distances reflect movements athletes perform during their specific sport. A recent study reported the importance of hip mobility and strength in ice skaters, specifically with females. The authors found female figure skaters had increased hip strength on their take-off leg when compared to the landing leg, and may benefit from hip strengthening training.(37) YBT component and composite scores may also be influenced by gender, as YBT COMP Diff, PM Diff, and PL Diff all had significant effects on this variable in our study.

In our study, the LE injured cohort had greater differences between limbs in all three component tests, as well as with the composite score, compared to the non-injured cohort. Previous research has identified cutoff scores with asymmetry found in the YBT

scores, that may put an athlete at risk for an injury. For example, Smith et al. used a Receiver Operating Curve (ROC) to determine a cutoff score of four centimeters with the ANT direction of the YBT for injury prediction (sensitivity 59%; specificity 72%).(38) The Division-I athletes in this study who had ANT asymmetry greater than, or equal to, four centimeters had a significantly higher odds ratio of getting hurt when compared to those that had less than four centimeters difference between limbs in this direction of the YBT (OR, 2.20; 95% CI=1.09-4.46).(38) The LE injury population in our study had average ANT Diff of 3.50 ± 2.43 cm, which goes against Smith et al.'s findings. Another study also used a ROC analysis and found a significant odds ratio between the PM direction and non-contact injuries (OR, 3.86, 95% CI=1.46-10.95), meaning athletes who had PM Diff greater than, or equal to, four centimeters were 3.86 times more likely to get a LE non-contact injury ($p=0.001$). (15) The LE injured cohort in our study had an average PM Diff of 5.24 ± 4.36 , which would support this study's findings.

We also found that females performed better on the YBT, as the male population had higher average differences between limbs in the ANT, PM, PL direction, and overall composite score. Comparable to our findings, other researchers have reported female collegiate athletes had less asymmetry in the ANT direction than males.(5,16) Female collegiate student-athletes may have more mobility, balance, coordination, or a combination of the above than male collegiate student-athletes. Previous research on the fitness of children and adolescents reported females were more flexible than males in

six to 19 year olds and 20-39 year olds.(42) These results indicate females may perform better on the YBT due to their increased joint flexibility when compared to males. The YBT COMP Diff showed a significant interaction between quadratic time and sport, meaning that YBT composite scores are affected by the sport of the athlete over time. Athletes participating in sports that have more LE involvement or demand, such as tennis when compared to golf, may produce better composite scores as their lower body is more trained and adapted to multi-directional movement.

The YBT may be a more valid pre-participation screening device, as it has shown more consistent results compared to the SEBT and FMS.(6,9,35) For example, Coughlan et al. found the YBT to have excellent inter-rater reliability (ICC=0.99-1.00) and excellent intra-rater reliability (ICC=0.85-0.91) compared to the SEBT,(9) while Chimera et al. found the YBT to have very good reliability compared to the FMS and SEBT for normalized reach distances (ICC=0.99-1.00, 95% CI: 0.92-1.00) and composite scores (ICC=0.97-0.99, 95% CI: 0.92-0.99).(6) Studies have also reported the YBT places more neuromuscular demands on the body as greater hip and ankle range of motion, as well as muscle activation, is highly influential over performance scores.(3,14,27,31) The neuromuscular stress the YBT requires for sufficient results relates to the advanced requirements of the body during athletic competition. Any weakness or deficiencies seen with the hip or ankle may be detrimental to one's performance on the YBT, and more importantly to one's risk of receiving a LE injury during an event. This test may serve as a great tool for evaluating an athlete's symmetrical performance in a single-leg stance.

4.3 Intervention & Performance Maxes

Only a small number of studies have used a pre-test-post-test design with the FMS and/or YBT to observe if scores improve after a period of training or competition.(13,19,22,28) Of the authors who utilized this design, most did not find significant differences between participants' scores and risk of injury on either screening test. (13,19,22) However, when using the FMS and YBT, one researcher observed subjects who were deemed at moderate or substantial risk for injury were almost nine times more likely and 17.6 times more likely to get an injury compared to those at normal risk for injury.(28) While many studies have used a resistance training program as an intervention between strength evaluations, few studies have used this intervention between screening tool evaluations in conjunction with strength evaluations. One study tested a group of elite-level female basketball players in the YBT before and after an experimental group had completed a neuromuscular training intervention. Results presented the experimental group had improved PM reach distances and overall better composite scores than the control group.(3) The current study is not only unique for testing NCAA Division-I athletes on both the FMS and YBT, but also for using a strength and conditioning intervention and evaluating performance at three different time points.

As expected, the average bench press and front squat maxes increased over time (Tables 4). The sports-specific strength and conditioning program implemented for each of the four teams was designed to improve the strength, speed, power, coordination, and mobility of the athletes. Based on our results, it is

evident that the training program accomplished its goal of increasing the athletes' strength (Table 4). Other studies have found similar trends in the effect of a training program on strength gains. For example, a study found the average back squat 1RM of male collegiate volleyball players increased over the course of a competitive season (135.9 ± 11.1 kg Pre-Season, 145.0 ± 12.0 kg Mid-Season, 151.4 ± 11.3 kg Post-Season), while bench press 1RMs were only slightly increased (97.7 ± 14.1 kg Pre-Season, 97.1 ± 13.3 kg Mid-Season, 100.1 ± 12.3 kg Post-Season).(18) Another study saw significant increases in the squat 1RM of collegiate football players over a competitive season (155.0 ± 31.8 kg Pre-Season, 163.3 ± 30.0 kg Post-Season; $p < 0.05$).(20) No significant increases were found with the bench press, maxes were only maintained. These studies tested only male athletes on the back squat exercise, an exercise in which higher loads can typically be achieved when compared to the front squat. The current study, along with past research, supports the effectiveness of a supervised training program on strength increases. Previous research used a 12-week resistance training program as in intervention on 21 youth male rugby players.(10) This experimental group performed supervised resistance training three times per week, while a matched control group performed unsupervised training. The authors found the supervised group had significant increases in both the 3RM back squat and bench press from time 1 to time 2, and time 2 and 3 when compared to the unsupervised group

($p < 0.05$).⁽¹⁰⁾ These results support our finding that a supervised training program can increase the strength of athletes.

We expected to see an improvement over time in both FMS and YBT component and composite scores, as well as an increase in the maximum squat and bench press of student-athletes. Our findings support these hypotheses, as the average differences between limbs of the YBT component and composite scores decreased, average FMS component and composite scores had slight increases, and strength measurements increased over time (Tables 3 and 4). One may also relate the improved YBT scores to the improved coordination, mobility, and strength of the student-athletes, as these athletic characteristics are necessary during the test's performance. Just as strength and conditioning coaches continually re-evaluate student-athletes on performance measures, such as the squat and bench press 1RM, these athletes should also be repeatedly re-tested on screening tools like the FMS and YBT. This frequent feedback can reveal the strengths and weaknesses in the biomechanics of student-athletes, while also providing feedback to strength and conditioning coaches on the effect of their training programs.

4.4 Limitations

It is important to note there are some limitations associated with the current study. A student-athlete was diagnosed as injured by the University's Sports Medicine Staff, while the type of injury, acute or chronic, was defined at the discretion of the strength and conditioning coach who analyzed the SWOL database. Subjects who had surgery

during or prior the study period were not excluded from the study, as they were cleared for restricted activity in the weight room. Surgical athletes were not excluded from the study and still participated in testing if they were pain free, any movements that caused pain were immediately stopped and resulted in a score of zero for that component of testing. The strength and conditioning programs differed between sports regarding program design and goals, volume, intensity, frequency, duration, and location of training. The performance numbers taken throughout the course of the study were influenced by these program variables and the competition status of a team. For example, an in-season team would not be tested in the squat or bench press exercises to avoid injury and overload. Furthermore, individual one-rep maximums may have gone down after a competition phase due to decreased volume, frequency, and duration of training. If a team's competition phase took place during the middle of the study the performance numbers would reflect this fluctuation.

4.5 Clinical Application

With the rising number of injuries, especially to the LE region, in today's student athletic population, there is a strong need for a reliable and valid screening tool. A device that can be utilized as a quality movement assessor would greatly benefit strength coaches, athletic trainers, and the overall health and well-being of student-athletes. With all the literary discrepancy on the FMS, it appears to be a sufficient tool for assessing movement, but not for predicting injury. Using the FMS as a training tool may benefit strength and conditioning programs as it can give coaches a quantitative

read on where the strengths and weakness within individual athletes, or as a team, lie regarding biomechanics. Evaluating athletes in simple strength movements may explain any deficits seen with FMS component scores. Furthermore, improving an athlete's strength through training may lead to improvement on component and composite FMS scores. We believe that certain components, specifically the deep squat, may improve over time through a strength and conditioning program. The YBT is a newer screening tool with strong reliability, yet there is some debate surrounding its relationship with LE injuries. Not only should researches continue to study the abilities and validity of the YBT, trainers, coaches, and other clinicians should greatly consider using this device as a pre-participation screening tool and measure of symmetry between limbs. Over the 17-month study we saw improvements in YBT performance, specifically with decreases in limb asymmetry. The YBT may serve as a beneficial rehabilitation tool when testing lower limb symmetry after an injury, or generally throughout one's athletic career. The movement patterns required to perform the three component tests are like the mechanics required of athletes during activity or competition. The ankle, knee, and hip joints, both bilaterally and unilaterally, especially play a crucial role in both the YBT and most athletic events. We believe that when utilizing the FMS and YBT, strength gains over time may have an effect on these test scores.

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Appendix A

LITERATURE REVIEW

A.1 Introduction

With the rising number of students who participate in collegiate sports year-round, the frequency and presence of injuries are also at a constant incline. Much research surrounds injury prevention with the use of pre-participation screening tools;(2,3,8,16,25,28,37,39,47,54,55) however there is a gap in the consistency of their findings. The Y-Balance Test (YBT) and Functional Movement Screen (FMS) are two screening tools commonly used in today's athletic population that produce varying outcomes on their effectiveness. While some researchers have associated one, or both, of these apparatuses with the prediction or risk of injury(3,8,16,28,37,39) other researchers have not been able to find a significant relationship.(2,47,54,55) A valid and reliable screening tool is essential for improving both the safety and performance of today's collegiate student-athletes.

A.2 Injury

Participation in the National Collegiate Athletic Association (NCAA) has greatly risen over the years, with an 80% increase in female participation and a 20% increase in male participation.(23) More than 478,869 student-athletes were a part of NCAA organized collegiate sports from 2013-2014.(56) The Center for Disease Control and Prevention (CDC) sampled NCAA data over five academic years from 2009-2010 and 2013-2014, and projected 1,053,370 injuries to have occurred with an estimated 176.7 million athlete-exposures (i.e. one athlete's participation in one competition or one practice) to potential injury.(27,56) Previous research has found that 50% of collegiate injuries occur in the lower extremity (LE).(12,23) Due to steady injury rates

and the prevalence of LE injuries, preventing these injuries is essential for the safety and performance of student-athletes. A lower extremity injury is defined by Plisky as any damage to the lower region of the body, including the hip but not the sacroiliac joint or lumbar spine, resulting in restriction from participation in a game or practice.(42) Many researchers have found lower extremity injuries occur in over 50% of all sport- related injuries.(12,23,49) One study conducted by Hutchinson et al found lower limb injuries happen twice as often as upper extremity injuries in elite tennis players.(24) Wright concluded of 189 Division-I athletes, 103 lower extremity injuries occurred in one school year.(55) On another note, Hootman reported larger injury rates during preseason practices (6.6 injuries per 1000 A-Es) compared to in- season (2.3 injuries per 1000 A-Es) and post-season practices (1.4 injuries per 1000 A-Es).(23) With higher rates of injuries appearing in pre-season practices and to the lower- extremity, screening tools that can efficiently predict injuries before the start of competition are crucial. Tests that can reliably determine an athlete's risk of injury before they begin participation may reduce the frequency of damage that occurs during pre-season practices, especially to the lower extremity area.

A.3 Screening Tools for Injury Prediction

Many clinicians today utilize screening tools as a means of assessing baseline movement, evaluating natural physiology, and observing for any deficiencies or weaknesses before working with a client or athlete. While multiple screening measures exist, determining which tool is the best predictor of performance or injury is of much debate and uncertainty. The Balance Error Scoring System (BESS) is one clinical tool used to evaluate static balance in a cost effective and objective way.(41) Balance is assessed on an error system in three different stance conditions (double-leg, single-leg,

tandem), on two different surfaces (hard and foam), with the eyes closed and hands on the hips. Little research has been done examining balance and LE injury risk; however, McGuine et al. reported a relationship between balance deficits and incidence of ankle injury in a study using the BESS on high school basketball players.(36) Other measures similar to BESS that are commonly used to assess balance include velocity of sway, center of pressure, time to stabilization, entropy, and the Star Excursion Balance Test (SEBT).

Figure 3. Balance Error Scoring System Test
(www.humankinetics.com/excerpts/excerpts/measure-balance-and-stability)

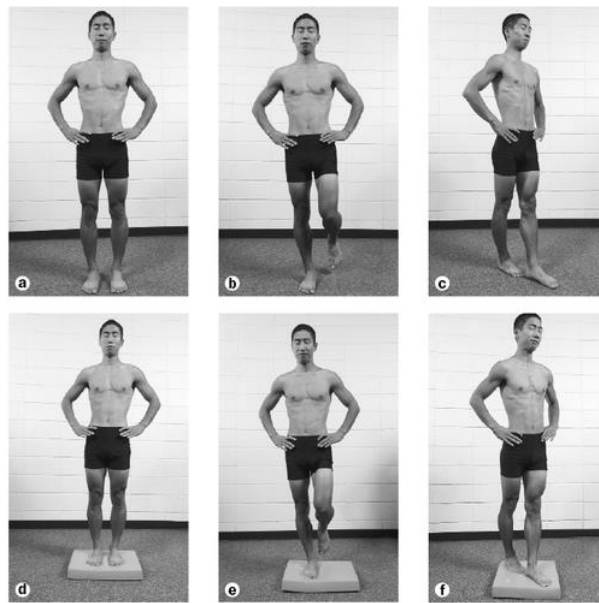


FIGURE 12.3 Balance error scoring system (BESS). Top row, firm surface condition. Bottom row, soft surface condition. Left column, parallel stance. Middle column, single-leg stance. Right column, tandem stance.

The SEBT is a measure of dynamic balance developed by Gray.(10) The test involves moving from a two-legged stance to a single-leg stance while maximally reaching along a line with the opposite leg in eight different directions. In Gribble's

systematic review of 44 peer-reviewed articles using the SEBT as a measurement tool, it was found to be a reliable measure and predictor of LE injury risk and dynamic balance deficits.(18) Stiffler tested 393 healthy male and female NCAA Division-I athletes in the SEBT and found 66.9% had a composite score below 89.6%, and 84.2% had composite scores below 94%.(50) These results were compared to a previous study that placed football players 3.5 times more at risk for a lower extremity injury if a composite score less than 89.6% was obtained.(5) Stiffler used these findings to conclude the majority of the athletes in his study are at risk for lower limb injuries as well.(49) In a separate study on the SEBT, this same researcher discovered an increase in the predicted probability of athletes experiencing a non-contact knee or ankle injury after controlling for anterior asymmetry.(50) Absolute and normalized anterior asymmetries were greater in injured athletes ($P=0.002$). Although studies have found the SEBT may serve as a dependable injury prediction tool, a modified version of the test has been shown as easier to administer, quicker to perform, and has excellent intra-rater reliability (ICC 0.85-0.91) and excellent inter-rater reliability (ICC 0.99-1.00) compared to the SEBT.(10)

Figure 4. SEBT Reach Directions
www.humankinetics.com/excerpts/excerpts/measuring-e-balance-and-stability

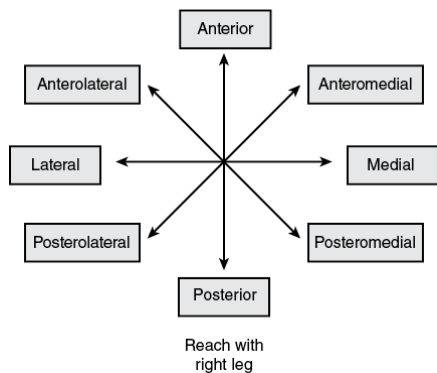
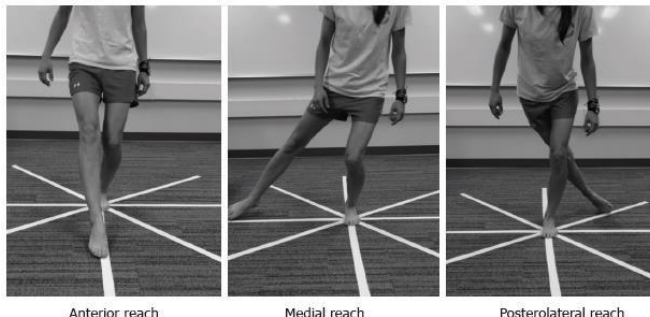


Figure 5. SEBT Being Performed in Three of the Eight Directions
www.wjnet.com/2218-5836/full/v7/i4/202.htm



A.4 Y-Balance Test

The YBT was developed through researching injury prevention and post-injury motor control changes.(51) The Lower Quarter YBT (YBT-LQ) is dynamic test performed in a single leg stance requiring strength, flexibility, core control, and proprioception at the limit of one's stability. It is a simplified version of the SEBT in which only three of the eight reach directions are performed.(10,29,51) It is an easy way to measure one's motor control and demonstrate functional symmetry.(51) Results from this test identify weaknesses to a person's functional ability both in rehabilitation and sports performance. Past studies have discovered the YBT places more neuromuscular demands on the body, as more hip range of motion is required to perform the test.(15,33) Lee found lower-limb strength was positively correlated with YBT reach distances in all three directions ($p < 0.05$).(33) Specifically, hip extensor and knee flexor strength was positively correlated with the anterior (ANT) direction ($r = 0.703$, $p < 0.05$; $r = 0.711$, $p < 0.05$) and posterolateral (PL) directions ($r = 0.748$, $p < 0.05$; $r = 0.828$, $p < 0.05$), while hip extensor, hip abductor, and knee flexor strength were positively correlated

with the posteromedial (PM) direction ($r=0.720$, $p<0.05$; $r=0.719$, $p<0.05$; $r=0.814$, $p<0.05$). As more hip flexor range of motion is required for obtaining greater reach distances, the hip extensor strength needed to maintain balance and control during the YBT is increased. Due to the body's demand for higher muscular strength and joint range of motion to efficiently perform the YBT, it may serve as a more relevant screening tool when evaluating an athlete's performance.

- a) Anterior (ANT) b) Posteromedial (PM) c) Posterolateral (PL)

Figure 6. YBT Reach Directions (www.functionalmovement.com)



Research on the YBT has produced inconsistent results on the tools' connection to injuries, as some studies report a relationship between YBT performance and injury risk and other studies report no relationship. Benis compared YBT results of Italian national female basketball players before and after a neuromuscular training intervention.(3) The players who underwent the training intervention had improved PM distances and overall composite scores when compared to the control group (Right=88.6% 6 +/- 3.2% versus 94.0% 6 +/- 1.8%, +5.4%, $P=0.0004$; left=89.2% 6 +/- 3.2% versus 94.5% 6 +/- 3.0%, +5.8%,

P=0.001). Having better neuromuscular control may improve YBT scores and decrease one's risk of obtaining an injury. Similarly, Gonell et al. utilized the YBT as a screening tool with 74 professional male soccer players.(16) The players performed the YBT as a baseline measure and injuries were tracked throughout the competitive season. The authors found athletes with a difference greater than or equal to four centimeters between lower limb reach distances in the PM direction were about four times more likely to sustain a lower extremity non-contact injury (P=0.001). Players who scored lower than the average in each direction were about two times more likely to receive an injury. Significant correlations were found between bilateral average active range of motion (AROM) and bilateral average YBT scores ($p \leq 0.05$) in active adults by Overmoyer et al.(39) In this study, 20 healthy, active, pain-free adults underwent YBT and AROM testing. Dorsiflexion at zero degrees and 90 degrees of knee flexion had a weak to moderate significant correlation in all three directions and in the overall composite score ($r=0.497-0.795$, $r=0.472-0.795$). Significant correlations between AROM and YBT asymmetries only existed with ankle plantarflexion in the ANT and PL directions and composite scores ($r=0.520-0.636$). Results from this study indicate plantarflexor muscles during dorsiflexion, especially in the ANT direction, may play an influential factor in one's flexibility during YBT performance. Injury or deficiencies to this area may lead to compensations that may increase one's risk of lower extremity injury.(39) A more recent study by Slater et al. compared YBT performance between sexes

and events in 32 elite figure skaters and found no significant difference between sexes in composite scores, but significant differences in the component tests did exist.(46) Females had greater absolute differences between limbs (mean difference= -3.62cm) and greater normalized PL differences between limbs (mean difference= -4.26% leg length).(46) While male single skaters had greater reach distances on the landing leg (mean difference=7.36% [CI:1.58, 13.14], $d=1.48$ [CI:0.30, 2.67], $P=0.012$) and take-off leg than female single skaters (mean difference=8.65% [CI: 2.31, 14.99], $d=1.59$ [CI:0.39, 2.79], $P=0.018$), female ice dancers had farther reach distances than the male ice dancers on both legs (mean difference of landing leg=10.22%, [CI:5.03, 15.41], $d=2.53$ [CI:1.01, 4.05], $P=0.001$) (mean difference of take-off leg=7.8% [CI:1.77, 13.93], $d=1.66$ [CI:0.35, 2.97], $P=0.009$). The authors suggested the asymmetrical hip strength seen in the landing leg of female skaters may increase their risk of LE injury; these females may benefit from hip strength training.(46)

On the other hand, some researchers have not found significant and beneficial effects of the YBT. When testing 184 Division-I college athletes, Smith found no significant difference between mean composite scores of injured vs. non-injured athletes (101.3% +/- 7.8% vs. 101.2% +/- 7.1%, $P=0.95$).(47) However, athletes with ANT asymmetry greater or equal to four centimeters (the determined cutoff point) were at greater risk for injury than those who had ANT asymmetry less than four centimeters. Lai et al. used the YBT-LQ to evaluate if scores could predict laterality and risk of sports related LE injury in 294 NCAA Division I

athletes (177 males, 117 females). Although a weak correlation was found between left composite scores and the number of left-sided LE injuries per AE ($R^2=0.02$, $P=0.03$), no other significant correlations were found between composite score and the number of LE injuries.(31) The authors did find ANT asymmetry of more than two centimeters and PL asymmetry of more than three centimeters were associated with a lower number of injuries per AE (0.52 ratio with 95% CI 0.49-0.55; 0.73 ratio with 95% CI 0.69-0.78; $P<0.01$); however, the authors concluded that YBT-LQ scores alone do not predict LE injury in an NCAA Division I population. Wright also could not find a significant difference between injured and non-injured Division I athletes using the Lower Quarter YBT (LQYBT).(55) Shaffer et al. conducted a study to analyze the inter-rater test-retest reliability of the YBT on military service members with multiple raters. Sixty-four service members (53 male, 11 female) voluntarily performed 15 counterbalanced tests, one of which was the YBT, as a part of LE injury prevention screening. Seven trained physical therapy students were randomly assigned to test different subjects each day of the study. No significant reach differences were found between limbs and days of testing ($p>0.05$), and no significant group mean difference in reach distances were found between limbs ($p>0.05$).(44) Inter-rater test-retest asymmetry for maximal reach distances had good reliability [ICC (2,1); 0.80-0.85], while inter-rater reliability for the average of the three reach distances also demonstrated good reliability [ICC (2,3) 0.85-0.03].

A.5 Functional Movement Screen

The FMS is composed of seven different functional movements in which subjects are scored on each test on an ordinal scale of zero to three.(30) The seven FMS evaluations include the deep squat, hurdle step, in-line lunge, shoulder mobility, active straight leg raise, trunk stability push-up, and rotary stability test, depicted below in Figure 4.(9) Previous studies have found the FMS to have moderate to excellent inter and intra-rater reliability.(7,35,52) Letafatkar et al. found high average inter-rater reliability (ICC=0.877-0.932) between testers in one study,(35) while Chimera et al. found good inter-rater reliability in two testing sessions (Session 1 ICC=0.89, 95% CI: 0.8-0.95; Session 2 ICC 0.87, 95% CI: 0.76-0.94) and good intra-rater reliability with four testers (ICC=0.81-0.91).(7) Teyhen et al. found good inter-rater reliability of FMS composite scores (ICC=0.76, 95% CI: 0.63-0.85), but only moderate intra-rater reliability of the composite scores (ICC=0.74, 95% CI: 0.6-0.83).(52) The researchers also found moderate to excellent inter-rater reliability of FMS component tests.

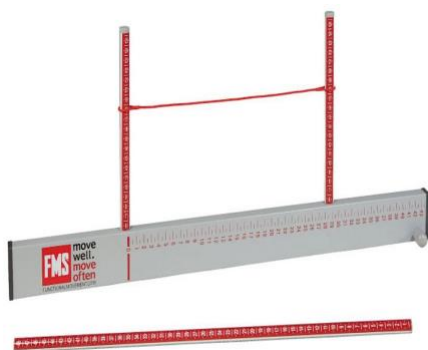


Figure 7. FMS Kit
(www.functionalmovement.com)



Figure 8. Seven FMS Tests
(www.functionalmovement.com)

Along with the YBT, FMS-focused studies have shown various findings in the tool's relationship to injury. A systematic review by Whittaker evaluated 17 studies using screening tools, 15 of which were on the FMS, and their ability to make an association between poor movement and lower extremity injury in sport and military/first responder occupations.(54) The author concluded a lack of consistent, high-quality cohort study evidence and validity exists to support the claim that insufficient movement is related to lower extremity injuries. Similarly, Moran's systematic review on 24 studies using the FMS also concluded the evaluation could not be supported as an injury prediction tool.(38) In this article, Moran states there is a need for a consistent definition of an injury as well as the need for post-test evaluations on the FMS, as scores can change within four to eight weeks following a corrective exercise program. FMS did not show as a valid predictor of injury in high school athletes in a study by Bardenett.(2) For example, injured athletes (2.21 +/- 0.61) scored higher on the in-line lunge test than non-injured (1.97 +/- 0.55) players (P=0.022), which could not be explained by the researchers. The 9+ functional movement test is a modified version of the FMS that includes nine assessments scored on a scale from zero to three, with 33 being the maximum score.(1) A two-year prospective cohort study by Bakken et al. examined the association between 9+ functional movement test and lower extremity injuries. Time-loss injuries and exposure in training/matches were tracked in 362 professional male football players who were tested in this version of the FMS. Over

9two seasons 526 injuries occurred in 203 players (56.1%), with thigh injuries being the most common.(1) The authors could not find an association between the 9+ functional movement test and the risk of lower extremity injuries (HR 1.02, 95% CI 0.99 to 1.05, $p=0.13$); therefore, this modified screening tool could not be recommended as an injury predictor. In comparison, Dorrel et al. also could not recommend using the FMS as an injury prediction tool, but more as a movement quality assessor. These authors tested 257 Division II NCAA athletes in the FMS and tracked these athletes for severe, musculoskeletal, or overall injuries throughout a competitive season. While the screening tool had a slightly better than 50/50 chance of classifying athletes at risk for injury, it could not accurately predict which type of injury.(13) A cutoff score of 15 further produced inadequate validity.(13) The authors concluded the FMS may be beneficial when analyzing an athlete's overall movement patterns, but it is not a valid predictor of injury.

Contrary to these results, an intervention run by Kiesel found a significant difference between mean FMS scores ($p<0.05$) in injured and non-injured high school football players.(28) An association between poor FMS scores and the likelihood of serious injury was found using a Receiving Operating Curve for a composite score cutoff point; players who received a composite score below 14 had a higher probability (51%) of suffering serious injury (specificity 0.91, sensitivity 0.54). Chorba et al. found a composite FMS score of 14 or less was significantly associated with injury ($p=0.0496$) in an analysis on female athletes.(8) Of the 38 Division-II female collegiate athletes, those who received an injury had a mean composite score of 13.9 ± 2.12 , while the

healthy athletes had a mean composite score of 14.7 +/- 1.29. Of those who received a composite score of 14 or lower, 68.75% had sustained an injury during the competitive season. Comparably, 81.82% of those who scored at or below 13 and 48.28% of those who scored at or below 15 acquired an injury. Comparably, FMS composite scores of 14 or under increased an athlete's risk of injury when compared to athletes who received a higher composite score (Confidence Interval: 0.39, 1.19; P=0.15; sensitivity 26.3%; specificity 58.7%) in a study by Mokha et al.(37) Additionally, out of the 84 Division-III collegiate athletes who participated, those with asymmetry or individual FMS scores of one were almost three times more likely to get an injury than those who scored higher than a one (Confidence Interval: 1.36, 5.4; P=0.0001; sensitivity 81.5%; specificity 54.3%). Letafatkar et al. found a cutoff score of 17 with an odds ratio of four point seven when testing 100 college recreational athletes.(35) The authors concluded an athlete had a four point seven greater chance of suffering a LE injury during a competitive season if a composite FMS score of 17 or lower was performed.(35) The average inter-rater reliability between testers was high (ICC=0.877-0.932), with sensitivity of 0.645 and specificity of 0.780. A significant difference was also found between the non-contact injury and no injury groups (p=0.32) and between the contact injury and no injury groups (P=0.013).(35) Although these authors found a relationship between FMS scores and injury in a college athletic population, it is valid to question the consistency of these results and if this relationship is applicable to a more competitive varsity population.

While many studies focus on finding an association between FMS scores and injury prediction, Janicki et al. hypothesized decreased dorsiflexion and hip flexion range of motion could explain lower FMS scores in the hurdle-step over test.(25) No significant correlations between range of motion and hurdle-step over scores were found when all subjects and sexes were considered. Even though it was not proven that range of motion can significantly lower FMS scores, it was concluded that joint and muscle weaknesses could still influence scores. For instance, those who scored a two on the hurdle-step over test had slightly lower ankle dorsiflexion averages bilaterally, hip flexion on the right limb, and total range of motion bilaterally ($p>0.05$) compared to those who scored a three. Although not significant ($p>0.05$), higher range of motion averages were found on the dominant limb for both males and females. These results suggest poor range of motion in the lower extremity, especially in the non-dominant limb, may limit one's ability to perform certain movements, leading to an increase risk of injury.

A.6 Y-Balance Test & Functional Movement Screen

Little research has been conducted comparing the performance of both the YBT and FMS on the same athletic population in a single study. Engquist et al. compared performance on the two screening tools by student athletes and non- student athletes at one Division-I college.(14) Surprisingly, no overall difference was seen between the two populations on either test. No significant difference in the percent of students who overall scored below or equal to a 14 on the FMS ($p=0.59$) was found between groups.

While no distinction was made between the two male populations, female athletes scored higher than general female students in the deep overhead squat FMS test ($p=0.01$) and had higher composite scores with the YBT ($p<0.0001$). These differences may indicate female athletes undergo more intensive and specific training than non-athlete females, or that recreational men may be more prepared for squat-specific strength movements than recreational women. The general female population also may have been challenged more from a sensorimotor standpoint, resulting in shorter reach distances in the YBT. Lehr and Plisky also used both the FMS and YBT screening tools in a study on 183 Division-II athletes from 10 different sports. Uniquely, participants were placed into four risk categories by algorithms created by the two authors: normal, slight, moderate, or substantial risk.(34) Over the study period, 42 athletes sustained non-contact LE injuries and 64 (34%) were classified as at high risk for injury. Subjects who were deemed at moderate and substantial risk for injury were almost nine times more likely (Confidence Interval: 1.2-64.8) and 17.6 times more likely (Confidence Interval: 2.5-123.6) to get an injury compared to those at normal risk for injury.(34) Kelleher et al. used both screening tools in a study on 78 healthy, general subjects aged 18-69 years old. FMS composite scores were compared to YBT reach distances for the purpose of assessing if dynamic postural control influences performance. Weak correlations were found between composite FMS scores and PL reach distances, PM reach distances, and YBT composite scores ($r=0.36, 0.37, 0.36; p<0.05$). (26) No correlation was found between composite FMS scores and ANT reach distances on the

YBT ($r=0.22$; $p=0.053$). The authors concluded FMS scores do not represent a single hypothetical construct.

Chimera et al. conducted a literary review on the FMS and YBT, among other clinical movement screening tools, in order to highlight the apparatus's strengths and/or weaknesses. When analyzing the FMS, the authors concluded there is a lack of consistency surrounding the ability of the FMS to be a single score injury predictor.(7) Studies using this device have varying definitions of an injury, populations being tested, and overall results. Due to the conflicting evidence, these authors state much caution should be used when making clinical recommendations for the FMS and its use. On the other hand, the authors found the YBT and SEBT to have very good inter-rater reliability; specifically, the YBT shows slightly higher inter-rater reliability than the SEBT for normalized reach distances [ICC 0.99-1.00 (95% CI: 0.92-1.0) vs 0.89-0.94] and the composite score ICC ranges [0.97-0.99 (95% CI: 0.92-0.99) vs 0.92 (95% CI: 0.85-0.96)].(7) When taking all the studies under review into consideration, an anterior reach asymmetry of four centimeters or more seemed to predict non-contact injury.(7)

While these authors did not support the use of the FMS as an injury predictor tool, they highlighted the YBT for its consistency and sound ability as a screening tool. While some researchers have found an association between injury risk and poor YBT and FMS composite or compound scores, other studies have concluded these screening tools may not accurately and reliably predict the prevalence and possibility of injury. Few studies exist testing the effect of both tools on a collegiate population in a single intervention. With all the discrepancy surrounding these tools' ability to predict injury,

future research should be conducted on the effect of the FMS and YBT in a controlled intervention to provide alternative purposes for their use.

A.7 Interventions

Most studies utilizing the SEBT, YBT, and/or FMS consist of testing an athletic population once as a baseline measurement and following the participants over the course of a competitive season for injury.(2,6,8,10,14,16,28,29,34,37,42,47,49,50,55) Additionally, many of these researchers refer to a training intervention that takes place after baseline testing for injury tracking during performance. Only a small number of studies have follow-up tested its participants in order to observe for a change in performance or compare pre and post measurements. Hoch et al. were one of the few studies to test an athletic team before and after a competitive season. In this study, 20 NCAA Division I female field hockey players were assessed in the YBT during pre-season and post-season in order to determine if scores were affected by athletic performance. Although a low mean bias was found across measurements ($\leq 1.67\%$), there was high variability within the posterior reach directions over time (± 4.75 to $\pm 14.83\%$).(21) This indicates there may have been large, nonsystematic changes individually over time; however, it is not clear if these changes were a result of measurement error or other influential performance factors. Overall, no significant differences were seen between preseason and postseason reach distances in any of the three directions, on either limb ($P \geq 0.31$) or in between limbs ($P \geq 0.52$).(21) Another study by Benis et al. pre and post tested a group of elite-level female basketball

players in the YBT. After undergoing a neuromuscular training intervention, the experimental group had improved reach distances in the PM direction and overall better composite scores than the control group (Right=88.6% \pm 3.2% versus 94.0% \pm 1.8%, +5.4%, $P=0.0004$; left=89.2% \pm 3.2% versus 94.5% \pm 3.0%, +5.8%, $P=0.001$).(3) Similar to Benis et al, a more recent study by Bouteraa et al. tested 26 female adolescent basketball players in the YBT before and after an eight week balance and plyometric training program. Test-retest reliability for the YBT was high (ICC=0.90-0.95).(4) The authors found a significant main effect of time on the YBT ($p=0.013$, $d=0.123$), with a tendency toward a significant group x time interaction ($p=0.087$, $d=0.06$). A post-hoc analysis showed the experimental group, players who completed the balance and plyometric training intervention, had significant increases of YBT performance ($\Delta 9.7\%$, $d=3.92$, $p<0.001$). It was concluded that these female basketball players benefited from an in-season combined training program.(4) While it is implied that athletes train throughout a study period, it is rarely controlled for as an intervention or used as a co-variate with YBT and FMS performance. Only a few studies have evaluated performance using both the YBT and FMS.(6,14,34) An intervention using both measurements may offer a better purpose for these screening tools if an improvement in performance is seen consistently. Not only testing a collegiate athlete population in both the YBT and FMS, but also controlling for a strength and conditioning-based intervention may provide unique results to current research. Tracking performance through strength evaluations may further validate improved YBT and FMS scores after training.

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APPENDIX B
DATA COLLECTION SHEETS

**B.1 IRB and Consent Form 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 (UD Physician), Bethany Wisthoff (Doctoral Student Dept. of Kinesiology & Applied Physiology)

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 or surrounding local institutions (i.e. Wilmington University, Goldey-Beacom College, and Neumann University). 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 during your time at the University of Delaware or surrounding local institutions (i.e. Wilmington University, Goldey-Beacom College, and Neumann University). 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/Athletic Training Research 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.

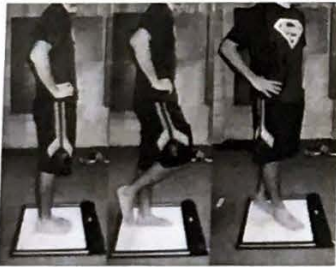
Strength Testing: Ankle strength will be measured using an isokinetic dynamometer; a device that you will sit on that easily measures ankle force. Strength measurements will be performed on both ankles at a slow and fast speed for all four ankle motions (up, down, in, and out). You will wear running 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.

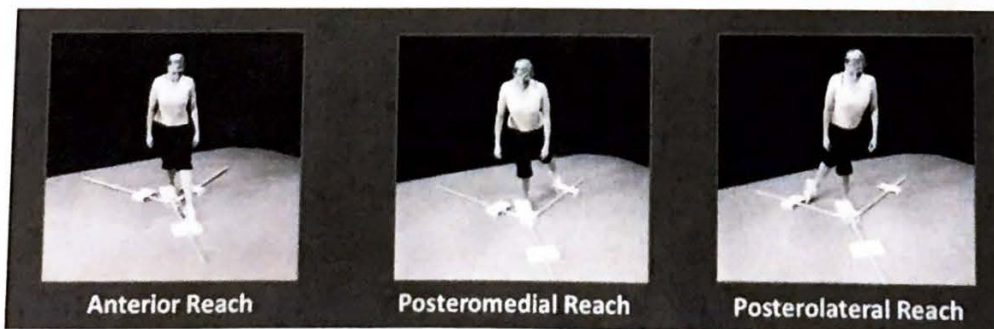


Balance Assessment (using the Balance Error Scoring System (BESS))



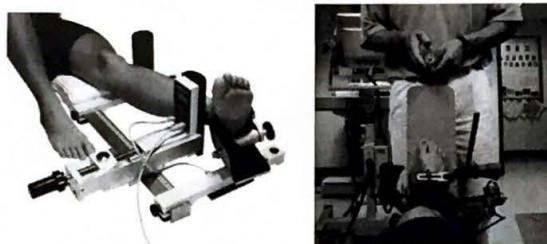
We will assess your balance while standing quietly on either a firm or foam surface using the three stances shown above. Balance will be **evaluated** using the Tekscan MobileMat™ BESS while the mat surface shown above is connected to a laptop computer which performs all scoring. You are to remain as motionless as possible during each test trial. Each trial is timed for 20 sec. You will perform one trial of each stance in your bare feet.

Balance Assessment (using the Y-Balance Test)



The Y-Balance Test consists of the subject standing on one leg (dominant) and moving the other leg in three different directions (Figure). The moving leg follows the test lines that have been laid out on the floor in the shape of a large “Y” symbol. The subjects will be tested on both legs. Subjects are asked to reach as far as possible, without losing their balance, and pushing the block as far back as they can. They must then return to the starting position. The distance (in cm) from the balance leg to this point is recorded. If they lose their balance the trial is discarded and performed again. One trial in each reach direction is performed. The entire test takes less than 5 minutes.

Ankle Arthrometer: Ankle looseness will be measured using two different devices that will be 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.



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.

Post-Acute Ankle Injury Follow-Up Testing: In addition to the above mentioned injury tracking; following any acute ankle sprains we intend to perform these post-injury tests (described above) at multiple time points (24 hr., 2-4 weeks, 3 months, 6 months, 1 year, and 2 years) over the course of their athletic career at the discretion of the university medical staff:

- 1) Questionnaires
- 2) Strength Testing
- 3) Stability
- 4) Balance Assessments (Y-Balance & BESS)
- 5) Ankle Arthrometer
- 6) Ultrasound Imaging

CONDITIONS OF SUBJECT PARTICIPATION

All the data will be kept confidential. Aggregate (cumulative) data from this study will be shared with the sports medicine or student health center staff at the University. In addition, records of any athletic-related injuries that you experience while participating as a student-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.

Initial _____

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

Subject Consent Signature

Date

Principal Investigator Signature

Date

B.2 FMS Scoring Sheet

THE FUNCTIONAL MOVEMENT SCREEN

SCORING SHEET

NAME _____ DATE _____ DOB _____

ADDRESS _____

CITY, STATE, ZIP _____ PHONE _____

SCHOOL/AFFILIATION _____

SSN _____ HEIGHT _____ WEIGHT _____ AGE _____ GENDER _____

PRIMARY SPORT _____ PRIMARY POSITION _____

HAND/LEG DOMINANCE _____ 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 | | | |

Raw Score: This score is used to denote right and left side scoring. The right and left sides are scored in five of the seven tests and both are documented in this space. 78

Final Score: This score is used to denote the overall score for the test. The lowest score for the raw score (each side) is carried over to give a final score for the test. A person who scores a three on the right and a two on the left would receive a final score of two. The final score is then summarized and used as a total score.

B.3 YBT Scoring Sheet**-Balance Test**

Right Limb Length (cm): _____ *Distal ASIS to Distal Medial Malleolus

Left Limb Length (cm): _____

| Direction | Right Trial 1 | Right Trial 2 | Right Trial 3 | Left Trial 1 | Left Trial 2 | Left Trial 3 |
|----------------|---------------|---------------|---------------|--------------|--------------|--------------|
| Anterior | | | | | | |
| Posteromedial | | | | | | |
| Posterolateral | | | | | | |

| Direction | Greatest Right | Greatest Left |
|----------------|----------------|---------------|
| Anterior | | |
| Posteromedial | | |
| Posterolateral | | |

$$\text{Composite Score} = \frac{(\text{Anterior} + \text{Posteromedial} + \text{Posterolateral})}{(3 \times \text{Limb Length})} \times 100$$

| | |
|-----------|--|
| Composite | |
| Right | |
| Left | |



Page: Injury General

Institution: University of Delaware

Current User:

Athlete:

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TRE DRO INS MED REF SIGN SURG SCAT VOMS

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Status

Athletic Quick Hidden

Injury Date: 02/26/2018

Time: 9:45 AM

Ret to Play: 80

Days Out: _____

Closed: _____

Days Open: _____

Sport: Soccer (M)

Action

AT Action Referred

Hospitalized Surgery

Description

Body Area: Lower extremity
 Body Part: _____
 Side: _____

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