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Injury Prediction in Division-I Collegiate Cross-Country Runners using Functional Movement Tests

by

Samuel McMullen, ATC

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

_________________________________________
Phillip Gribble, Committee Chair

_________________________________________
Dr. Brian Pietrosimone, Committee Member

_________________________________________
Dr. Kate Pfile, Committee Member

_________________________________________
Dr. Patricia R. Komuniecki, Dean
College of Graduate Studies

The University of Toledo

May 2013
An Abstract of
Injury Prediction in Division-I Collegiate Cross-Country Runners using Functional Movement Tests

by
Samuel McMullen

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**Objective:** The overall purpose of this study is examine how best to predict RRI in cross country runners. The study more specifically sought to: (1) Examine FMS, mFMS and SEBT-AR performance during pre-and post-workout states between collegiate cross-country runners that do and do not suffer a chronic injury to the lower extremity, and subsequently establish cut-off scores that can predict an increase in risk of musculoskeletal injury in cross-country athletes.

(2) Examine FMS, mFMS, and SEBT-AR performance during pre- and post-workout states between cross-country runners that do and do not have a previous acute or chronic injury history, and subsequently establish a cut-off scores that can identify athletes that may have performance deficits from their previous injuries. (3) Determine if performance of the mFMS and SEBT-AR are different post-workout compared to a pre-workout state in cross-country athletes. (4) Determine if previous injury history has a direct relationship to in-season injury status. **Design, Setting, and Data Source:** A prospective cohort design was utilized. Separate independent T-tests were used to determine if there was a difference in scores between those that sustained an in-season chronic RRI and
those who did not for the FMS, mFMS, and SEBT-AR during pre-workout conditions, as well as for the mFMS and SEBT-AR during the post-workout conditions. A Receiver Operator Characteristic Curve (ROC) was used to determine cut-off scores for the full FMS, mFMS, and SEBT-AR pre-workout, and mFMS and SEBT-AR post-workout which maximize sensitivity and specificity. A Chi-Squared analysis was used to determine if there was a relationship between previous injuries and in-season injuries. Significance was set to p<.05. **Results:** A total of 28 athletes met the inclusion criteria and completed the study and the 2012 cross-country season. Of the 28 subjects, 22 (79%) had sustained a previous injury while still allowing them to meet the inclusion criteria. Of the 28 subjects, 12 (43%) sustained an in-season injury. No significant difference was detected between those who did and did not suffer in-season or previous injuries from any of the screening scenarios. However, once ROC cut-off scores were established greater risk of injury was noted for both in-season injury and previous injury in certain screening scenarios. The pre-workout FMS had a specificity of .63 and pre-workout SEBT-AR had sensitivity of .83. When combined these tests produced a DOR of 8.7 for in-season injuries. The pre-workout FMS and SEBT-AR had DOR of 4.0 and 5.0 for previous injuries. The mFMS was significantly worse post workout (p=.05). The SEBT-AR was significantly better post-workout (p<.001). There was no significant interaction between previous injury and in-season injury status. **Conclusion:** A combination of the pre-workout SEBT-AR and full FMS should be used to optimize the prediction model as individual testing scenarios have a low DOR’s (<1.66). Athletes falling below both the pre-workout SEBT-AR cut-off of 79.32 and FMS of 16.25 are 8.7 times more likely to suffer an in-season injury. The pre-workout SEBT-AR (DOR= 5.0) and pre-workout
FMS (DOR= 4.0) were the most effective at identifying deficits in athletes with a previous injury. However, it cannot be determined whether the deficits are the result of previous injury or naturally occurring. This study supports the use of functional movement testing as a method of identifying lingering functional deficits and creating an individualized prevention protocols in an attempt to prevent future injury.
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List of Abbreviations

+ LR........................................Positive likelihood ratio;[sensitivity/(1-specificity)]
- LR........................................Negative likelihood ratio;[(1-sensitivity)/specificity]
DOR.........................................Diagnostic odds ratio; (+LR/-LR)
fFMS..........................................Full Functional Movement Screen
mFMS........................................Modified Functional Movement Screen
SEBT-AR..................................Star Excursion Balance Test- Anterior Reach
Chapter 1

Introduction

Epidemiology, Functional Movement Tests, and Fatigue

Cross-Country and recreational runners incur a high rate of running related injuries (RRI) to the back and lower extremity annually.\textsuperscript{1-3} Over one cross country season, approximately 38\% of high school runners sustained a RRI\textsuperscript{1}, while over the course of training between 19-80\% of recreational and marathon runners reported a RRI.\textsuperscript{3-8} Most RRs occur at the knee joint, accounting for approximately 42\% of RRIs, followed by the foot/ankle (16.9\%), lower leg (12.8\%), and hip joints (10.9\%).\textsuperscript{2,3} Additionally, the three most common RRs reported in recreational runners are patellofemoral pain, iliotibial band syndrome, and plantar fasciitis.\textsuperscript{2,3}

Running related injuries may be linked to a number of factors. Variables include age, Body Mass Index, running experience, weekly mileage, and previous injury history.\textsuperscript{9} Q-angle and age have also been linked to injury risk however they are non-modifiable factors.\textsuperscript{2,3} There is mounting evidence supporting the fact that a previous injury can increase the risk of future injury in runners.\textsuperscript{4,7,10,11} A number of theories behind this concept exist including incomplete healing, faulty biomechanics, or repeated training errors.\textsuperscript{4,11} The influence of previous injury may also vary between sexes.\textsuperscript{4,5,11} Men with a previous injury in the last 12 months were up to 6.3 times and women up to 7.6 times more likely to be injured compared to males and females who did not have a history of previous injury.\textsuperscript{4,5,11} With back and lower extremity injury rates so high among runners, and potentially identifiable underlying impairments such strength deficits, running biomechanical alterations, and decreased dynamic postural control among runners, a
functional pre-participation screening tool such as the Functional Movement Screen (FMS) and Star Excursion Balance Test (SEBT) may be effective in identifying athletes at risk for RRIs.

The developers of the FMS, claim to be able to identify athletes at risk of an in-season injury by detecting deficits in movement patterns, strength, flexibility, and neuromuscular control using this system.\textsuperscript{12} Several researchers report the FMS test to have strong interrater reliability.\textsuperscript{13,14} The lowest interrater reliability was reported for the inline lunge test with 83-91\%.\textsuperscript{14}, while the remaining tests scored upwards to 100\% reliability.\textsuperscript{14} Chorba et al\textsuperscript{15} reported that athletes without major musculoskeletal or ACL reconstructed knees that scored a 14 or less on the FMS had a significant increase in traumatic or acute injury risk compared to athletes who scored 15 or greater.\textsuperscript{15} However, recent investigations by Gribble et al contradict these findings, indicating performance on the FMS is not a strong predictor of traumatic injury in collegiate football players (Gribble et al, unpublished data). More specifically, these models were based on the prediction of traumatic injuries and not overuse or chronic injuries providing no generalization to other sports such as cross-country where RRIs are primarily chronic in nature. The current FMS also utilizes upper body tests which might not be relevant to a lower extremity oriented sports such as cross-country. By modifying the FMS (mFMS) to be lower extremity oriented and focusing on the deep squat, hurdle-step, and the in-line lunge, clinicians can potentially make the testing more sensitive and time efficient.

Another functional test, the SEBT, has been recognized for its ability to distinguish pathological movement patterns between healthy and injured subjects.\textsuperscript{16} The SEBT has been established as a reliable screening tool with intratester reliability between .67-.96
depending on the reach direction\textsuperscript{17,18}, and intertester reliability between .84-.92 after practice trials are utilized\textsuperscript{19}. Preliminary tests have established the SEBT as having potential injury predictive qualities.\textsuperscript{20} For example, women’s high school basketball players with less than 94% reach of their leg length on the composite SEBT score were 6.5 times more likely to have an in-season lower extremity injury compared to those that scored 95% or greater.\textsuperscript{20} However, despite the large number of studies utilizing the SEBT, this screening tool has yet to be used to evaluate cross-country runners. The anterior reach (SEBT-AR) portion of the SEBT simulates a common movement pattern found in sports, such as biomechanics of running, and thus could be a useful injury predicting tool.

During prolonged athletic activity such as running, fatigue can manipulate the body into vulnerable or injury susceptible running patterns, and negatively impact dynamic postural control. The role of fatigue is that it decreases the conduction velocity of afferent motor neurons, creating a delay in efferent output, and negatively impacting the ability of muscles to contract and optimally stabilize the body. For example, in subjects with hip musculature fatigue their center of pressure (COP) excursion velocity significantly increased from 3.6cm/s to about 4.0cm/s compared to subjects with no prior lower extremity injury indicating a delayed ability to recruit muscles in order to steady the body.\textsuperscript{21,22} Few changes may be detectable in kinematics while running when fatigued, however altered kinetics have been detected potentially indicating altered muscle firing patterns.\textsuperscript{23,24} Altered firing patterns and muscle imbalances are magnified by fatigue and place the athlete in susceptible injury positions potentially resulting in chronic RRIs. The
FMS and SEBT-AR could possibly identify these deficits in an at-risk population of cross-country runners.

**Statement of Problem**

A large number of cross-country athletes participate at the Collegiate Division 1 level, with a large percentage of runners incurring injuries. Therefore, it is important to find a screening tool that can identify risk factors that may predispose runners to a chronic RRI. While there is evidence for and against the ability of the FMS to predict injury in football athletes, its ability to predict injury in Division 1 collegiate cross-country runners remains unknown. Cross-country running is a repetitive, endurance, fatiguing task compared to other sports such as football. The ability to detect differences in FMS and SEBT-AR performance post-workout and its relationship to chronic injury risk has yet to be assessed. While suggested as a risk factor, the influence of previous injuries upon future injuries has yet to be assessed in competitive Division-I cross-country runners.

**Statement of Purpose**

The overall purpose of this study is examine how best to predict RRI in cross country runners. The specific aims of the study are:

(1) Examine FMS, mFMS and SEBT-AR performance during pre-and post-workout states between collegiate cross-country runners that do and do not suffer a chronic injury to the lower extremity, and subsequently establish cut-off scores that can predict an increase in risk of musculoskeletal injury in cross-country athletes.

(2) Examine FMS, mFMS, and SEBT-AR performance during pre- and post-workout states between cross-country runners that do and do not have a previous acute or chronic
injury history, and subsequently establish a cut-off scores that can identify athletes that may have performance deficits from their previous injuries.

(3) Determine if performance of the mFMS and SEBT-AR are different post-workout compared to a pre-workout state in cross-country athletes.

(4) Determine if previous injury history has a direct relationship to in-season injury status.

**Research Hypothesis**

**H**<sub>1</sub>: Cross-Country athletes who do not suffer a chronic in-season lower extremity injury will have a significantly higher FMS, mFMS, and SEBT-AR scores than those who do suffer a lower extremity RRI.

**H**<sub>2</sub>: There will be specific FMS, mFMS, SEBT-AR scores pre- and post-workout that will produce sensitivity and specificity scores greater than 0.7 associated with prediction of lower extremity RRI

**H**<sub>3</sub>: There will be specific FMS, mFMS, and SEBT-AR scores that will produce sensitivity and specificity scores greater than 0.7 for identification of athletes with a previous acute or chronic lower extremity RRI.

**H**<sub>4</sub>: Scores of the mFMS and SEBT-AR test will be lower in the post-workout state than pre-workout.

**H**<sub>5</sub>: Cross-Country athletes who have a previous acute or chronic lower extremity RRI will have significantly lower FMS, mFMS, and SEBT-AR scores than those without a previous injury.

**H**<sub>6</sub>: Those with a previous injury history will be more likely to be injured in-season.
Significance of Study

The FMS and SEBT-AR, whether in a pre or post-workout state, may reveal underlying weaknesses that may predispose an athlete to a chronic musculoskeletal RRI. Additionally, previous injury history may play a significant role in the development of future injuries. With the results from this study, clinicians may be able to integrate interventions into running programs in order to prevent injuries in runners and decrease time away from running and competition.
Chapter 2

Literature Review

Running Injury Epidemiology

The incidence of running related injuries (RRI) varies between 19-80% annually. The most commonly diagnosed running related injuries are patellofemoral pain (PFP) at 21%, followed by iliotibial band friction syndrome (ITBS) at 10.6%, and plantar fasciitis at 10%, trailed by meniscal injuries, tibial stress syndrome, patellar tendonitis, and Achilles tendonitis all at under 6%. Additionally, it has been reported that women have an inherently higher risk of injury than men.

Variation in injury statistics largely depends on the injury definition, the population surveyed, and the time span over which injuries are tracked. In order to determine an accurate rate of RRI's an injury definition must be moderate enough to encompass true structural damage related to injury while still being strict enough to avoid counting athletes complaining of daily soreness related to the workout. A RRI should be a modified definition of musculoskeletal injury such as the criteria defined by Rauh et al: (1) injury occurred as a result of participation in an organized practice or meet, (2) required the athlete to seek medical attention from the team’s certified athletic trainer, and (3) required the athlete to be removed from at least one practice or meet. Injuries that did not occur during participation, or were unrelated to running were excluded. A day lost to injury was any in which the runner was not able or permitted to participate in an unrestricted manner.
However, chronic overuse injuries make up the majority of RRIs, and 28% of all injuries in the NCAA Big Ten. Chronic injuries can be harder to define compared to acute injuries. Often times chronic injuries do not linger very long nor do they always completely impede the ability of an individual to participate in athletics. In RRI studying, an injury was defined as: clinical signs of tissue damage as found by an ATC or physician as well as the inability to return to practice/game that day. Acute injuries were defined as being traceable to a single event. Chronic overuse injuries were defined as injuries with a gradual onset without a single traumatic event. Furthermore, severity is defined into four categories base of time loss. The categories were (1) no time loss, (2) minor- less than 1 week, (3) moderate- one to three weeks lost, (4) more than 3 weeks time lost. This injury definition is more appropriate because it implies that some pathological condition has occurred and is similar to other studies that have examined occurrence of traumatic injury in a variety of sports in high school and collegiate athletes.

Functional Movement Screen Testing

The Functional Movement Screen (FMS) consists of seven stations that are designed to place an athlete in functional positions where balance, strength, stability, mobility, and neuromuscular control can be readily assessed. When a patient has deficits in stability, mobility, or neuromuscular control the body, or entire kinetic link model, creates less efficient compensatory movement patterns in order to perform optimally. The kinetic link model demonstrates how each independent body segment must work in combination with others in order to operate efficiently. If the patient lacks an efficient pattern, it may predispose the athlete to an increased risk of injury.
Clinicians can utilize the FMS to identify poor movement patterns and muscle imbalances that may predispose an athlete to injury. The seven tests included were chosen as they are different movement patterns that test different muscle groups. For each of the seven tests subjects are given a score between 0 and 3. A 3 is given for subjects that complete each task successfully and without pain. A 2 is given for subjects that complete the task with compensatory movement/s but without pain. A 1 is given for subjects that are unable to complete the task and have no pain. A 0 is given if the subject has pain at any time during each test. Each movement is performed three times with the lowest score being utilized. For tests that require both limbs to be tested, the order of the test side is randomized.\textsuperscript{28,29} Identifying muscular imbalances can allow clinicians to provide an intervention to help the athlete overcome these restrictions and move more efficiently.

The first of the testing stations, the deep squat, is performed with feet shoulder width apart, and arms overhead while holding the dowel parallel to the shoulders. The subject is then instructed to lower himself into a deep squat position. The goal is to have the subject in a deep squat with the pelvis lower than the knees and the torso parallel to the tibia. At the same time the athlete’s feet should remain flat on the ground, knees straight over the feet, and the dowel pressed in a level position overhead. Points are deducted for deviations from the goal position.\textsuperscript{28} A compensatory position that receives a 2 for this test allows the subject to put heels on the 2x6in board.

The hurdle step test requires the subject to step over the hurdle cord that is the same height as the subject’s tibial tuberosity. The subject is asked to hold the dowel level on the posterior aspect of the shoulders. The subject then touches the moving heel to the
ground on the other side of the hurdle and then moves back to the starting position. The same procedure is performed for both legs. The goal of the task is to keep the hips, knees, and ankles aligned in the sagittal plane while maintaining an upright torso. Deductions from 3 points are made for the inability to complete and maintain the goal positions. The in-line lunge requires the subject to perform a lunge from a fixed position on a board. The heel of the one leg stays on the end of the board while the heel of the other leg is placed in front of the other foot at a distance equivalent to the length of the subject’s tibia. The subject is then instructed to hold a dowel vertically in alignment with the spine which touches the subject’s head, thoracic spine, and sacrum. The arm on the side of the front leg holds the dowel around the cervical region while the other hand holds the dowel within the lumbar region. The subject must keep the dowel in a vertical position while the subject touches the knee of the posterior leg to the heel of the front foot. The subject is then asked to return to the starting position. Deductions from 3 points are made for the inability to complete and maintain the goal positions. For the shoulder mobility test, the subject is asked to reach over the shoulder with one arm as far down the spine as possible, while the opposite arm reaches as far up the spine from under the shoulder, with an aim of reaching the hands together. Measurements are taken as the distance between the two fists. Deductions are made from 3 points (hands within 1 hand length) if the hands are 1-1.5 hand lengths apart and then over 1.5 hand lengths apart. For the active straight leg raise, the subject is asked to lay supine with arms and legs flat against the floor. The tester holds the dowel perpendicular to the ground midway between the subject’s ASIS and mid-point of the patella. The subject is asked to bring the
testing limb into hip flexion while maintaining full knee extension and ankle dorsiflexion. Deductions are made from 3 points depending on the level of hip flexion obtained relative to the vertical dowel.\textsuperscript{29}

For the trunk stability push up, the subject is instructed to lay prone with knees extended and ankles in dorsiflexion. The subject then executes a push up with the hands placed even with the clavicle for females, and even with the chin for males. Deductions are made from 3 points for poor form or if the subject needs to alter the pushup position in order to complete the test.\textsuperscript{29} Compensatory test positions receiving a 2 bring the subject’s hand position in line with the chest.

For the rotary stability test, the subject is directed to assume the quadruped position, with hips and knees flexed at ninety degrees. Next the subject flexes one shoulder parallel to the spine, while extending the ipsilateral hip in the same parallel fashion. Deductions are made from 3 points for poor form.\textsuperscript{29} The compensatory position receiving a 2 allows the subject to complete the task touching contralateral elbow and knee.

While the FMS was initially designed with a perfect score of 21, based on the 3 points per individual test, recently a new 100 point score was introduced with a comparable interrater reliability (.91-1.0 on each FMS test).\textsuperscript{13} The advantage to the 100 point scale is that it is more specific in identifying the compensatory movement.\textsuperscript{13} The authors hypothesized that improved precision will help to identify more specific areas for weakness that may be corrected via interventions, which will improve the usefulness of the test. However, additional research is warranted to compare the two scoring scales prior to utilizing the 100 point scale.
The limited research available suggests that the FMS is a reliable functional assessment tool. When 2 experts and 2 novice raters are used to test the FMS for 40 subjects, there was an excellent agreement in 14 of 17 scores (91%-100% agreement) and substantial agreement on 3 of 17 scores (83.4%-89.8% agreement) when comparing the average scores of the experts to the novice raters.\textsuperscript{14} This demonstrates the ability of multiple raters of varying expertise to utilize the FMS and fall upon similar results.\textsuperscript{14}

A recent paper by Gribble et al\textsuperscript{30} examined the intrarater reliability of scoring the FMS within different groups of varying levels of clinical experience, and experience with the FMS. It was determined that FMS test has high intrarater reliability and increases in reliability as FMS experience increases. This is noted by a strong ICC of .946 from the experienced ATC group and a moderate ICC of .771 from the inexperienced AT group.

Research studies using the FMS to predict injury have used a broad injury definition. For example, researchers have used a time period of 3 weeks on the injured reserve and subsequent removal from practice\textsuperscript{12} or on the other hand simply seeking medical attention.\textsuperscript{15} These definitions could include irrelevant conditions or injuries, or include minor injuries that do not impede physical activity participation. For example, a definition could include concussions and illness that placed a professional football player on the injured reserve, but these are not conditions that can be screened for by a functional test such as the FMS. Chronic running injuries are often the result of a combination of extrinsic factors such as training errors, and intrinsic factors such as biomechanical malalignment.\textsuperscript{2,3} According to designers of the FMS tool, poor biomechanical patterns of stability, mobility, and muscle weakness and neuromuscular control deficits\textsuperscript{28,29} may be magnified by extrinsic factors when combined with long
repetitive training sessions inducing fatigue. If compensatory motions are created as a result of these biomechanical flaws then this potentially puts the athlete at greater risk of injury.\textsuperscript{28,29}

Sports medicine professionals utilize pre-participation physicals (PPE’s) to screen for conditions that indicate need for intervention. The PPE typically includes screening for serious life threatening pathologies involving the cardiovascular and other internal systems, with only minor examination of the musculoskeletal system usually based on the athlete’s self-reports. Although PPE’s may be helpful in identifying general medical conditions, they fail to efficiently assess athletes’ abilities and injury predispositions;\textsuperscript{28,29} even more specifically in distance runners. There is little evidence suggesting that these PPE’s predict musculoskeletal injury at all and therefore may not be sufficient in identifying at risk athletes. Therefore, there is a need for simple, yet effective screening tools for musculoskeletal conditions that can be added to a PPE to improve the prediction for these conditions.

Recently, two studies have investigated the implementation of a preseason FMS screening and its ability to predict an in-season injury. Kiesel et al studied the predictability of injury utilizing the FMS testing protocol in NFL football players. They reported an optimal cut-off score of 14 points that resulted in a maximized sensitivity of 0.54 and a specificity of 0.91.\textsuperscript{12} Subjects that scored below a 14 were 11.61 times more likely to sustain an acute lower extremity injury compared to the football players that scored above a 14 on the FMS.\textsuperscript{12}

Chorba et al\textsuperscript{15} studied the injury predictability of the FMS test in 38 female collegiate athletes, free of previous major musculoskeletal injuries. The authors measured
preseason FMS test scores and then over the course of an athletic season, recorded athletic related injuries. Using the cut-off score of 14 established in the study by Kiesel et al, they report that 69% of the athletes with scores of <14 resulted in a higher likelihood of injury and would be at 4x greater risk of injury than athletes scoring 14 or greater. Sensitivity and specificity were found to be 0.58 and 0.74 making it a moderately effective test. Therefore, this study suggests that the FMS can identify athletes with compensatory movements that might predispose them to greater.

One of the major inconsistencies between the studies by Chorba et al and Kiesel et al is their definition of an injury. Chorba et al defined an injury as a musculoskeletal injury resulting from an intercollegiate practice or competition that required the athlete to seek advice from an ATC or physician. While Kiesel et al defined an injury as a musculoskeletal injury that required the player to miss at least three weeks of practice. The study by Kiesel et al likely did not include a large number of injuries because of such a strict standard of injury. In fact only 13 of 46 subjects were injured in this study. There were likely injuries that resolved before this three week standard which may have further influenced the sensitivity and specificity of the results from Kiesel et al results. The definition by Chorba et al could be the opposite in that it is too broad allowing for the inclusion of a wider spectrum of injuries. The definition lacked any discrepancy of how serious the injury was and therefore may have allowed traditionally noted non-injuries to be considered injuries such as contusion that the athlete could play through. A potential flaw in the Chorba et al study is that it used the cut-off score established by Kiesel et al to differentiate players at risk for injury. This study should have utilized its own cut-off score because of the poor injury definition in the Keisal et al study.
Finally, both of these studies did not differentiate between contact or non-contact injuries. In a sport like football having good balance, flexibility and strength can only predict the quality of performance of the player himself which the FMS is designed to detect. It is not the purpose of the FMS to predict contact injuries which are dependent on outside factors that cannot be easily controlled or predicted such as an opponent. Therefore, the FMS may have better application for prediction of lower extremity injuries that are more are attributable to biomechanical flaws such as non-contact injuries.

As noted in the epidemiological section, RRIs are primarily lower extremity injuries. This indicates the need to more thoroughly screen for lower extremity deficits. The current full FMS utilizes upper body tests which might not be relevant to a lower extremity sports such as cross-country. By modifying the FMS to be lower extremity oriented (mFMS), clinicians can potentially make the testing more sensitive and time efficient.

**Star Excursion Balance Test**

The Star Excursion Balance Test (SEBT) is both a rehabilitative and dynamic stability assessment tool that closely replicates the demands of certain physical activities. The SEBT requires the subject perform a single leg squat movement while reaching the non-stance leg as far as possible in eight directions away from the stance leg. These lunges are performed in the anterior, posterior, lateral, medial, posterolateral, posteromedial, anterolateral, and anteromedial directions with the directions named in reference to the stance leg. Each direction creates a different challenge in balance, proprioception, flexibility, and stability. The goal is to reach the nonstance leg as far as possible making a light touch along the direction’s axis then return to bilateral stance.
The trial is considered a failed trial if the reach limb touches down heavily, makes floor contact before or after maximal reach to regain balance before returning to bilateral stance, or if the subjects’ hands are removed from their placement on the hips. Assessors should make note of failed trials as excessive failed trials may indicate a deficit in itself. The reach distance of three trials is averaged and normalized as a percentage of the subject’s leg length. Leg length is measured from the base of the medial malleolus to the ipsilateral anterior superior iliac crest. Normalization to leg length is conducted as performance is influenced by leg length.\textsuperscript{32}

Recently, researchers of the SEBT have found that the SEBT can be limited to the anterior, posteromedial, and posterolateral directions and still achieve a sufficient understanding of overall dynamic balance.\textsuperscript{33} Reducing the SEBT to these three directions rather than all eight make this test much more time efficient and increases the potential for its use as a readily available screening tool. The anterior reach portion in particular is one of the most common movement patterns performed in numerous sports, such as running, making it a particularly important movement to evaluate.

Intratester and intertester reliability of the SEBT has been assessed in a number of studies with moderate to strong reliability reported (ICC= .67-.96) depending on the reach direction.\textsuperscript{17,18} Intratester reliability was heavily dependent upon the reach direction, whereas intertester reliability varied not only on direction, but also from day 1 (ICC=.35-.84) to day 2(ICC=.81-.93).\textsuperscript{17} The change in reliability between days can be attributed to a learning effect where the participants’ performed better simply through practice. To minimize this effect, researchers have noted that only 4 practice trials should be allowed for each direction before testing.\textsuperscript{19,34} When only four practice trials are performed the
Inter-rater reliability of the test was stronger (ICC.84-.92).\(^\text{19}\) An additional consideration when using the SEBT is the consistency in the time of day the test is performed when used over a longer time span as circadian rhythm can influence performance.\(^\text{35}\)

Research has also addressed the influence of gender and fatigue on SEBT performance. While healthy men and women seem to have similar normalized scores at rest,\(^\text{36}\) these scores can change after fatigue protocols. Gribble et al\(^\text{36}\) found women were able to reach farther than men when fatigued. Both groups still had negatively impacted scores due to fatigue. This led to the theory that women were able maintain greater knee flexion compared to their male counterparts.\(^\text{36}\) Gribble et al\(^\text{37}\) also noted that both healthy subjects and subjects with chronic ankle instability have significant decreases in SEBT score after fatigue protocols.\(^\text{37}\)

Similar to the FMS, the SEBT has the potential to identify functional deficits by movement pattern assessment. In the anterior direction of the SEBT, 28% of the variance in performance was found to be related to the subjects’ dorsiflexion range of motion (ROM).\(^\text{32,38}\) Therefore, the less dorsiflexion ROM the subject has, the worse the performance on the SEBT. Proximally at the knee joint, knee flexion ROM was found to contribute to movement in the anterior, anteromedial, and posteromedial directions.\(^\text{39}\) Normal dorsiflexion and knee flexion are necessary to achieve an optimal squatting position and therefore without proper ROM a far reach cannot be obtained. This information may prompt clinicians to assess knee ROM more readily when subjects lack sufficient scoring in these directions.

The SEBT also has the ability to identify pathological individuals in particular those with chronic ankle instability (CAI),\(^\text{33,37,40}\) patellofemoral pain syndrome (PFPS),\(^\text{41}\)
and those that are ACL deficient. Individuals with CAI have significantly less knee and hip flexion on the affected side compared with healthy limbs within and across subjects. Knee and hip flexion measured when performing the SEBT-AR accounts for 49% of variance in SEBT performance in CAI subjects. Similar patterns in decreased hip flexion and knee flexion were found in subjects with PFPS and ACL deficiency.

The SEBT has been reported to have injury predictive capabilities. Plisky et al was the first study to find that women’s high school basketball players with less than 94% on composite SEBT scores were 6.5 times more likely to have an in-season lower extremity injury compared to those athletes that scored 95% or above. This information in combination with the findings by Gribble et al that fatigue and pathological conditions decrease SEBT performance make it more plausible that the SEBT may also prove a useful screening tool in cross-country runners.

**Effects of Fatigue**

Several research studies have identified the negative impact of fatigue on postural control, strength, kinematics, and neuromuscular control. Posture implies the subject’s ability to maintain an erect position, either with or without intended movement, depending on whether the assessment is of static or dynamic control, respectively. Fatigue of hip musculature during sagittal and frontal plane movements induces a significant reduction in postural control. Conversely fatigue of the ankle musculature had minimal effect on postural control. There is a need to assess variables influenced by fatigue such as neuromuscular and postural control.

Fatigue can have significant adverse effects on running kinematics. Subjects fatigued during a prolonged running protocol demonstrated increased hip flexion
excursion from about 5.1 to 6.2 degrees and decreased knee flexion from 13.6 to 8.1 degrees. These kinematic changes resulted concurrently with kinetic alterations of increased peak impact acceleration of the shank at heel strike. Combined, these kinetic and kinematic alterations could lead to a force overload of the shank and without proper intervention could result in injury.

Distally at the lower leg, fatigue of the ankle dorsiflexors and inverters can have a significant impact on the loading rate during running or walking. Researchers noted that the dorsiflexors produced 57.6%+/−10.6% and the invertors produced 71.4%+/−15.3% torque during the first 50% of the stance phase of running compared to pre-fatigue levels. In addition, a decrease of 3.2 degrees of dorsiflexion and 2.2 degrees of inversion ROM at heel strike occurred when fatigued. However the influence of the decreased ROM may not be influential as not all runners land on their heels. Overall fatigue is a significant contributor to changes in running kinematics and may play a vital role in lower extremity injury.

The impact of fatigue on running mechanics may be influenced by the population of individuals or the running task. Changes in running kinematics did not occur when experienced runners were given varied amounts of rest between intervals of running. Experienced runners may be more resistant to fatigue and may not show significant alterations in running kinematics.

Influence of Previous Injury History on Future Injury

There is mounting evidence supporting the fact that presence of a previous injury may increase the risk of future injury in runners. A number of theories behind this concept exist stemming from incomplete healing, faulty biomechanics, or repeated
training errors. The influence of previous injury however may vary between sexes. Men with a previous injury in the last 12 months were 1.7-6.3 times, and women 1.9-7.6 times more likely to be injured over the course of the study compared to men and women without a previous injury in the past 12 months.

**Summary**

The incidence of running related injuries (RRI) varies between 19-80% annually. Functional movement tests such as the FMS and SEBT have the potential to predict in-season injury. Fatigue has also been shown to amplify deficits in movement performance. Therefore, these tests in combination with a fatigued state and a previous injury history may have the potential to predict injury in a cross-country runner population. The FMS and SEBT have high interrater and intrarater reliability making them credible tools for screening athletes at risk of injury. Fatigue contributes to decreased postural control and altered running kinematics and kinetics possibly increasing the risk of sustaining an injury. The combination of high rate of RRIs, ability of the FMS and SEBT to predict risk of injury, and the contribution of fatigue to injury prone positions, warrants the necessity of pre-season screening tools to predict runners at risk for RRIs. The deep squat, hurdle step, inline lunge and anterior reach of the SEBT are designed to target the hip, knee, ankle, and core stability and mobility which are used during running, and therefore may prove useful as a modified version of the full FMS. If these muscles and joints are repetitively stressed and fatigued during running it might give the greatest likelihood of detecting a difference in FMS and SEBT test score performance post-fatigue due to altered kinematics.
Chapter 3
Methodology

Study Design

Prospective cohort study.

Subjects

All participants were on the Division 1 Collegiate Cross-Country team at the University of Toledo. This study included 11 males (20.0± 1.2yrs, 69.0± 5.3kg, 179.0± 9.2cm) and 17 females (19.3± 1.1yrs, 52.5± 4.5kg, 167.2± 4.3cm). All participants were cleared to participate at the time of data collection. Subjects were excluded if they had a previous history of: vestibular dysfunction, lower extremity or back surgery, or a concussion within last 3 months. These subjects were excluded due to the possible influence of their recent injury upon their movement patterns. Each subject signed an informed consent form as approved by the University of Toledo’s Institutional Review Board before participation.

Instrumentation

A Functional Movement Screen test kit included a two inch by six inch board, hurdle, and measuring dowel, and string. For the SEBT-AR the six-inch in-line lunge board from the FMS will be used with a metric tape measure.

Independent Variables

Injured Status: Chronic Injury or Injury free in-season

Previous Injury history: Chronic/Acute Injury or Injury Free

Time: Pre-workout, Post-workout

Dependent Variables
Pre-workout full FMS score
Pre-workout mFMS score
Post-workout mFMS score
Pre-workout SEBT-AR score
Post-workout SEBT-AR score

**Procedure**

Prior to the beginning of the cross-country season, subjects were evaluated on their performance on the full FMS in a pre-workout state. All testers were trained in FMS testing via a standard protocol. For each of the seven tests the subjects were given a score between 0 and 3. A 3 was given for subjects that complete each task successfully without pain. A 2 was given for subjects if the task was completed with a compensatory movement without pain; or completed the alternative position correctly. A 1 was given for subjects if the task was unable to be completed but without pain. A 0 was given if the subject had pain at any time during each test. Additionally, each movement was performed three times with the lowest score being utilized. The order of the side tested was randomized.

For the SEBT-AR the athlete stood on a flat surface with toes behind the beginning of the measuring tape. The athlete reached anteriorly and touch as far as possible along the tape measure with the non-stance limb while keeping the stance foot flat on the ground. This touch point was measured in centimeters and normalized as a percent of the athlete’s leg length.

All athletes completed a cross-country interval workout with 5 sets of 3 minutes “hard” running with a 2 minute recovery jog. Runners were instructed to complete the
last interval “all out” in order to be as close to fatigue as possible. The athletes completed the workout in groups of three, staggered five minutes apart. Within 2 minutes of the workout being completed, the athletes completed the deep squat, hurdle step, in-line lunge, and Star Excursion Balance Test- Anterior Reach. The order of tests and starting limb was randomized.

**Injury Exposure and Definition**

An injury was defined as: a musculoskeletal injury of the lower extremity or back that met the following criteria: (1) injury occurred as a result of participation in an organized practice or meet, (2) the injury was assessed by an athletic trainer or physician, and (3) required the athlete to be removed from at least three consecutive practices or meets. Injuries that did not occur during participation, or were unrelated to running were excluded. Acute injuries were defined as a result of a single traumatic event. Chronic injuries were defined as non-traumatic injuries. A day lost to injury was defined as any in which the runner was not able or permitted to participate in an unrestricted manner. This definition was used to ensure that the injury is actually an injury and not just extreme soreness as sometimes can be perceived.

Injury exposure rates were described as the number of injuries per hour of running and per day. This was modified from the typical exposure definition of injuries per practice/competition due the large variation in training duration per athlete. Subjects who were injured were not included in the injury exposure rate during their time off but resumed their influence as they progressed back into running.
Injury analysis

All athletes’ health status were tracked throughout the season and then categorized as being Injured (I) or Injury-Free (IF). Subjects in each of these groups were also categorized as having a previous injury history or not.

A questionnaire describing the athlete’s age, sex, and previous or current injuries, and previous treatment/rehabilitation was completed before the study began. The current and previous injury sections of the questionnaire were oriented to allow the researchers to understand whether the nature of the injury was acute or chronic. Acute injuries were defined as a result of a single traumatic event. Chronic injuries were defined as non-traumatic injuries. The questionnaire also determined the extent of the injury noting the number of days injured, whether a health care professional was consulted, and how many days of training were lost as a result.

Statistical Analysis

Separate independent T-tests were used to determine if there was a difference in scores between those that sustained an in-season chronic RRI and those who did not for the FMS, mFMS, and SEBT-AR during pre-workout conditions, as well as for the mFMS and SEBT-AR during the post-workout conditions. Independent T-tests were also performed for the same screening scenarios to determine if there was a difference in scores between those who had a previous history of an acute or chronic injury and those that did not. To determine if there was a significant difference between pre-workout and post-workout mFMS and SEBT-AR scores, dependent t-tests were used.

A Receiver Operator Characteristic Curve (ROC) was used to determine cut-off scores for the FMS, mFMS, and SEBT-AR pre-workout, and mFMS and SEBT-AR post-
workout which maximize sensitivity and specificity. This compared the number of true positives, (sensitivity), versus the number of false positives (1-specificity). The optimum injury threshold score was determined by analyzing this curve by finding the uppermost left part of the graph. A 2x2 contingency table was used to dichotomize the athlete’s suffering or not suffering an injury above or below this threshold score. From this contingency table the odds, likelihood ratios, diagnostic odds ratios, sensitivity and specificity were created based off the following formulas:

\[ +LR = \frac{\text{sensitivity}}{1 - \text{specificity}} \]
\[ -LR = \frac{1 - \text{sensitivity}}{\text{specificity}} \]
\[ \text{DOR} = \frac{+LR}{-LR} \]

Sensitivity is useful for ruling out athletes that are not at-risk, whereas specificity is useful for ruling in at-risk athletes. Positive likelihood ratios determine the increase in post-test probability of an injury, while negative likelihood ratios determine the decrease in post-test probability of an injury. Lastly, diagnostic odds ratios determine the overall increased risk of injury for an athlete that scores below the determined cut-off score.

A Chi-Squared analysis was used to determine if there was a relationship between previous injuries and in-season injuries. This was done using a 2x2 contingency table to categorize subjects into having a 1) previous injury with in-season injury, 2) previous injury with no in-season injury, 3) no previous injury with in-season injury, 4) no previous injury with no in-season injury.

SPSS 19.0 was used for all statistical analyses. An a-priori alpha level of p<.05 was used as a threshold of significance.
Chapter 4

Results

A total of 28 athletes met the inclusion criteria and completed the study during the 2012 cross-country season. Of the 28 subjects, 22 (79%) had sustained a previous injury while still allowing them to meet the inclusion criteria. Of the 28 subjects, 12 (43%) sustained an in-season injury.

Males and females scored similar at baseline on the composite FMS score (M: 16.27 ± 1.74; F: 16.50 ± 1.82; p = 0.74) and SEBT-AR (M: 72.60 ± 4.11%; F: 74.44 ± 5.71%; p = 0.36). Similar baseline values allowed for pooling of male and female data without creating a covariate.

Injury Incidence Rates

The female cross country runners accumulated 91 days, or 1297 hours of in-season training during the fall 2012 cross-country season. Nine of the females sustained a lower extremity injury. The injury incidence rate was 8.75 injuries/1000 AE, when one day is considered an athletic exposure, or a rate of 9.25 injuries/1000 hours of running for females. On the other hand, the male cross country runners accumulated 83 days, or 1020 hours of training during the fall 2012 cross-country season, and only three sustained an injury to the lower extremity. The injury incidence rate was 3.46 injuries/1000 AE when one day is considered an athletic exposure, or 2.94 injuries/1000 hours of running for males. While there did appear to be a discrepancy in the injury rates between males and females, the relatively small sample size precluded the ability to effectively compare male and female injury prediction based on the performance scores.
Functional Movement Screen

Results regarding the FMS and mFMS with in-season injury status can be found in Tables 1, 2, and 3. Regardless of previous injury or in-season injury status, the mFMS scores were worse post-workout (5.96±1.01) compared to the pre-workout (6.40±1.13; p=0.05).

For the full FMS, there were no statistically significant differences between subjects that did (16.58 ±1.50) or did not suffer an in-season RRI (16.97 ±1.86, p = .563). A cut off score for the full FMS of 16.25 was associated with a sensitivity of 0.50 and a specificity of 0.62, resulting in a diagnostic odds ratio of 1.66.

There were no statistically significant differences between subjects that did (6.58 ±1.24) or did not suffer an in-season RRI (6.53 ±1.11) on the pre-workout mFMS (p =.908). A cut off score for the mFMS of 7.25 was associated with a sensitivity of 0.83 and a specificity of 0.25, resulting in diagnostic odds ratio of 1.63.

There were no statistically significant differences between subjects that did (6.25 ±1.29) or did not suffer an in-season RRI (6.25 ±.58) on the post-workout mFMS (p = 1.00). A cut off score for the post-workout mFMS of 6.25 was associated with a sensitivity of 0.583 and a specificity of 0.044, resulting in an odds ratio of 0.064.

Results regarding the FMS and mFMS with previous injury status can be found in Tables 4, 5, and 6. There were no statistically significant differences between subjects that did (16.48 ±1.94) or did not suffer a previous injury (16.14 ±1.35) on the full FMS (p = .678). A cut off score for the full FMS of 16.5 was associated with a sensitivity of 0.62 and a specificity of 0.71, resulting in a diagnostic odds ratio of 3.995.
There were no statistically significant differences between subjects that did (6.52 ±1.25) or did not suffer a previous injury (6.00 ±.58) on the pre-workout mFMS (p =0.298). A cut off score for the mFMS of 7.5 was associated with a sensitivity of 0.86 and a specificity of 0.29, resulting in a diagnostic odds ratio of 2.509.

There were no statistically significant differences between subjects that did (6.14 ±1.01) or did not suffer a previous injury (5.42 ±.79) on the post-workout mFMS (p = 0.102). A cut off score for the post-workout mFMS of 7.5 was associated with a sensitivity of 0.95 and a specificity of 0.14 resulting in a diagnostic odds ratio of 3.095.

**Star Excursion Balance Test- Anterior Reach**

Results regarding the SEBT-AR with in-season injury status can be found in Tables 1, 2, and 3.SEBT-AR scores were significantly greater post-workout (78.17±6.17%) compared to the pre-workout (73.99±4.78%; p<0.001).

There were no statistically significant differences between subjects that did (75.11 ±5.48%) or did not suffer an in-season RRI (72.32 ±4.64%) on the pre-workout SEBT-AR (p = 0.157). A cut off score for the pre-workout SEBT-AR of 79.32%, was associated with a sensitivity of 0.83 and a specificity of 0.19, resulting in a diagnostic odds ratio of 1.17.

There were no statistically significant differences between subjects that did (80.2 ±5.18%) or did not suffer an in-season RRI (76.71 ±6.55%) on the post-workout SEBT-AR (p =0.152 ). A cut off score for the post-workout SEBT-AR of 80.38, was associated with a sensitivity of 0.64 and a specificity of 0.47, resulting in a diagnostic odds ratio of 1.577.
Results regarding the SEBT-AR with previous injury status can be found in Tables 4, 5, and 6 There were no statistically significant differences between subjects that did (73.71 ±5.26%) or did not suffer a previous injury (72.94 ±5.00%) on the pre-workout SEBT-AR (p = 0.735 ). A cut off score for the pre-workout SEBT-AR of 76.6%, was associated with a sensitivity of 0.71 and a specificity of 0.67, resulting in a diagnostic odds ratio of 4.972.

There were no statistically significant differences between subjects that did (78.58 ±5.70) or did not suffer a previous injury (76.55 ±8.00%) on the post-workout SEBT-AR (p =.487). A cut off score for the post-workout SEBT-AR was 79.6% was associated with a sensitivity of 0.62 and a specificity of 0.50, resulting in a diagnostic odds ratio of 1.632.

**Previous Injury History Influence on Future Injury**

A Chi-Square 2x2 contingency table was developed in an attempt to understand the influence of previous injury history on in-season injury (Table 4.7). Of the 28 subjects in the study, 10 had a previous injury with a new in-season injury (35.7%), 11 had a previous injury without a new in-season injury (39.3%), 2 had no previous injury with a new in-season injury (7.1%), and 5 had no previous injury without a new in-season injury (17.9%). This resulted in a significance of p=.008 indicating that there was no significant influence of previous injury upon the development of an in-season injury. However, there was a larger distribution of runners that had a previous injury.
Table 1: In-Season Injury Status Means and P-Values

<table>
<thead>
<tr>
<th></th>
<th>Pre-workout Full FMS</th>
<th>Pre-workout mFMS</th>
<th>Pre-Workout SEBT-AR</th>
<th>Post-Workout mFMS</th>
<th>Post-Workout SEBT-AR</th>
</tr>
</thead>
<tbody>
<tr>
<td>Injury Free Mean Score</td>
<td>16.97 (±1.86)</td>
<td>6.53 (±1.11)</td>
<td>72.32 (±4.64)%</td>
<td>6.25 (±.58)</td>
<td>76.71 (±6.55)%</td>
</tr>
<tr>
<td>Injured Mean Score</td>
<td>16.58 (±1.50)</td>
<td>6.58 (±1.24)</td>
<td>75.11 (±5.48)%</td>
<td>6.25 (±1.29)</td>
<td>80.2 (±5.18)%</td>
</tr>
<tr>
<td>P-Value</td>
<td>0.563</td>
<td>0.908</td>
<td>0.157</td>
<td>1.00</td>
<td>0.152</td>
</tr>
</tbody>
</table>

*Numbers based on injured side values or average of R/L values in healthy subjects

Table 4.1 represents the in-season injury status mean scores (standard deviations) and associated p-values. With significance level set to p<.05, no significant difference was found between in-season injured and injury free subjects in each scoring scenario.

Table 2: In-Season Injury Status Diagnostic Statistics

<table>
<thead>
<tr>
<th></th>
<th>Pre-workout Full FMS</th>
<th>Pre-workout mFMS</th>
<th>Pre-Workout SEBT-AR</th>
<th>Post-Workout mFMS</th>
<th>Post-Workout SEBT-AR</th>
</tr>
</thead>
<tbody>
<tr>
<td>ROC Cut-off Score</td>
<td>16.25</td>
<td>7.25</td>
<td>79.32%</td>
<td>6.25</td>
<td>80.38%</td>
</tr>
<tr>
<td>Sensitivity</td>
<td>0.5</td>
<td>0.83</td>
<td>0.83</td>
<td>0.583</td>
<td>0.64</td>
</tr>
<tr>
<td>Specificity</td>
<td>0.625</td>
<td>0.25</td>
<td>0.19</td>
<td>0.044</td>
<td>0.47</td>
</tr>
<tr>
<td>Pos LR</td>
<td>1.33</td>
<td>1.107</td>
<td>1.028</td>
<td>0.61</td>
<td>1.208</td>
</tr>
<tr>
<td>Neg LR</td>
<td>0.8</td>
<td>0.68</td>
<td>0.879</td>
<td>9.478</td>
<td>0.766</td>
</tr>
<tr>
<td>Dx Odds Ratio</td>
<td>1.66</td>
<td>1.628</td>
<td>1.17</td>
<td>0.064</td>
<td>1.577</td>
</tr>
</tbody>
</table>

*Numbers based on injured side values or average of R/L values in healthy subjects

Table 4.2 represents the diagnostic statistics of an in-season injury status. Sensitivity and specificity significance level were set to .7. Only the pre-workout mFMS (.83) and pre-workout SEBT-AR (.83) were found to have strong sensitivity. None of the screening scenarios reached a strong specificity.
Table 3 In-season Injury Status Contingency Tables

<table>
<thead>
<tr>
<th></th>
<th>Pre-workout mFMS</th>
<th>Injury Free</th>
<th>Post-Workout mFMS</th>
<th>Injured</th>
<th>Injury Free</th>
</tr>
</thead>
<tbody>
<tr>
<td>(+) &lt;7.25</td>
<td>10</td>
<td>12</td>
<td>(+) &lt;6.25</td>
<td>7</td>
<td>9</td>
</tr>
<tr>
<td>(-) &gt;7.25</td>
<td>2</td>
<td>4</td>
<td>(-) &gt;6.25</td>
<td>5</td>
<td>7</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th></th>
<th>Pre-workout SEBT-AR</th>
<th>Injured</th>
<th>Injury Free</th>
<th>Post-Workout SEBT-AR</th>
<th>Injured</th>
<th>Injury Free</th>
</tr>
</thead>
<tbody>
<tr>
<td>(+) &lt;79.32</td>
<td>10</td>
<td>15</td>
<td>(+) &lt;80.38</td>
<td>8</td>
<td>10</td>
<td></td>
</tr>
<tr>
<td>(-) &gt;79.32</td>
<td>2</td>
<td>1</td>
<td>(-) &gt;80.38</td>
<td>4</td>
<td>6</td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th></th>
<th>Pre-workout Full FMS</th>
<th>Injured</th>
<th>Injury Free</th>
</tr>
</thead>
<tbody>
<tr>
<td>(+) &lt;16.25</td>
<td>6</td>
<td>6</td>
<td></td>
</tr>
<tr>
<td>(-) &gt;16.25</td>
<td>6</td>
<td>10</td>
<td></td>
</tr>
</tbody>
</table>

*Numbers based on injured side values or average of R/L values in healthy subjects

Table 4.3 represents the dichotomous 2x2 contingency of the number of injured or injury-free subjects falling above or below the ROC cut-off score in each screening scenario in terms of their in-season injury status.

Table 4 Previous History Means and P-values

<table>
<thead>
<tr>
<th></th>
<th>Pre-workout Full FMS</th>
<th>Pre-workout mFMS</th>
<th>Pre-Workout SEBT-AR</th>
<th>Post-Workout mFMS</th>
<th>Post-Workout SEBT-AR</th>
</tr>
</thead>
<tbody>
<tr>
<td>Injury Free Mean</td>
<td>16.14 (±1.35)</td>
<td>6.00 (±.58)</td>
<td>72.94 (±5.00)%</td>
<td>5.42 (±.79)</td>
<td>76.55 (±8.00)%</td>
</tr>
<tr>
<td>Score</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Injured Mean</td>
<td>16.48 (±1.94)</td>
<td>6.52 (±1.25)</td>
<td>73.71 (±5.26)%</td>
<td>6.14 (±1.01)</td>
<td>78.58 (±5.70)%</td>
</tr>
<tr>
<td>Score</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>P-Value</td>
<td>0.678</td>
<td>0.298</td>
<td>0.735</td>
<td>0.102</td>
<td>0.487</td>
</tr>
</tbody>
</table>

*Numbers based on BL FMS and average SEBT-AR scores

Table 4.4 represents the previous injury status mean scores (standard deviations) and associated p-values. With significance level set to p<.05, no significant difference was found between previously injured and injury free subjects in each scoring scenario.
Table 4.5 represents the diagnostic statistics of previous injury status. Sensitivity and specificity significance levels were set to 0.7. Only the pre-workout FMS (.86), pre-workout SEBT-AR (.71), and Post-workout mFMS (.95) yielded strong sensitivity. Only the pre-workout full FMS yielded strong specificity (.71).

Table 5 Previous Injury History Diagnostic Statistics

<table>
<thead>
<tr>
<th></th>
<th>Pre-workout Full FMS</th>
<th>Pre-workout mFMS</th>
<th>Pre-Workout SEBT-AR</th>
<th>Post-Workout mFMS</th>
<th>Post-Workout SEBT-AR</th>
</tr>
</thead>
<tbody>
<tr>
<td>ROC Cut-off Score</td>
<td>16.5</td>
<td>7.5</td>
<td>76.6%</td>
<td>7.5</td>
<td>79.6%</td>
</tr>
<tr>
<td>Sensitivity</td>
<td>0.62</td>
<td>0.86</td>
<td>0.71</td>
<td>0.95</td>
<td>0.62</td>
</tr>
<tr>
<td>Specificity</td>
<td>0.71</td>
<td>0.29</td>
<td>0.67%</td>
<td>0.14</td>
<td>0.5</td>
</tr>
<tr>
<td>Positive LR</td>
<td>2.138</td>
<td>1.211</td>
<td>2.152</td>
<td>1.105</td>
<td>1.24</td>
</tr>
<tr>
<td>Negative LR</td>
<td>0.535</td>
<td>0.483</td>
<td>0.433</td>
<td>0.357</td>
<td>0.76</td>
</tr>
<tr>
<td>Dx Odds Ratio</td>
<td>3.995</td>
<td>2.509</td>
<td>4.972</td>
<td>3.095</td>
<td>1.632</td>
</tr>
</tbody>
</table>

*Numbers based on BL FMS and average SEBT-AR scores*
### Table 4.6: Previous Injury History Contingency Tables

<table>
<thead>
<tr>
<th>Pre-workout mFMS</th>
<th>Injured</th>
<th>Injury Free</th>
<th>Post-Workout mFMS</th>
<th>Injured</th>
<th>Injury Free</th>
</tr>
</thead>
<tbody>
<tr>
<td>(+) &lt;7.5</td>
<td>17</td>
<td>6</td>
<td>(+) &lt;7.5</td>
<td>20</td>
<td>6</td>
</tr>
<tr>
<td>(-) &gt;7.5</td>
<td>5</td>
<td>0</td>
<td>(-) &gt;7.5</td>
<td>2</td>
<td>0</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Pre-workout SEBT-AR</th>
<th>Injured</th>
<th>Injury Free</th>
<th>Post-Workout SEBT-AR</th>
<th>Injured</th>
<th>Injury Free</th>
</tr>
</thead>
<tbody>
<tr>
<td>(+) &lt;76.6</td>
<td>15</td>
<td>3</td>
<td>(+) &lt;79.6</td>
<td>14</td>
<td>2</td>
</tr>
<tr>
<td>(-) &gt;76.6</td>
<td>7</td>
<td>3</td>
<td>(-) &gt;79.6</td>
<td>9</td>
<td>3</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Pre-workout Full FMS</th>
<th>Injured</th>
<th>Injury Free</th>
</tr>
</thead>
<tbody>
<tr>
<td>(+) &lt;16.5</td>
<td>12</td>
<td>3</td>
</tr>
<tr>
<td>(-) &gt;16.5</td>
<td>10</td>
<td>3</td>
</tr>
</tbody>
</table>

*Numbers based on BL FMS score and Average SEBT-AR

Table 4.6 represents the dichotomous 2x2 contingency of the number of injured or injury-free subjects falling above or below the ROC cut-off score in each screening scenario in terms of their previous injury status.

### Table 7: Chi-Squared Analysis of Previous vs. New Injuries

<table>
<thead>
<tr>
<th></th>
<th>New Injury</th>
<th>No New Injury</th>
</tr>
</thead>
<tbody>
<tr>
<td>Previous Injury</td>
<td>35.7%</td>
<td>39.3%</td>
</tr>
<tr>
<td>No Previous Injury</td>
<td>7.1%</td>
<td>17.9%</td>
</tr>
</tbody>
</table>

Table 4.7 represents a chi-square analysis of the previous injury relationship with in-season injury status. The analysis suggests that there was a larger distribution of runners with a previous injury, but previous injury history does not influence future injury status (p=.008).
**Chapter 5**

**Discussion**

**Injury Incidence Rates**

During the 2012 cross-country season 43% of the Division-I collegiate cross country runners developed an injury. This rate falls within the previously published RRI incidence rates of 19-80%. Training pace and volume remain inconclusive as an injury risk factor which is why it is logical that our incidence rates are comparable to those of recreational runners.

Among our season’s data, the female injury incidence rate was 8.75 injuries/ 1000 AE, when one day is considered an athletic exposure, or a rate of 9.25 injuries/ 1000 hours of running. The male injury incidence rate was 3.46 injuries/ 1000 AE when one day is considered an athletic exposure, or 2.94 injuries/1000 hours of running. Combined data for NCAA Division-I sports, not including cross-country, was 15.47 injuries/1000 AE for games and 4.27 injuries/1000AE for practices; Our incidence rates seem reasonable to be in between these two values. However, the injury exposure rating in terms of hours of training may be more relevant for determining risk across running studies in the future.

**Overall Group Scores**

The mean full FMS score for all cross-country runners in this study was 16.39± 1.79 (associated ROC cut-off of 16.25) as compared to 16.9± 3.0 for professional football players and 14.3± 1.77 for NCAA D-II collegiate female soccer, volleyball, and basketball players (associated ROC cut-off of 14). The variability among these results
indicates the need for a sport specific full FMS cut-off score in order to maximize the ability of the FMS to detect differences in at-risk athletes.

The normalized pre-workout SEBT-AR mean for cross-country runners was 73.14± 6.57% (associated ROC cut-off of 79.32%), compared to high school basketball players which was 83.9± 7.1% (associated ROC cut-off of 94.4%).20 The variability in average scores and ROC cut-off scores for the FMS and SEBT-AR seems logical as various sports require varying levels of balance, coordination, strength, and flexibility. This contrast in scores seems increasingly likely as cross-country runners move primarily in a sagittal plane whereas other sports require multiplanar movements and may carry over greater balancing ability to the sagittal plane.

**In-season Injury Status**

The primary purpose of this study was to examine if there was a difference in FMS, mFMS, and SEBT-AR scores during pre- and post-workout states for cross-country runners who went on to sustain an in-season injury compared to those who did not. The results of this study indicate that there is no statistically significant difference in FMS, mFMS, or SEBT-AR scores between athletes who sustained an in-season injury versus those that remained injury free, regardless of the test being performed in a pre- or post-workout state.

However, there is still some degree of increased injury risk for those falling below each tests’ cut-off score. The full FMS had the best prediction in this regard (DOR of 1.66) compared to our other screening scenarios indicating that athletes falling below the cut-off score of 16.25 were 1.66 times more likely to suffer an in-season injury. The pre-workout mFMS was a close second with a DOR of 1.63. The pre-workout SEBT-AR
and mFMS had the highest ability to rule out those remaining healthy in-season (sensitivity was .83 for both) while no test yielded above a moderate specificity (.63 being the highest from the full FMS). Clinicians might consider using the pre-workout SEBT-AR to rule out those who will remain healthy above the cut-off score of 79.32% and then use the full FMS cut-off of 16.25 to rule in those who will likely suffer in-season injury after falling below the mFMS cut-off. This would produce a DOR of 8.7 and increase the identification of in-season injury risk. It is surprising that the full FMS had slightly better diagnostic odds than the mFMS scenarios as it seems more logical that the variance in injury prediction would come from lower extremity deficits for chronic RRIIs. This small additional increase in the diagnostic odds may indicate the role that core plays in development of chronic injuries as the mFMS did not include the quadruped or plank-pushup positions.

Previous studies have noted that subjects with a previous injury have magnified movement deficits compared to those without injury in fatigue testing scenarios.\(^{16,37}\) It was interesting to note that the post-workout mFMS and SEBT-AR did not identify those who would suffer an in-season injury more readily. However, this may be due to the difference in fatigue levels and fatigue protocol.

Our results come in contrast to previous FMS and SEBT studies which claim to be able to differentiate between athletes who did and did not suffer an in-season injury.\(^{12,15,20}\) The difference in predictability may be traceable to injury definition discrepancies. Chorba\(^{15}\) and Kiesel\(^{12}\) both included acute injuries and different time restrictions in their injury definition while the prospective aspect of our study only included chronic lower extremity injuries. Previous SEBT-AR (Plisky\(^{20}\) DOR=6.5) and
FMS (Chorba\textsuperscript{15} DOR= 3.85, specificity= .737; Kiesel\textsuperscript{12} DOR=11.67, specificity=.91) studies may have had greater ability to rule in and predict at risk athletes because other sports may require more neuromuscular control, strength, and flexibility than cross-country. Therefore, movement deficits in other sports may predispose athletes to injury more readily than deficits in cross-country athletes resulting in a greater specificity and DOR’s for those sports.

**Previous Injury History**

The secondary purpose of this study was to determine if the FMS, mFMS, and SEBT-AR in a pre- and post-workout could detect differences in cross-country athletes with or without a previous injury history. The results of this study indicate that there was no statistically significant difference in FMS, mFMS, or SEBT-AR scores between athletes with a previous injury history versus injury-free subjects regardless of the test being performed in a pre or post-workout state. However, if an optimized ROC cut-off score is produced there are notable increases in previous injury incidence for those subjects falling below that cut-off score. The pre-workout full FMS and SEBT-AR (odds ratios of 4.0 and 5.0, respectively) were the best at identifying cross-country runners with previous injury. The large difference in diagnostic odds ratios from the prospective aspect of our study compared with the retrospective aspect is likely due to the individual differences in injury exposure. Each athlete had varying levels of training and experience prior to the study and therefore affected their previous injury status greater than in-season exposure could. The results indicate that functional movement tests may be able to identify persistent movement deficits; however, those deficits may not necessarily contribute to future injury. Furthermore, these results are not able to determine whether
deficits persist as a result of a previous injury or are naturally occurring deficits which led
to the previous injury.

**Effects of Workout State on Test Score Performance**

The tertiary purpose of the study was to determine if there was a difference in pre vs.
post-workout scoring of the mFMS and SEBT-AR. The mFMS scores were worse after
the workout compared to before the workout. This is consistent with findings from
previous studies and confirms the ability of fatigue to hinder neuromuscular control and
test performance.\textsuperscript{21,22,37,39} On the other hand, SEBT-AR scores were better after the
workout compared to before the workout. This opposing relationship between mFMS
and SEBT-AR performance from pre to post workout is perplexing as previous research
indicates the negative influence of fatigue upon performance.\textsuperscript{21,22,36,37,39} The lower post-
workout modified FMS score seems logical as fatigue has been demonstrated to
adversely affect performance.\textsuperscript{21-24,36} The higher post-workout SEBT-AR does not seem
logical at first glance. However, previous studies reporting a decline in SEBT
performance post-fatigue have not used a fatigue protocol that included a running
workout or cross country runners. Additionally, dorsiflexion range of motion has been
linked to SEBT-AR performance which could potentially explain this result.\textsuperscript{32,38} With
increased activity the subjects’ available dorsiflexion range of motion could have
increased due to an increase in muscle extensibility, thus contributing to an increase in
SEBT-AR post-workout scores. However dorsiflexion range of motion is also critical for
performance on the deep squat and inline lunge of the FMS which had poorer results
post-workout. Thus the inverse relationship between post-workout mFMS and post-
workout SEBT-AR is not fully explainable at this time and requires further investigation.
**Influence of Previous Injury History on In-Season Injury Status**

The Chi-square analysis suggests that previous injury history is prevalent among the cross country runners in this study, but did not influence future injury history (p=.008). This comes in contrast to previous studies which state previous injury history increases risk of future injury.\(^4,^7,^10,^11\) However, our study only had 28 subjects which would increase the possibility of a type-2 error. Also, because there was also a disproportionate amount of runners with a previous injury history (22) compared to those with no previous injury (6). This would make the subject pool more likely to have a previous injury which may or may not be recent enough to influence a new injury during the season. This could be improved by creating a more in-depth definition of previous injury such as previous injury occurring between 3-12 months prior to the beginning of the study. This would make the injury recent but not so recent that the subject would meet the exclusion criteria. A previous injury in other RRI epidemiological studies\(^4,^5,^11\) was defined as occurring within the past 12 months which may explain the discrepancy about the influence of previous injury on future injury.

**Influence of previous injury on in-season injury may become more accurate when considering the type and location of injury.** Perhaps the development of the same injury as previously sustained may be better to examine, compared to examining the development of any new injury. For example, Wen et al\(^7\) found that runners with a prior history of shin injuries were 7.24 times more likely to have another shin injury compared to those without a history of shin injury. It is likely that our study did not have enough injuries to appropriately analyze this concept.
Limitations

Several factors may have influenced this study. Training is individually tailored to the athlete, therefore some athletes ran faster or slower paces and for a longer of shorter amount of time compared to other runners which would result in varying levels of exposure. These factors are also difficult to assess as minute exposure varies throughout the season. Minute exposure for athletes injured at the beginning of the season is not comparable to minute exposure at the end of the season. Additionally our study is limited in interpretation because of our small sample size. Our study only included 28 subjects which may have increased the chance for a type-2 error in comparison with other studies which included hundreds of subjects.

Motivation level varies greatly between athletes. Motivation towards performance on the functional tests, and motivation to perform well over the season will vary for each individual athlete. For example, an athlete with low motivation or enthusiasm partaking in the tests may perform poorly on purpose, yet not go on to experience an injury. Athletes motivated to do well over the course of the season may push themselves harder in workouts resulting in increased cumulative fatigue, placing an increase in stress on inert tissues, and therefore a greater risk of injury.

Although most runners looked and sounded fatigued by the end of the workout some may have also began to recover quicker than others, creating a semi-fatigued workout state. Although most runners finished very close to the mFMS and SEBT-AR post-workout stations some finished a little farther from the testing station and therefore may have also began recovering while walking or jogging to the testing station. Therefore, the post-workout state might not reflected a fatigued state as well as it could
have. This could be addressed in the future by performing the workout on a track where athletes start and finish exactly adjacent to the testing station to minimize any recover time. Heart rate monitors or rating of perceived exertion could also be utilized to more accurately assess fatigue during post-workout testing.

**Conclusion and Clinical Relevance**

Results from this study initially suggest that functional performance testing does not have the ability to distinguish between collegiate cross-country runners who will suffer an in-season injury and those who won’t. However, if optimized ROC curve cut-offs are utilized in-season, then injury prediction capability increases. A combination of the pre-workout SEBT-AR and full FMS should be used to optimize the prediction model as individual testing scenarios have a low DOR’s (<1.66). The combining of their sensitivity and specificity would produce a test with a DOR of 8.7. In retrospective analysis, the increased diagnostic odds ratios of the functional movement tests indicate there is a higher likelihood of having a previous injury when falling below each test’s cut-off score. The pre-workout SEBT-AR (DOR of 5.0) and pre-workout FMS (DOR of 4.0) were the most effective at identifying these deficits. However, it cannot be determined whether the deficits are the result of previous injury or naturally occurring. Clinicians can utilize this information to identify lingering functional deficits and create an individualized prevention protocols in an attempt to prevent future injury.
References


