

Prediction of Athletic Injury with a Functional Movement Screen™

by

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The Functional Movement Screen™ (FMS) is a screening tool designed to quantify movement quality. The ability of the FMS to identify individuals likely to be injured has been examined in athletic and military settings. However, the predictive ability of the FMS has not been examined in a cohort of intercollegiate football players. **PURPOSE:** The purpose of this study was to determine if the FMS, body mass index (BMI), or two bilateral body mass asymmetry measures accurately predict injury in intercollegiate football players over the course of one season. **METHODS:** Participants ($N = 81$) were tested using the FMS protocol. Seven tests were scored on a 0 to 3 scale resulting in a possible composite score of 21. Participants were categorized as having positive or negative tests based on 14-point and 15-point cutoff scores. BMI was calculated from measured height and weight. Participants were categorized as having positive or negative tests based on a $BMI \geq 30 \text{ kg}\cdot\text{m}^{-2}$. Bilateral body mass asymmetry was assessed twice by weighing participants on two identical scales with one foot on each scale. Feet were placed a standardized distance (one-third of height) apart for one measure and shoulder width apart for the second measure. Participants were categorized as having positive or negative tests based on a difference between the two scales of $\geq 5\%$ of body mass. Injury reports were obtained from the athletic training staff. Musculoskeletal injuries were classified via NCAA Injury Surveillance System criteria. Participants were categorized as injured or not injured based on injury reports. Intrarater reliability was estimated for the FMS on all participants by viewing

videotaped procedures. Interrater reliability was estimated on 18 participants viewed in real time by two raters. Sensitivity and specificity were calculated to examine the accuracy of the different screening measures to identify participants who were injured or not injured. **RESULTS:**

Participants had a mean composite FMS score of 15.4 (± 1.7) and a mean BMI of 30.1 (± 5.3) $\text{kg}\cdot\text{m}^{-2}$. Bilateral body mass asymmetry measures averaged 4 (± 3) percent of body mass for the standardized difference and 5 (± 5) percent of body mass for the shoulder width difference.

Intraclass correlation coefficients for intrarater reliability (.94) and interrater reliability (.92) for the composite FMS score were high. Forty-three injuries (17 direct contact, 12 indirect contact, 11 non-contact, 2 overuse, and 1 unknown mechanism) to 31 players were reported. No significant relationship was found between the FMS, BMI, or the bilateral body mass asymmetry measures and injury ($p > .05$). Sensitivity values were: FMS 14-point cutoff = .26, FMS 15-point cutoff = .42, BMI cutoff = .42, bilateral body mass asymmetry standardized difference cutoff = .31, bilateral body mass asymmetry shoulder width difference cutoff = .52. Specificity values were: FMS 14-point cutoff = .70, FMS 15-point cutoff = .51, BMI cutoff = .64, bilateral body mass asymmetry standardized difference cutoff = .74, bilateral body mass asymmetry shoulder width difference cutoff = .68. **CONCLUSIONS:** The FMS can be used reliably with intercollegiate football players, but the validity of the FMS to predict athletic injury is questionable. The FMS did not predict injury more accurately than anthropometrically derived measurements. Although as accurate as the FMS, BMI and the two bilateral body mass asymmetry measures did not accurately predict injury.

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Chapter I: Introduction

Football is a violent sport where injuries are common (Dragoo, Braun, Bartlinksy, & Harris, 2012). Carter, Westerman, and Hunting (2011) reported that people spend more time per day playing football than any other sport and were almost twice as likely to be injured in football (5.1 injuries per 10,000 playing hours) than in basketball (2.7 injuries per 10,000 playing hours).

Football tends to have numerous injuries during practice and competition (Hootman, Dick, & Agel, 2007). Hootman et al. (2007) studied 16 years (1988 - 1989 to 2003 - 2004) of National Collegiate Athletic Association (NCAA) Injury Surveillance System (ISS) data. The NCAA ISS has been used to collect data since 1988 on various intercollegiate sports. Hootman et al. reported that football had the highest game injury rate and spring football had the highest practice injury rate.

Dick et al. (2007) summarized the same 16 years (1988 - 1989 to 2003 - 2004) of NCAA ISS data, but specifically examined football. Fall pre-season practice injury rates were three times higher than in-season or post-season practice injury rates. The game injury rate was more than nine times higher than the in-season practice rate, and players were two times more likely to get injured in spring practice in comparison to fall in-season practice.

Dick et al. (2007) remarked that strength and conditioning programs are not currently meeting the injury prevention challenges that football presents. During the 16 years (1988 - 1989 through 2003 - 2004) of available ISS data, Dick et al. remarked that even though strength and conditioning programs had improved dramatically, injury rates in games and practices had remained unchanged. In 1988 - 1989, the fall practice injury rate was 4.3 injuries per 1,000 athlete exposures, 10.6 injuries per 1,000 athlete exposures during spring practice, and 32.5 injuries per 1,000 athlete exposures during games. In 2003 - 2004, the fall practice injury rate

was 4.1 injuries per 1,000 athlete exposures, 7.9 injuries per 1,000 athlete exposures during spring practice, and 32.4 injuries per 1,000 athlete exposures during games. Wilkerson, Giles, and Seibel (2012) stated that some football programs may overemphasize the development of muscular power through high-load weightlifting. This process can lead to lumbar-spine dysfunction, which may increase the predisposition of the athlete to core/lower extremity sprain/strain.

The high number of injuries that occur in college football coupled with the idea that current strength and conditioning programs might not be meeting the injury prevention challenges of football alludes to the idea that an injury prevention tool is needed. The Functional Movement Screen™ (FMS) is a pre-participation screening tool developed to quantify movement quality (Cook, 2001). Normative data for the FMS has been developed in adults (Schneiders, Davidson, Hörman, & Sullivan, 2011), as well as in children (Duncan & Stanley, 2012). The FMS has been used to evaluate the effectiveness of training (Kiesel, Plisky, & Butler, 2011) and predict injury (Chorba, Chorba, Bouillon, Overmyer, & Landis, 2010; Kiesel, Plisky, & Voight, 2007; O'Connor, Deuster, Davis, Pappas, & Knapik, 2011).

The effectiveness of the FMS to predict injury in various populations has been examined (Chorba et al., 2010; Kiesel et al, 2007; O'Connor et al., 2011). Kiesel et al. (2007) studied a group of American professional football players. Using a receiver operating characteristic (ROC) curve, Kiesel et al. developed a 14-point cutoff that other studies (Chorba et al., 2010; O'Connor et al., 2011) have used. Kiesel et al. found that 70% of individuals who scored 14 or less on the FMS experienced an injury, while only 17% of individuals who scored 15 or more on the FMS experienced an injury. Various authors (Chorba et al., 2010; O'Connor et al., 2011; Peate, Bates, Lunda, Francis, & Bellamy, 2007; Schneiders et al., 2011; Teyhen et al., 2012) suggest that the

research base is insufficient to conclusively determine that a cutoff of 14 on the FMS provides the most accurate cutoff for predicting injury.

O'Connor et al. (2011) studied a group of Marine Corps Officer Candidates ($N = 874$). Using the 14-point cutoff developed by Kiesel et al. (2007), O'Connor et al. found a relationship with injury, although not as strong as the relationship reported by Kiesel et al. Depending on their training group, candidates who scored 14 or less on the FMS had a risk ratio of either 1.65 (95% CI = 1.05 - 2.59) or 1.91 (95% CI = 1.21 - 3.01) to experience "any injury" in comparison to those individuals who scored 15 or more on the FMS.

Chorba et al. (2010) studied a group of female volleyball, soccer, and basketball intercollegiate athletes. Using the 14-point cutoff developed by Kiesel et al. (2007), Chorba et al. dichotomized their data. Similar to results reported by Kiesel et al., Chorba et al. found that 69% of individuals who scored 14 or less on the FMS experienced an injury, while only 36% of those who scored 15 or more on the FMS experienced an injury.

Both intra- and interrater reliability have been shown to be high for the FMS. Reliability has been evaluated via videotape (Minick et al., 2010; Teyhen et al., 2012) and in real time (Onate et al., 2012).

Minick et al. (2010) had two FMS certified professionals and two individuals who were not certified by FMS view and score videotaped FMS screens of 40 participants. The raters were blind to the other raters' scores. Minick et al. examined the reliability of each component of the FMS, including the bilateral scores for the various tests. When compared, both groups (FMS certified and not FMS certified) demonstrated moderate agreement on some tests, substantial agreement on some tests, and excellent agreement on other tests. When the certified FMS professionals' scores were averaged and compared to the non-certified raters' scores, they

demonstrated excellent agreement on 14 of the 17 measures and substantial agreement on the remaining 3 measures.

Onate et al. (2012) studied both interrater and intersession reliability in real time. The intersession reliability was tested on two days, separated by a week. The two raters for the interrater reliability estimates differed on their knowledge of the FMS; one of the raters was FMS certified while the other rater was not. Intraclass correlation coefficients (R) were high for both intersession ($R = .92$) and interrater ($R = .98$) reliability. High levels of interrater and intersession reliability were found for every movement except the hurdle step.

Others have shown that FMS scores can improve with interventions (Cowen, 2010; Goss, Christopher, Faulk, & Moore, 2009; Kiesel et al., 2011). Cowen (2010) used a yoga intervention to improve FMS scores in a group of firefighters. Cowen reported that the mean baseline composite FMS score was 13.3 (± 2.3), while post-intervention the mean composite FMS score was 16.5 (± 2.2). Goss et al. (2009) reported that composite FMS scores improved by a mean of 2.5 (S not reported) in a military cohort. Kiesel et al. (2011) reported a mean improvement in composite FMS scores of 2.0 (± 2.4) after training in a group of professional football players.

The FMS is a screening tool that has been applied in various settings. Some literature has examined the use of the FMS in intercollegiate sport, but the predictive ability of the FMS has not been examined in a cohort of intercollegiate football players. Additionally, the FMS has not been compared to other methods of predicting injury. Comparison methods will provide additional evidence to aid in interpretation of the predictive validity of the FMS.

Purpose Statement

The purpose of this study was to determine the ability of the Functional Movement Screen™ (FMS), body mass index (BMI), and two bilateral body mass asymmetry measures to predict injury in intercollegiate football players.

Hypothesis

It was hypothesized that the FMS would predict injury in intercollegiate football players more accurately than BMI and the two bilateral body mass asymmetry measures.

Significance

This study examined the reliability and validity of the FMS to accurately predict athletic injury in a group of intercollegiate football players over an entire season. This study was one of the first to use the FMS as a predictor of intercollegiate football injury over the course of the season. The current study had one of the largest sample sizes using the FMS in intercollegiate sport to date.

Delimitations

The study included the following delimitations:

1. The East Carolina University football team was assessed with the FMS and followed for one season.
2. The FMS was used as the screening tool to assess functional movement.
3. One of the raters was a certified FMS rater while the other rater was not. Both raters trained together.

Limitations

The study included the following limitations:

1. The players were not wearing any protective gear (such as ankle braces) while being tested, even though they may have worn these implements in competition.
2. There was an inability to determine “limited” practice participation during the season.
3. Interrater reliability was calculated on a small sample.

Definition of Terms

Athletic injury: Athletic injury was defined by meeting three criteria (a) the injury occurred when the athlete participated in an organized practice/game; (b) the injury required medical attention by either an athletic trainer or physician; and (c) the injury prevented participation in an organized practice/game for one or more days past the day of injury.

Direct Contact Injury: an acute injury that occurred at the site of player-to-player contact.

Indirect Contact Injury: an acute injury that occurred away from the site of player-to-player contact.

Non-Contact Injury: an acute injury that occurred in the absence of player to player contact.

Overuse Injury: a chronic injury with an insidious onset and no definable time of occurrence.

Chapter II: Review of Literature

Injury in College Football Players: Prevalence, Etiology, and Prevention

Football is a popular sport. Carter et al. (2011) found football to be the second most popular sport among males, but players spent the most time (2.4 hours per day) playing football. Knowles et al. (2006) estimated that 36% of all male high school athletes in North Carolina played football between 1996 and 1999. Football is a sport where numerous injuries occur. Albright et al. (2004) stated that football players will experience injuries in any setting or season, while Kaplan, Flanigan, Norwig, Jost, and Bradley (2005) stated that the nature of football lends itself to many injuries.

Defining Injury

Many studies have examined injury rates in various populations using a variety of operational definitions. While a universal definition of injury does not exist, consistencies do exist across different studies.

Various studies have used the National Collegiate Athletic Association (NCAA) Injury Surveillance System (ISS), which uses a specific injury definition (Agel & Schisel, 2013; Dick et al., 2007; Dragoo et al., 2012a; Dragoo, Braun, Durham, Chen, & Harris, 2012b; Hootman et al., 2007; Hunt, George, Harris, & Dragoo, 2013). For an injury to be reported in the NCAA ISS, it must have met three criteria: (a) the injury occurred when the athlete participated in an organized practice/game; (b) the injury required medical attention by an athletic trainer or physician; and (c) the injury restricted participation/performance for one or more days past the day of injury (Hootman et al., 2007). Other criteria have been used to define injury. Albright et al. (2004) examined football injury rates in the Big Ten conference using a different definition. Injuries required evidence of tissue damage, which included (but was not limited to) warmth, tenderness,

swelling, and/or laxity. The player’s inability to return to practice that day was also required as part of a reportable injury (except in the case of concussions, dental injuries, and fractures).

Other injury definitions can be found in Table 1.

Table 1
Injury Definitions Used in Various Studies

Author(s)	Injury Definition
Hagel et al. (2003)	Acute injuries were defined as those injuries that resulted in full or partial practice time loss. Any concussion or neck injury was reported regardless of time lost.
Kelly et al. (2004)	Injuries included in the data were those that occurred during the season (between the first day of the pre-season and the Super Bowl) and resulted in two or more days of restricted participation.
Knowles et al. (2006)	An injury was one that occurred from participating in a high school sport and (a) limited participation in the sport the following day, or (b) required medical attention from a trained professional.
Meyers (2010)	A reportable injury was defined as a game-related football trauma that resulted in some time loss (all or part of a game), time away from the competition, as well as any injury reported to or treated by the athletic trainer. All head/neck injuries were reported.
Wilkerson et al. (2012)	An injury was defined as a core or lower extremity sprain/strain that required attention from the athletic trainer. This event had to have occurred as part of participation in an organized practice, conditioning session, or game, and limited football participation for at least one day after the occurrence.

To calculate injury rates, athlete exposures are often used (Agel & Schisel, 2013; Albright et al., 2004; Dick et al., 2007; Dragoo et al., 2012a; Dragoo et al., 2012b; Hagel, Fick, & Meeuwisse, 2003; Hootman et al., 2007; Hunt et al., 2013; Knowles et al., 2006; Powell & Dompier, 2004). An athlete exposure is defined as an athlete participating in a practice or game in which there is a possibility of being injured (Hunt et al., 2013). Carter et al. (2011) used a different measure because of the limitations of the athlete exposure. Carter et al. argued that the athlete exposure is limited because it does not take into account individual absences or time spent playing in games or practices. Carter et al. did acknowledge that such data are not often collected because of the effort and resources needed.

One method of analyzing injury uses time loss and two studies (Albright et al., 2004; Meyers, 2010) have categorized injuries based on the severity of the injuries. Albright et al. (2004) categorized injuries as minor, moderate, or major. Minor injuries were those associated with 7 days of time lost while moderate injuries were associated with 8-21 days lost. Major injuries were associated with more than 21 days lost. Meyers (2010) used a similar protocol, classifying injuries as minor, substantial, and major. Injuries that were associated with 0-6 days lost were considered minor, injuries resulting in 7-21 days lost were considered substantial, and injuries associated with more than 22 days lost were considered severe.

Injury Prevalence

Football is a violent sport that is characterized by high speed collisions. The high-contact, high-collision nature of the sport means that injuries are common (Dragoo et al., 2012a).

Hootman et al. (2007) summarized 16 years of NCAA ISS data. The ISS collected data from 1988 to 2004 in the following sports: men's and women's basketball, baseball, softball, women's field hockey, spring and fall football, men's and women's gymnastics, men's ice

hockey, men's and women's lacrosse, men's and women's soccer, women's volleyball, and men's wrestling. The injury criteria have been described above.

Results showed that across Divisions I, II, and III, pre-season practice injury rates were between two and a half to three times greater than in-season practice injury rates and four and a half to five and a half times higher than post-season practice injury rates (Hootman et al., 2007). Division I practices had the highest practice injury rates across divisions. Spring football had the highest rate of ankle ligament sprains (1.3 per 100 athletic exposures). Football accounted for 53% of all reported anterior cruciate ligament injuries and 55% of all reported concussions. Football had the highest game injury rate (35.9 per 1,000 athlete exposures) and spring football had the highest practice injury rate (9.6 per 1,000 athlete exposures). Fall football had an injury rate of approximately 4 injuries per 1,000 athlete exposures.

A similar study was conducted by Dick et al. (2007). Sixteen years of NCAA ISS data was reviewed to report injury data specific to football. Over the 16 year period, approximately 19% of schools with a varsity football programs participated in the NCAA ISS.

The results demonstrated that fall pre-season practice injury rates were three times higher than in-season or post-season practice injury rates (Dick et al., 2007). In those practices, knee internal derangements, ankle ligament sprains, upper leg muscle-tendon strains, and concussions were the most often reported injuries. Dick et al. (2007) reported that running backs were the most often injured (20% of injuries) and quarterbacks were the next most often injured (18% of injuries). The game injury rate was more than nine times higher than the in-season practice rate. Players were two times more likely to get injured in spring practice in comparison to fall in-season practice.

Brophy, Barnes, Rodeo, and Warren (2007) reviewed the prevalence of musculoskeletal disorders in a sample of potential National Football League (NFL) players. The data included 5,047 complete medical records over a 14 year period (1987 - 2000) from one NFL team's medical staff evaluations at the NFL combine. The NFL combine is a place where elite college football players are evaluated by NFL teams. Physical and mental abilities of each player are evaluated, along with a review of medical history, imaging studies, and a physical examination. The information is used to rate players with regard to their potential to participate in the NFL. A scale of one to nine was used to medically evaluate each player. A score of nine indicated that a player had had no injuries while a low score (three or below) indicated that injury was likely to recur and that the player shouldn't be drafted based on his medical evaluation.

The results indicated a mean of 2.5 (no *S* reported) injury diagnoses per player and a mean of 0.5 (no *S* reported) operational procedures per player. The mean rating of a player was 6.5 (no *S* reported) out of a possible 9 with approximately 6% of players receiving a rating of 1. Ninety-four percent of the players participating in the combine came from NCAA Division I programs. The most common injuries were ankle sprains (29.1 per 100 players) with "burners", wrist/hand injuries, medial collateral ligament injuries, and acromioclavicular joint injuries being the next most common. A "burner" is a common nerve injury in football that results from trauma to the neck and/or shoulder (Kuhlman & McKeag, 1999).

The mean number of diagnoses increased from 1.8 (no *S* reported) per player in 1987 to 3.4 (no *S* reported) per player in 2000 (Brophy et al., 2007). The mean number of procedures per player also increased, from 0.5 (no *S* reported) per player in 1987 to 0.7 (no *S* reported) per player in 2000. The mean rating per player decreased from 6.9 (no *S* reported) in 1987 to 6.0 (no *S* reported) in 2000. Brophy et al. stated that almost every diagnosis went up during the study

period, but the percentage of athletes who received a failing grade (a score of one on their medical evaluation) decreased.

Knowles et al. (2006) estimated injury incidence and identified injury risk factors in high school varsity athletes in North Carolina. The study included boy and girl varsity athletes from 100 public schools in North Carolina. Injury and risk factor data were collected for 12 sports: boys'/girls' soccer, boys'/girls' track, boys'/girls' basketball, baseball, softball, wrestling, volleyball, cheerleading, and football. Data were collected using an athlete's demographic questionnaire, a coach's demographic questionnaire, an injury report form, and a weekly participation form. The questionnaires were completed before the season started, while the participation form was completed each week to track number of games and practices per week. Injury report forms were completed for each sustained injury, so a single event could include multiple injuries and injury report forms. Football had the highest rate of injury incidence, as 42% of injured males played football. Football was also associated with a substantially higher rate of injury in games compared with the other sports. Knowles et al. remarked that there were clear differences between practice injury rates in football and the practice injury rates in other sports.

Carter et al. (2011) documented the risk of injury from participation in three different sports: basketball, football, and soccer. The U.S. population and hours of participation were each used as a denominator. The rates of injuries treated in an emergency room from the three sports were calculated by using data from the National Electronic Injury Surveillance System, the American Time Use Survey, and the U.S. census. The National Electronic Injury Surveillance System is a national probability sample of U.S. and U.S territory hospitals. Information is collected from each hospital for every emergency room visit and the database contains

information on age, sex, and body part injured. The total number of injuries that were treated in an emergency room nationwide for the three sports was estimated. The American Time Use Survey is a 24 hour time diary that is randomly administered to residents living in U.S. households who are 15 years or older. Only one member of the household completes the survey. Fifty percent of the diaries are for weekdays and 50% are for weekend days. Carter et al. used data from the U.S. census for individuals who were over 15 years of age as of July 1st, 2005.

The average number of injuries treated annually in emergency room departments was highest among basketball players (350,033), with football having the second most injuries (219,164). When the data were analyzed using the entire population, football had an injury rate of 0.9 injuries per 1,000 U.S. population, which was the second most to basketball (1.5 injuries per 1,000 U.S. population). However, when the data were analyzed using the American Time Use Survey, people were almost twice as likely to be injured in football (5.1 injuries per 10,000 playing hours) than in basketball (2.7 injuries per 10,000 playing hours) or soccer (2.7 injuries per 10,000 playing hours). The most common injury in all three sports was a sprain or strain, but football had the highest percentage of fractures (20% of all football injuries were fractures).

Authors have reported on the incidence of specific injuries in football. Hunt et al. (2013) described the incidence of and possible risk factors for high ankle sprains in NCAA football players. Data for the study were obtained using the NCAA ISS. The results indicated that the injury rate was highest in-season compared to pre-season and post-season, and there was a higher injury rate during games than in practice. Hunt et al. reported that high ankle sprains are 14 times more likely in games in comparison to practices. The authors hypothesized that a game environment is less predictable than a practice environment, in addition to being faster and more intense. These combinations could be why more ankle sprains are seen during games in

comparison to practices. Of those injuries that occurred during practice, players were more likely to be injured during a pre-season practice in comparison to an in-season or post-season practice. The median number of days lost to injury was 16.6 (95% CI: 15.2 - 18.0), but there was no difference in time lost when injuries that occurred during games were compared to injuries that occurred during practice. Running backs suffered more high ankle sprains than players at other positions and contact with another player was the most frequent cause of injury (75% of all high ankle sprains). These injuries occurred most often during running plays, either on offense (33% of injuries) or defense (19% of injuries).

Dragoo et al. (2012b) reviewed NCAA ISS data to determine the injury rate of and risk factors for anterior cruciate ligament injuries. Only complete anterior cruciate ligament tears were examined, of which 318 occurred during the 5 year period between 2004 - 2005 and 2008 - 2009. These injuries accounted for $\leq 1\%$ of all injuries during this time. The authors stated that although the injury rate was highest during the post-season, it was not significantly different from the injury rate during pre-season or in-season. Players were approximately 10 times more likely to sustain an injury during a game in comparison to a practice. Dragoo et al. stated that the injury rate was highest among Division III athletes, but the injury rate was not significantly different from the injury rate in Division I or Division II.

Dragoo et al. (2012a) examined NCAA ISS data from 2004 - 2005 through 2008 - 2009 on shoulder injuries in football. Dragoo et al. identified risk factors for and the incidence of acromioclavicular joint injuries. Dragoo et al. reported that between 9 and 10% of schools sponsoring varsity football programs participate in the ISS.

Approximately 2,325 shoulder injuries were sustained by NCAA football players (Dragoo et al., 2012a). Thirty-two percent of those injuries (748) were to the acromioclavicular

joint, which accounted for approximately 5% of all injuries. The mean amount of time lost to these injuries was 11.6 (no *S* reported) days. The injury rate was highest among Division III football players (3.5 injuries per 10,000 athlete exposures), but that rate was not statistically different from the injury rate for Division I (3.4 injuries per 10,000 athlete exposures) or Division II (3.0 injuries per 10,000 athlete exposures). The injury rate was highest in-season (3.6 injuries per 10,000 athlete exposures), which was significantly more than in the post-season (1.5 injuries per 10,000 athlete exposures), but not the pre-season (3.1 injuries per 10,000 athlete exposures).

Injury Mechanisms

Understanding the way in which injuries occur is important. If we understand the way in which injuries occur, prevention strategies can be developed and implemented. Contact, both with another player and with the playing surface, is the most common cause of injury in football.

Dragoo et al. (2012b) examined basic injury mechanisms for anterior cruciate ligament injuries in intercollegiate football players. Dragoo et al. found the most common cause of injury to be contact with another player (53% of injuries). Non-contact was the second basic injury mechanism (40% of injuries). Being tackled (20% of injuries) was the most common cause of injury. Dragoo et al. (2012a) studied injury mechanisms for acromioclavicular joint injuries in college football players. Dragoo et al. reported that 72% of injuries were the result of contact with another player, while contact with the playing surface (27%) and overuse injuries (non-contact, 1%) comprised the remaining injuries (Dragoo et al., 2012a). These findings are similar to those of Kelly, Barnes, Powell, and Warren (2004) who studied shoulder injuries in quarterbacks in the National Football League. They found that the majority of injuries occurred because of contact (82%) and that was also true for shoulder injuries (82%).

Albright et al. (2004) examined legislation implemented by the Big Ten conference in 1998 and whether it reduced the number of injuries in spring football as it was intended. The number and types of practices in the spring were limited in order to reduce the number of injuries. Albright et al. analyzed injury data from the Big Ten ISS for the years 1992 - 1997 (before the rule change) and from 1998 - 2000 (after the rule change). The Big Ten ISS is similar to the NCAA's ISS described above. Practice sessions were categorized as: limited contact, full-contact, and scrimmages. Limited contact practices were completed at a lesser intensity than the other practices, while a full-contact practice was the general routine for the team. Scrimmages were high-risk situations where players tried to impress the coaches.

Results indicated that scrimmages in both the fall and the spring produced the greatest number of injuries (Albright et al., 2004). The legislation had little effect, as spring football injury rates were significantly higher than fall practice injury rates before and after the rule implementation. Before 1998, the fall practice injury rate was 13.7 per 1,000 athlete exposures, while the spring practice injury rate was 18.8 per 1,000 athlete exposures. After 1998, the fall practice injury rate was reduced to 5.2 injuries per 1,000 athlete exposures, but the spring practice injury rate was 16.4 injuries per 1,000 athlete exposures, indicating that the restrictions on the number of and type of practice had limited effects. Albright et al. also reported that limited contact practices produced a significantly higher rate of injury than contact practices.

Injury Risk Factors

Many risk factors have been hypothesized and identifying them is important to understanding the etiology of injuries. In an editorial, Reider commented that the risk of injury is a combination of many variables, but predisposing factors must be identified (Reider, 2004). Studies have examined the relationship between injury and risk factors such as: playing surface

(Dragoo et al., 2012a; Dragoo et al., 2012b; Hagel et al., 2003; Hunt et al., 2013; Kelly et al., 2004; Meyers, 2010), prior injury (Hagel et al., 2003; Kaplan et al., 2005; Knowles et al., 2006), “elite” status (Kaplan et al., 2005; Kelly et al., 2004), and other risk factors.

Wilkerson et al. (2012) assessed the effectiveness of core and lower extremity sprain/strain predictors in a sample of intercollegiate football players. A secondary purpose of the study was to develop a set of predictors that would categorize players as high- or low-risk for core/lower extremity sprain/strain. Participants in the study were 83 football players who voluntarily completed physical tests and surveys before the start of the pre-season. To assess self-perception of functionality of different body parts (low back, knees, and ankles/feet), three surveys were given: the Oswestry Disability Index, the knee function scale from the International Knee Documentation Committee, and the sports component of the Foot and Ankle Ability Measure. Core musculature endurance was measured by four different isometric tests: horizontal back-extension, sitting 60⁰ trunk-flexion, side-bridge, and bilateral wall-sit. Aerobic capacity was measured using the three minute step test.

Results indicated that 46 core and lower extremity injuries were documented over the course of one season (Wilkerson et al., 2012). At least one core/lower extremity injury was experienced by 47% of the players. The best injury predictors, identified through logistic regression, were high game exposure, low trunk-flexion time, high Oswestry Disability Index score, and low wall-sit time. Two or more of these factors were identified in 92% of injured players, but 52% of non-injured players also had two or more of these factors. Wilkerson et al. (2012) reported that three or more risk factors provided the best balance between sensitivity (.62) and specificity (.91).

Game exposure was the strongest predictor of injury risk, but its inclusion in the primary prediction model is impractical (Wilkerson et al., 2012). This is because game-exposure cannot be quantified until a season is over. Wilkerson et al. (2012) also stated that some football programs may overemphasize the development of muscle power through high-load weightlifting. This process can lead to lumbar-spine dysfunction, which may increase the predisposition of the athlete to core/lower extremity sprain/strain. Dick et al. (2007) remarked that strength and conditioning programs are not currently meeting the unique injury prevention challenges that football presents. During the 16 years (1988 - 1989 through 2003 - 2004) of available NCAA ISS data, Dick et al. remarked that even though strength and conditioning programs had improved dramatically, injury rates in games and practices had remained unchanged. In 1988 - 1989, the practice injury rate was 4.3 injuries per 1,000 athlete exposures, 10.6 injuries per 1,000 athlete exposures in the spring, and 32.5 injuries per 1,000 athlete exposures during games. In 2003 - 2004, the practice injury rate was 4.1 injuries per 1,000 athlete exposures, 7.9 injuries per 1,000 athlete exposures in the spring, and 32.4 injuries per 1,000 athlete exposures during games.

Kaplan et al. (2005) determined the prevalence of various shoulder injuries in elite college football players at the NFL combine. The authors hypothesized that shoulder injuries are related to player position. A total of 336 college football players were invited to participate at the 2004 NFL combine in Indianapolis, Indiana. Player positions were categorized as: quarterbacks, running backs, wide receivers, tight ends, offensive linemen, defensive linemen, linebackers, defensive backs, and placekickers. There were a total of 171 offensive players, 154 defensive players, and 11 placekickers.

A total of 167 athletes (50%) reported experiencing a shoulder injury at some point while playing football and a total of 226 shoulder injuries were recorded (Kaplan et al., 2005). The

most common shoulder injury was an acromioclavicular joint injury (41%), followed by anterior instability (20%), and rotator cuff injuries (12%). Fifty-six (34%) of the individuals who experienced a shoulder injury underwent surgery for a total of 73 procedures. Of those players reporting shoulder injuries, 83 played defense, 82 played offense, and 2 played special teams. The position with the highest percentage of shoulder injuries was quarterback, followed by defensive back and linebacker.

These findings were similar to those of Albright et al. (2004), who found that players in “skill” positions are at the highest risk of injury. Dick et al. (2007) reported that running back was the most often injured position, while quarterback was the next most often injured position. Hunt et al. (2013) stated that running backs suffer more high ankle sprains than other positions. Wilkerson et al. (2012) reported that injury incidence by position (dichotomized as either linemen or non-linemen) was not significantly different. Hunt et al. reported that most injuries occurred during running plays, either on offense or defense, while Dragoo et al. (2012a) reported that acromioclavicular joint injuries were more common on offensive plays in comparison to defensive plays. Dragoo et al. (2012b) also reported that anterior cruciate ligament injuries were more common on offensive plays in comparison to defensive plays.

Even though field surface cannot be controlled for (at least in competitions), it still has been hypothesized as a risk factor for injury. Hagel et al. (2003) tried to determine which risk factors are the best predictors of injury in specific body regions in intercollegiate football players. The data obtained for this study came from three sources: a pre-season medical history form, a daily participation log for every athlete, and an injury report form. Acute injuries were the focus of this study. The three primary sites of injury examined were head/neck, upper extremity (scapula to hand), and lower extremity (hip to foot). The injury predictors examined in

this study were playing session (game vs. practice), field type, year of varsity sport participation, field conditions, university, and injury history.

Results demonstrated that game participation increased the injury rates across the three sites (Hagel et al., 2003). Hagel et al. (2003) also found a greater rate of injury associated with artificial turf in comparison to natural grass. Hagel et al. estimated the rate of injury on synthetic fields to be almost twice as high as the rate of injury on natural grass fields. The authors hypothesized that athlete speed increased on dry artificial turf, which leads to greater forces of impact. However, one university played all of its home games on artificial turf. This led the authors to hypothesize that visiting teams may have had higher injury rates because they were less familiar with the turf, indicating that artificial surfaces may be safe if used consistently. Wet field conditions resulted in lower injury for all three sites on both natural and artificial fields, except in the case of lower extremity injuries on wet, artificial fields. This led the authors to hypothesize that the condition of the field may modify the risk associated with that type of field.

In support of the findings above, Dragoo et al. (2012b) found that playing surface had a significant effect on injury rates. The rate of anterior cruciate ligament injuries was 1.7 injuries per 10,000 athlete exposures on artificial surfaces compared to 1.2 injuries per 10,000 athlete exposures on grass. Acromioclavicular joint injury rates were also significantly higher on artificial playing surfaces (3.0 injuries per 10,000 athlete exposures) in comparison to natural grass surfaces (1.8 injuries per 10,000 athlete exposures) (Dragoo et al., 2012a). Hunt et al. (2013) determined that third generation artificial surfaces (called “fill” surfaces) were associated with more ankle injuries than grass or other “no fill” artificial surfaces. Hunt et al. argued that the unique footwear that is worn when playing on this type of surface may be the cause of these injuries, as the shoes tend to “stick” to the surface.

In contrast to the findings above, Meyers (2010) found that significantly fewer total injuries, minor injuries, substantial injuries, and severe injuries occurred on FieldTurf in comparison to natural grass. FieldTurf (Montreal, Quebec, Canada) is a synthetic surface composed of a polyethylene fiber blend that has been proposed as an alternative to natural grass. Meyers studied 24 NCAA Division I football teams and their game-related injuries on FieldTurf in comparison to natural grass. A total of 465 games occurred during the study (2006 - 2008), with 230 games played on FieldTurf and 235 played on natural grass. Exclusion criteria for the study included (a) any known pre-existing congenital/developmental factor that predisposed an athlete to injury, and (b) the acknowledgement, complaint, or observed evidence of a medical/orthopedic problem that could compromise an athlete's performance or health. All regular season games (conference and non-conference), as well as bowl games, were included in the data analysis.

Meyers (2010) reported a total of 2,253 injuries, with 1,050 occurring on FieldTurf and 1,203 occurring on natural grass. Upperclassmen (seniors and juniors) experienced more injuries than freshmen and sophomores. Meyers also reported that incidence rates for both FieldTurf and natural grass showed that few injuries occurred pre-game, and that most injuries occurred in the first half of games. A significantly lower incidence of ligament and muscle tears occurred on FieldTurf in comparison to natural grass. Results also indicated that the majority of injuries occurred in dry conditions. Meyers concluded that FieldTurf is safer in many cases than natural grass and stated that artificial surfaces today are far superior to earlier synthetic surfaces. Caution must be taken when interpreting the results of this study, as FieldTurf provided funding for the research.

Psychological factors have also been hypothesized as potential injury risk factors. A review of psychological and sociocultural research examined how psychology and socioculture may influence injury occurrence (Wiese-Bjornstal, 2010). Wiese-Bjornstal (2010) concluded that there is significant evidence that psychological and sociocultural stressors/traumas are implicated in injury etiology. “High-intensity sport injuries are stress and trauma-related” (Wiese-Bjornstal, 2010, p. 108). Wiese-Bjornstal stated that injuries may not result in time loss because of the expectation that athletes play “through it”. Wiese-Bjornstal also stated that injuries may not be reported because participation could be limited/denied by medical professionals. This is because the normative culture encourages ignoring pain, either to earn respect through displayed toughness, or to achieve performance success by having a willingness to do whatever it takes to win.

With the high number of injuries occurring in football, being able to identify players at increased risk of injury would be an aid to both the medical and strength and conditioning professional. Previous research (Dick et al., 2007, Wilkerson et al., 2012) has suggested that strength and conditioning programs might not currently be meeting the injury prevention needs of the athlete. The Functional Movement Screen™ (FMS) is a tool that can be used by both medical and strength and conditioning professionals. The FMS is a pre-participation screening tool that has been purported to predict athletes who are at an increased risk of injury.

The Functional Movement Screen™ (FMS)

The Functional Movement Screen™ (FMS) is a tool that examines quality of movement (Cook, Burton, & Hoogenboom, 2006). Evidence of reliability and validity for predicting athletic injury has been demonstrated (Chorba et al., 2010; Kiesel et al., 2007; Minick et al., 2010; O'Connor et al., 2011; Onate et al., 2012; Teyhen et al., 2012). Normative data for the FMS have also been presented (Duncan & Stanley, 2012; Schneiders et al., 2011) and relationships between the FMS and other variables have been examined (Okada, Huxler, & Nesser, 2011; Parchmann & McBride, 2011).

Normative Values

Schneiders et al. (2011) studied 209 physically active college males ($n = 101$) and females ($n = 108$). The goal of their study was to establish some “normal” FMS values for young, healthy adults. A pilot study was conducted to obtain a high level of interrater reliability before starting the study. Individuals were asked to wear their normal “athletic” clothing and footwear on the day of the FMS testing. The FMS protocol as developed by Cook (2001) was followed.

Results indicated no sex differences overall. For women, the mean composite FMS score was 15.6 (± 2.0). For men, the mean composite FMS score was 15.8 (± 1.8) (Schneiders et al., 2011). The combined (men and women) median composite FMS score was 16 and 65 people (31%) had an FMS score of 14 or less. Schneiders et al. (2011) also found that 1% of their sample received a score of three on the rotary stability test. The authors concluded that the inclusion of the rotary stability test is questionable along with the idea that the cutoff of 14 or less as devised by Kiesel et al. (2007) might not be appropriate for all populations.

Duncan and Stanley (2012) studied 58 children (29 boys, 29 girls) between the ages of 10 and 11 years. Eighty-one percent of the children were Caucasian and the mean age of the children was 10.7 (± 0.4) years. The purpose of the study was to compare objectively measured physical activity levels, functional movement, and weight status in children. Height and weight were measured to determine body mass index (BMI). Physical activity was assessed using a sealed pedometer over a four day period, and those individuals who reported removing the pedometer for more than one hour were excluded from the data set. Functional movement was assessed via the FMS and a trained rater scored all of the movements. A $2 \times 2 \times 2$ analysis of variance was used to determine if differences existed in FMS score in terms of gender, weight status, and physical activity.

Results demonstrated that FMS scores were negatively correlated with BMI ($r = -.81$) and positively correlated with physical activity level ($r = .30$) (Duncan & Stanley, 2012). Results indicated no significant differences between boys (13.5 ± 3.4) and girls (14.5 ± 2.8) in mean composite FMS scores. A statistically significant main effect from the ANOVA for weight status was present; normal weight children scored significantly better on the FMS than overweight/obese children. A multiple linear regression showed that average steps/day and BMI predicted 60.2% of variance found in the FMS scores. The researchers found that the mean composite FMS score for overweight/obese children ($n = 19$) was 10.6 (± 2.1). The researchers worry that if suboptimal movement patterns are present in children, those movement patterns could track into adolescence/adulthood, possibly leading to musculoskeletal issues. Duncan and Stanley also hypothesized that the relationship between physical activity and functional movement status is magnified as children get older (if weight is controlled), possibly resulting in reduced levels of physical activity, composite FMS scores, or both.

The FMS and its Relationship with Injury

The FMS has been used to predict athletic injury (Chorba et al., 2010; Kiesel et al., 2007; O'Connor et al., 2011). In a study that examined FMS scores and the relationship with injuries in professional football, Kiesel et al. (2007) used a receiver operating characteristic curve to determine a low score on the FMS as being a score of 14 or less. Subsequent studies have used this same cutoff to examine validity evidence for the FMS (Chorba et al., 2010; O'Connor et al., 2011).

Kiesel et al. (2007) examined scores of a group of 46 professional football players who had completed the FMS. The purpose of the study was to examine the relationship between FMS scores and the likelihood of suffering a serious injury. To protect the identity of the team and players involved in the study, no descriptive statistics were presented. All participants were on the active roster at the start of the season. Kiesel et al. defined injury as membership on the injured reserve and time loss of at least three weeks.

Results indicated that the mean composite FMS score was 16.9 (± 3.0) (Kiesel et al., 2007). Significant differences existed between the mean composite FMS score for those who suffered an injury (14.3 ± 2.3) and the mean composite FMS score for those who did not suffer an injury (17.4 ± 3.1) ($t_{(44)} = 5.62, p < 0.05$). Kiesel et al. determined that a cutoff score of 14 maximized sensitivity (.54) and specificity (.91). Sensitivity was the probability that an individual experienced an injury and scored 14 or less on the FMS. Specificity was the probability that an individual did not experience an injury and scored 15 or more on the FMS. Kiesel et al. reported that players who scored 14 or less on the FMS were eleven and half times more likely to experience an injury.

Chorba et al. (2010) followed a cohort of Division II female fall and winter sports athletes at The University of Findlay in Findlay, Ohio. Chorba et al. used the cutoff of 14 or less established by Kiesel et al. (2007) to dichotomize their data. The participants were 38 female athletes competing in intercollegiate volleyball, basketball, or soccer. The participants completed the FMS within the first two weeks of pre-season practice and the researchers followed the participants through their respective seasons. Chorba et al. defined an injury as a musculoskeletal condition that occurred in practice or competition that required the athlete to seek medical assistance or advice. Sixteen of the 38 participants received a score of less than 14, with approximately 69% of those individuals experiencing an injury. Approximately 81% of the individuals who scored less than 13 were injured, indicating that the 14-point cutoff established by Kiesel et al. (2007) might not be ideal.

O'Connor et al. (2011) followed a military cohort of 874 Marine Corps officer candidates (18 - 30 years old) through Marine Corps Officer Candidate School. The hypothesis for the study was that the FMS would predict injury (specifically overuse injury) better than the physical fitness scores that the participants received. Physical fitness included scores (ranging from 0 - 100, with 100 being optimal) on a timed three mile run, maximum number of pull-ups to exhaustion, and number of abdominal crunches in two minutes. Participants were divided into two groups: a long cycle and a short cycle. The long cycle participants were those individuals who did not have a Reserve Officers' Training Corps (ROTC) background while those individuals in the short cycle did have an ROTC background. The long cycle was a 10-week program while the short cycle was a 6-week program. Even though the curriculum for the programs was the same, the short cycle is generally considered to be a more intense program. The FMS was administered as part of the medical in-screening process, while the physical fitness

scores were taken within the first week of training. The candidates were followed throughout the study and were monitored to see if they sought medical attention/advice for any condition.

Results demonstrated that candidates who scored 14 or less on the FMS were approximately 1.7 - 1.9 times more likely to suffer from any injury when compared to those who scored greater than 14 (O'Connor et al., 2011). Composite FMS scores did not predict overuse injuries. Individuals who scored score of 14 or less on the FMS and were in the short cycle were 1.9 times more likely to suffer any injury compared to short cycle individuals with an FMS score greater than 14. Long cycle candidates with composite FMS scores of 14 or less were 1.7 times more likely to suffer any injury in comparison to those long cycle candidates who scored greater than 14. The authors also found an increased risk ratio (1.6) in individuals in the long cycle that scored 18 or more in comparison to individuals who scored between 15 and 17 on the FMS, suggesting a bi-modal distribution.

Reliability of the FMS

Minick et al. (2010) reported evidence of interrater reliability of the FMS. Four raters viewed videotaped FMS screens, and the authors compared two novice FMS raters with one another and two expert FMS raters with one another. The data were averaged (novice and expert) and comparisons were made. Participants ($N = 40$) had a mean age of 20.8 (no S reported). There were 23 men and 17 women in the study, including 13 varsity athletes from the University of Evansville in Evansville, Indiana. Participants were videotaped completing the FMS from both an anterior and lateral view. After reviewing the videos, the novice and expert raters scored the movements and were blind to the other raters' scores. Evidence of interrater reliability was determined from the scores using weighted kappa values. The results indicated that novice raters had excellent agreement on 6 of the 17 tests, substantial agreement on 8 tests, and moderate

agreement on 3 tests. Expert raters had excellent agreement on 4 of the 17 tests, substantial agreement on 9 tests, and moderate agreement on 4 tests. When the data were averaged and compared (novice v. expert), the raters' shared excellent agreement on 14 of the 17 tests and substantial agreement on 3 tests. The authors concluded that FMS scores should be obtained from individuals who have been trained in the FMS protocol.

Oñate et al. (2012) studied both intersession and interrater reliability of the FMS on 19 physically active men/women, 16 of whom participated in the interrater reliability sample. The FMS was administered on two separate days, separated by one week. Participants received instruction and adequate practice trials to make sure that they understood the criteria of the test. This is a deviation from Cook's (2001) initial protocol. Cook advises not cueing movements because participants could demonstrate non-natural (closer to optimal) movement patterns. Cook also advises no practice trials, as individuals could learn the optimal movement pattern and score higher than their true score.

Both intersession and interrater reliability were determined in real time (Oñate et al., 2012). The two raters differed on their knowledge of the FMS; one individual had an FMS certification while the other did not. Intraclass correlation coefficients (R) were high for both intersession ($R = .92$) and interrater ($R = .98$) reliability. Every task but the hurdle step had moderate to high intersession reliability and good to high interrater reliability. The authors concluded that the FMS can be scored with good intersession and interrater reliability. The authors advised caution in working with the hurdle step, since it was the only test that did not show moderate intersession reliability or good interrater reliability.

Teyhen et al. (2012) studied 53 male and 11 female active-duty service members to determine the reliability of the FMS in a military setting. Participants had a mean age of 25.2 (\pm

3.8) years, a mean height of 175.5 (\pm 9.6) centimeters, and a mean weight of 77.5 (\pm 12.5) kilograms. The raters of the FMS were eight “novice” examiners who were all physical therapy students; each underwent approximately 20 hours of FMS training prior to the study. Four of those raters were randomly assigned to determine intrarater test/retest reliability while the other four raters were randomly assigned to determine interrater reliability in real time. All participants were screened using the FMS. Weighted kappa values, *R* values, standard error of measurement (SEM), and minimal detectable change (MDC₉₅) were used in the statistical analyses (Teyhen et al., 2012).

Results demonstrated that only 10 participants were found to be below the cutoff of 14 developed by Kiesel et al. (2007) and that the 7 movements of the FMS demonstrated moderate to excellent interrater agreement (Teyhen et al., 2012). Intrarater (test/retest) reliability for the various FMS tests was anywhere from poor (rotary stability) to substantial (trunk stability push-up, shoulder mobility, in-line lunge, deep squat, and active straight leg raise). The *R* values for interrater reliability and intrarater reliability were reported as .76 and .74, respectively. The authors concluded that the FMS had an adequate level of reliability when used with service members (and novice raters). The researchers also argued that a more conservative cutoff like 15, 16, or 17 might provide a more accurate prediction. Teyhen et al. reported that they found the rotary stability test to be the most difficult to perform, as only 5 of the 64 participants obtained a score of 3 on the first day of testing.

Relationship of the FMS with other variables

Okada, Huxel, and Nesser (2011) studied male and female (*N* = 28) recreational athletes who had a mean age of 24.4 (\pm 3.9) years. Okada et al. examined the relationship between functional movement, core stability, and performance. They hypothesized that there would be a

significant, positive relationship between core stability and functional movement (as measured by the FMS) and that a significant relationship would exist between functional movement and athletic performance. To measure athletic performance, the researchers calculated a total score from the three different athletic performance tests: a single leg squat, an overhead medicine ball throw, and a “t” agility run. To measure core stability, participants completed a series of isometric exercises (flexion, extension, and right/left lateral flexion). The individuals also completed the FMS. Individuals were randomized to test order and were also allowed 15 minutes to warm up prior to the test.

Okada et al. (2011) found no significant correlation between core stability and FMS score. Okada et al. found that while some FMS tests might have been significantly related to athletic performance, the associated r^2 values were small. The researchers concluded that the FMS is not effective in predicting athletic performance.

Parchmann and McBride (2011) studied male and female ($N = 25$) NCAA golfers who had no history of previous injury. Parchmann and McBride examined the relationship between the FMS and athletic performance as well as the relationship between one repetition maximum (1RM) and athletic performance. The authors hypothesized that there would not be a significant relationship between the FMS and athletic performance or between 1RM and athletic performance.

Participants took part in three different sessions: one for descriptive data, the second for FMS and back squat 1RM testing, and the third for a series of performance tests. The performance tests included: a vertical jump, 10- and 20- meter runs, and a “t” agility run. Club head speed was used as a measure of sport specific performance. Results indicated that the composite FMS score was not significantly correlated with club head speed or with any of the

performance tests, but that 1RM values were significantly correlated with all of the test variables. The authors concluded that FMS scores are not related to jumping, running, agility, or sport performance (club head speed) tests. Evidence does not support the idea that composite FMS scores predict performance.

Improving FMS Scores through Interventions

Kiesel et al. (2011) studied 62 healthy football players in order to determine if FMS scores can be improved through an off-season intervention. Before the off-season training program began, the participants were screened using the FMS to establish baseline scores. The goal of the off-season exercise program was to improve FMS scores above the cutoff of 14 (Kiesel et al., 2007). The program consisted of traditional strength and conditioning exercises as well as individualized corrective exercises (Kiesel et al., 2011). The corrective exercises were designed as intervention strategies to improve scores on each of the seven movements of the FMS (Kiesel et al., 2011). The intervention strategies were incorporated in the athlete's warm-up with the idea that the athletes would eventually progress to doing these movements on their own. The athletes were required to attend the supervised strength and conditioning sessions for four days a week over a seven week period, and two optional sessions per week were available. To analyze these data, participants were grouped as lineman/linebackers ($n = 32$) and other position players ($n = 30$).

Results indicated that the mean composite FMS posttest score for both lineman and position players was $3 (\pm 2.4)$ points higher than at baseline (Kiesel et al., 2011). At the beginning of the off-season program, only seven participants had FMS scores that were greater than 14. After the off-season program, 39 participants had scores greater than 14. At baseline, 31 players had a least one asymmetry (50%), while after the intervention only 20 players had an

asymmetry (32%). The researchers reported that logistic regression suggested that a poor deep squat at baseline predicted those individuals who could raise their FMS score above the cutoff of 14. Composite FMS scores appear to be sensitive to change following an intervention.

Cowen (2010) studied the effects of a worksite yoga initiative on FMS scores in a sample of male and female firefighters ($N = 108$). The firefighters ranged in age from 20 to 60 years with a mean age of $40.6 (\pm 9.2)$ years. The firefighters were screened using the FMS to establish a baseline before the intervention. The firefighters also completed a perceived stress scale. The yoga intervention included breathing (pranayama), postures (asana), and relaxation (savasana) and occurred while the firefighters were on-shift. The mean number of classes attended was 4 (no S reported) and 88 individuals had no prior experience with yoga. Follow-up tests were completed for 77 participants, as the other 31 participants could not be reached because of extenuating circumstances (alarm calls, job transfer, etc.). The baseline mean composite FMS score was $13.3 (\pm 2.3)$ while the post-intervention mean composite FMS score was $16.5 (\pm 2.2)$. For perceived stress, the mean score at baseline was $17.7 (\pm 5.2)$ and after the intervention it was $16.2 (\pm 5.1)$. Lower scores on the perceived stress scale are considered to be better. All participants who completed the follow-up test agreed that yoga helped them in their professional or personal lives. Evidence supports the notion that yoga can improve composite FMS scores in a sample of firefighters.

Goss et al. (2009) studied 80 males and 10 females with a mean age of 35 years (± 5.0) years and a mean weight of $88.2 (\pm 7.1)$ kilograms. The goal of this study was to examine the relationship between functional training and return to duty in Special Operations Soldiers. The program exists in Fort Bragg, North Carolina, and data presented were gathered over a two-year period. The three goals of the program are: to serve as a link between rehabilitation and return to

duty, to enhance performance, and to prevent injuries. Participation was the program is voluntary, but some individuals were highly encouraged to participate. The classes met 3 times each week for 75 minutes over a period of 6 weeks, and in addition to those sessions, individualized programs were distributed to the participants based upon their goals. One hundred fifty-five participants attempted the program, but 65 participants dropped out, resulting in the 90 individuals on whom complete data were available. FMS scores as well as other measures (vertical jump, “t” agility test, six meter hop for time, single leg hop for distance, MAST balance test, kip-up strength, and seven site skin folds) were evaluated before and after the six week intervention. Dependent t-tests were run between mean pretest and posttest scores.

Results showed a mean improvement on the FMS of 2.5 points (no *S* reported) as well as statistically significant improvements on all other functional assessments (Goss et al., 2009). The authors reported that the most improvement was seen in the active straight leg raise, shoulder mobility, and deep squat tests. Goss et al. concluded that programs like this may be beneficial to soldiers returning to duty. The researchers recommended that professionals in different military settings should consider implementing similar programs.

Peate et al., (2007) studied male and female firefighters ($N = 433$). The purpose of their study was twofold: (1) to use the FMS to assess firefighter injury risk, and (2) to implement an intervention to decrease injuries in those who may be at risk. The researchers wanted to examine the relationships between FMS and rank, tenure, and age. As a deviation from the protocol developed by Cook (2001), the FMS tests were demonstrated to the participants. FMS tests were conducted over a month on all participants. The intervention consisted of 21 different 3 hour seminars that were delivered to groups of 20 firefighters. Within those three hour sessions, participants were instructed on both causation and prevention of injuries. Core and/or stabilizing

exercises were shown to the participants. For one year after the intervention, data were kept on number and type of injuries, cost of treatment, and time loss due to injury.

Results indicated that increasing age, tenure, and rank were associated with lower FMS scores (Peate et al., 2007). The researchers reported that as each year passed, FMS scores decreased by approximately 0.1 points. The researchers dichotomized their data as a score ≤ 16 being a failing score and a score ≥ 17 as being a passing score. Results demonstrated that time lost due to injuries was 62% lower (compared to a historical control sample) and total injuries were reduced by 42%. The back and upper extremities were the sites where the most significant injury reductions were found, while results for the lower extremities were not statistically significant. The authors concluded that implementation of a functional movement intervention/enhancement program in order to reduce injuries in firefighters is justifiable.

Summary

The FMS is a tool that was designed to quantify movement quality (Cook, 2001). Several authors have reported that the FMS can be used to predict injury in various populations (Chorba et al., 2010; Kiesel et al., 2007; O'Connor et al., 2011). Injury definitions have varied widely across these studies. Composite FMS scores do not predict performance (Parchmann & McBride, 2011), but are sensitive to change via interventions (Cowen, 2010; Goss et al., 2009; Kiesel et al., 2011; Peate et al., 2007).

Chapter III: Methods

Study Design

This study was a prospective longitudinal study that followed the East Carolina University football team for one season. Participants were informed of benefits and risks associated with participation and informed consent was collected from all participants. Procedures were approved by the Institutional Review Board at East Carolina University.

Participants

Participants included members of the East Carolina University intercollegiate football team. Inclusion criteria for the study included members of the East Carolina University team who were in good standing, both academically and athletically. Inclusion on the official football roster was required. Individuals were deemed physically capable of playing football by a medical professional and were “cleared” to play. Individuals were free from orthopedic injury in the last 6 months.

Exclusion criteria for the study included individuals who were not medically “cleared” to play. Individuals who had experienced a serious orthopedic injury in the previous six months were excluded.

Functional Movement Screen™ (FMS) Design

The Functional Movement Screen™ (FMS) was designed to quantify the quality of a movement (Cook, 2001). This is in contrast with the way many pre-participation performance/skills tests are done, since most tests look at different variables in terms of quantity (Cook, 2001). Tests like the 40 or 60 yard dash, vertical leap, or the 1 repetition maximum (1RM) test all center on a quantity. While it may be true that these tests are valid predictors of athletic performance, they are not good predictors of athletic injury (Cook, 2001). Performance

based tests do not highlight an individual's risk for non-contact injuries, which Cook (2001) argued could be prevented. Cook argues that these injuries occur due to muscular tightness or weakness, poor coordination, or movement compensations. Cook stated that all athletes make some compensations due to the nature of their sport(s).

The FMS is a series of tests that have a defined grading system (Cook & Burton, n.d.). The tests require a balance of stability and mobility (Cook & Burton, n.d.). Cook (2001) argued that mobility is comprised of both joint range of motion and muscular flexibility. Mobility can include the multisegmental nature in which different body parts interact with one another (Cook, 2001). Cook explained stability as a question of body control; a person needs strength, coordination, and balance to show true stability. Cook noted that stability requires movement efficiency. The FMS is not designed as a diagnostic tool; it is meant to put individuals in positions that will exacerbate the movement compensations that each individual uses (Cook & Burton, n.d.). The goal of the FMS is to highlight movement limitations and/or asymmetries that might exist (Cook & Burton, n.d.).

The FMS is comprised of seven movements: squatting, stepping, lunging, reaching, striding/kicking, pressing/pushing, and crawling type movements (Cook, 2001). The movements are scored on a zero to three scale. If the athlete is able to complete the movement exactly as described without pain, a score of three is awarded. If minor compensations are present and the athlete can complete the movement without pain, a score of two is awarded. If the movement cannot be completed and no pain is present, a score of one is awarded. Any movement where pain is present receives a score of zero. Composite scores can range from 0 to 21. Three "clearing" exams are included to test for pain and are scored as pass/fail. The clearing exams are included after the shoulder mobility test, the trunk stability push-up, and the rotary stability test.

If pain is present in any of these tests, the individual receives a score of zero for the respective movement.

The first movement in the FMS is the deep squat and is designed to test mobility of the hips, knees, and ankles (Cook, 2001). A dowel is included in the deep squat in order to test mobility of the shoulders and thoracic spine. The participant assumes a slightly wider than shoulder width stance and grasps the dowel so that the arms form a 90 degree angle at the head. The individual then presses the dowel overhead before squatting as low as possible. The participant has a maximum of three trials to complete the movement to the best of his ability.

The second movement in the FMS is the hurdle step (Cook, 2001). This movement is designed to assess mobility and stability of the hips, knees, and ankles. The height of the participant's tibial tuberosity is the height of the hurdle. The participant (while holding a dowel across the shoulders) must step over the hurdle with one leg, touch the ground on the other side of the hurdle, and then return his leg over the hurdle. This test is done bilaterally, and the lower of the two scores is taken as the score for the test. The participant has a maximum of three trials to complete the movement to the best of his ability.

The third movement of the FMS is the in-line lunge (Cook, 2001). This movement is designed to assess quadriceps flexibility, hip mobility and stability, and bilateral ankle and knee stability. The height of the tibial tuberosity is used as the distance between the two feet. The individual must stand on a 2 × 6 board while holding a dowel behind his back. The dowel must maintain three points of contact (base of skull, thoracic spine, and sacrum) throughout the lunge. The back knee must touch the board behind the front foot and the feet must be kept in the sagittal plane during the lunge. The lower of the bilateral scores is the score for the test, and the participant has a maximum of three trials to complete the movement to the best of his ability.

The fourth movement of the FMS is the shoulder mobility test (Cook, 2001). This movement is designed to assess shoulder range of motion. Internal rotation is combined with adduction in one arm, while external rotation is combined with abduction in the other arm. The tester measures the length of the individual's hand from the crease of the wrist to the end of the middle finger. The participant then closes his hand, and using the motions described above, one hand reaches "over" and the other hand reaches "under" to try and touch behind his back. The tester then measures the distance between the two hands. The lower score is the score for the test. The participant has a maximum of three trials to complete the movement to the best of his ability.

The fifth movement in the FMS is the active straight leg raise (Cook, 2001). This movement is designed to assess flexibility in the lower extremity (both hamstrings and calves). The individual lies on his back with the 2 × 6 under his knees and legs straight. The leg that is not being tested must remain in contact with the floor with the foot in a dorsiflexed position. While maintaining contact with the floor through the head and lower back, the participant raises one leg straight as far as he can. The tester then places a dowel in line with the medial malleolus of the ankle to determine the score. This test is done bilaterally, and the lower of the two scores is taken as the score for the movement. The participant has a maximum of three trials to complete the movement to the best of his ability.

The sixth movement in the FMS is the trunk stability push-up (Cook, 2001). This movement is designed to assess trunk stability while an upper extremity motion is completed. The participant lies face down in a prone position with hands spaced shoulder-width apart. Males place the thumbs in line with the top of the head, while females place the thumbs in line with the chin. The individual lifts his body as a unit and completes one push-up. If the individual is not

able to complete the push-up, then the hand position is changed. The participant has a maximum of three trials to complete the movement to the best of his ability.

The seventh movement in the FMS is the rotary stability test (Cook, 2001). This movement is designed to test multi-planar stability with both upper and lower extremity movement. The participant assumes a quadruped position with both hands and both feet on the ground at relatively 90 degree angles (shoulders relative to the upper torso; hips/knees relative to lower torso). The 2 × 6 board is placed between the knees and hands so that both the hands and knees are touching the board. The participant then lifts the arm and leg (flexes shoulder, extends hip) on the same side and attempts to touch the knee and elbow together. If the participant is unable to complete such a repetition, the pattern changes to a diagonal pattern (opposite arm and leg). This test is done bilaterally, and the lower of the two scores is taken as the score for the movement. The participant has a maximum of three trials to complete the movement to the best of his ability.

FMS Testing Procedure

The testing procedures for the FMS have been previously defined by Cook (2001). Individuals were limited to approximately three trials for each movement and an extensive warm up was not included. Participants were not “cued” of their movements.

Procedures

Upon arrival to the Activity Promotion Laboratory, informed consent was obtained. Descriptive data such as height, weight, and playing position were collected.

Comparison Methods

Body mass index (BMI) and two bilateral body mass asymmetry measures were completed as comparison methods. BMI was calculated using the following formula: mass (kg) /

height² (meters). For the two bilateral body mass asymmetry measures, the participant stood on two identical scales with a foot in the center of each scale. During one of the bilateral body mass asymmetry measures, participants stood with feet a standardized distance apart. This distance was one-third of the participant's height. The other bilateral body mass asymmetry measure was completed with feet placed approximately shoulder width apart. The mass on each scale was recorded, and the difference between the two scales was calculated.

Injury Data Collection

Comprehensive injury reports were collected from the athletic training staff at East Carolina University. Musculoskeletal injuries were recorded and classified as follows: contact (with another player), indirect contact, non-contact, or overuse. Each injury was included in an overall injury count.

Reliability Measures

To provide evidence of interrater reliability, participants were simultaneously rated by two raters. The two raters differed in their knowledge and experience of the FMS. One rater was a certified FMS professional, having approximately two years of experience with the FMS. The other rater was not certified by FMS and had approximately 10 hours of training and experience working with the FMS.

A pilot study was conducted to provide evidence of interrater reliability of the two raters using the FMS. Ten college males and 10 college females with a mean age of 21.8 (3.1) years were screened using the FMS. The two raters viewed each participant's movements and were blind to each other's scores. Results indicated an intraclass correlation coefficient (*R*) value for mean composite FMS scores of .86 (95% CI: .66 - .95). Proportion of agreement (*Pa*) and modified kappa (*Kq*) values were determined as estimates of criterion-referenced reliability. *Pa*

values ranged from .65 (in-line lunge - right leg) to 1.00 (trunk stability push-up, rotary stability - right side, rotary stability - final). Corresponding Kq values ranged from .53 to 1.00.

To provide evidence of intrarater reliability, participants were videotaped completing the FMS. The videos were viewed at a later date and re-evaluated.

Statistical Analyses

Descriptive statistics, including age, height, body mass, and BMI, were calculated. Intrarater and interrater reliability estimates were calculated using a one-way analysis of variance (ANOVA). Criterion referenced reliability was determined with Pa and Kq statistics. Dependent t -tests were used to compare real time and videotape composite FMS means and to compare certified FMS rater and non-certified FMS rater composite FMS means. Cohen's d was calculated to determine effect size (ES).

The 14-point cutoff developed by Kiesel et al. (2007) was used to categorize participants. Additional cutoffs included a composite score of 15 on the FMS, having a BMI of $\geq 30.0 \text{ kg}\cdot\text{m}^{-2}$, and having a difference of 5% of body mass between the two scales on either of the bilateral body mass asymmetry measures. Sensitivity and specificity were calculated using the cutoffs described above. Sensitivity was the probability of being injured and obtaining a positive test. Specificity was the probability of not being injured and obtaining a negative test. Chi-square tests of independence were used to examine the relationship between test status (positive vs. negative test) and injury status (injured vs. not injured).

Chapter IV: Results

Descriptive Statistics

Descriptive statistics of the participants can be found in Table 2. A total of 81 participants completed demographic and FMS testing (68% African American, 32% Caucasian). Forty-five percent of the sample had a body mass index (BMI) between 25.0 kg•m⁻² and 30.0 kg•m⁻² and 39% of the sample had a BMI higher than 30.0 kg•m⁻². Thirty-three percent of the sample was in their first or second year in school.

Table 2
Descriptive Statistics for the Sample (N = 81)

Variable	Mean	S	Minimum	Maximum
Age (years)	20.0	1.5	17	23
Height (m)	1.9	0.1	1.7	2.0
Body Mass (kg)	104.3	22.2	74.1	149.3
BMI (kg•m ⁻²)	30.1	5.3	22.8	43.7

Reliability

Functional Movement Screen™ (FMS) videos were viewed 8.5 (± 1.4) days after the participant completed FMS testing. The mean composite FMS scores were not significantly different ($t_{(79)} = 0.56, p = .58, ES = 0.06$) between real time (15.4 ± 1.7) and videotape scoring (15.5 ± 1.8). Intrarater reliability for the composite FMS score was high, with an intraclass correlation coefficient (*R*) value = .94. Proportion of agreement (*Pa*) and modified kappa (*Kq*) values for the 17 FMS components are presented in Table 3. *Pa* values ranged from .84 to .99 and *Kq* values ranged from .79 to .98. Thirteen of the 17 *Pa* values were greater than or equal to .90.

Table 3
Intrarater *Pa* and *Kq* Values for FMS Movements

Movement	<i>Pa</i>	<i>Kq</i>
Deep Squat - Final Score	.84	.79
Hurdle Step - Right Leg	.96	.95
Hurdle Step - Left Leg	.98	.97
Hurdle Step - Final Score	.99	.99
In-line Lunge - Right Leg	.93	.91
In-line Lunge - Left Leg	.91	.88
In-line Lunge - Final Score	.96	.95
Shoulder Mobility - Right Arm	.88	.84
Shoulder Mobility - Left Arm	.86	.81
Shoulder Mobility - Final Score	.84	.79
Active Straight Leg Raise - Right Leg	.95	.93
Active Straight Leg Raise - Left Leg	.93	.91
Active Straight Leg Raise - Final Score	.94	.92
Trunk Stability Push-Up	.93	.91
Rotary Stability - Right Side	.95	.93
Rotary Stability - Left Side	.90	.87
Rotary Stability - Final Score	.95	.93

Means for composite FMS scores for the certified FMS rater (15.8 ± 1.9) and non-certified FMS rater (16.4 ± 1.5) were significantly different ($t_{(17)} = 3.01$, $p = .01$, $ES = 0.32$).

Interrater reliability for the composite FMS score was high, with $R = .92$. *Pa* and *Kq* values for the 17 FMS components are presented in Table 4. *Pa* values ranged from .78 to 1.0 and *Kq* values ranged from .70 to 1.0. Thirteen of the 17 *Pa* values were greater than or equal to .90.

Table 4
Interrater *Pa* and *Kq* Values for FMS Movements

Movement	<i>Pa</i>	<i>Kq</i>
Deep Squat - Final Score	.83	.77
Hurdle Step - Right Leg	.89	.85
Hurdle Step - Left Leg	1.00	1.00
Hurdle Step - Final Score	1.00	1.00
In-line Lunge - Right Leg	.78	.71
In-line Lunge - Left Leg	.89	.85
In-line Lunge - Final Score	.89	.85
Shoulder Mobility - Right Arm	.78	.71
Shoulder Mobility - Left Arm	.78	.71
Shoulder Mobility - Final Score	.78	.71
Active Straight Leg Raise - Right Leg	.83	.77
Active Straight Leg Raise - Left Leg	.89	.85
Active Straight Leg Raise - Final Score	.89	.85
Trunk Stability Push-Up	.94	.92
Rotary Stability - Right Side	.94	.92
Rotary Stability - Left Side	.89	.85
Rotary Stability - Final Score	1.00	1.00

n = 18

Functional Movement Screen™ (FMS)

Participants completed the FMS a mean of 11.2 (\pm 15.3) hours after their previous workout. The mean FMS score was 15.4 (\pm 1.7) and scores ranged from 11 to 18. The distribution of composite FMS scores is shown in Table 5.

Table 5
Distribution of Composite FMS scores

Composite FMS Score	% Receiving Score	Number of Participants Receiving score	Cumulative %
11	4	3	4
12	2	2	6
13	6	5	12
14	16	13	28
15	19	15	47
16	22	18	69
17	21	17	90
18	10	8	100

Figure 1 depicts a cumulative percentage distribution of participant scores on each FMS movement. The deep squat, hurdle step, in-line lunge, shoulder mobility, and rotary stability movements all had median scores of 2, while the active straight leg raise and trunk stability push-up movements has median scores of 3.

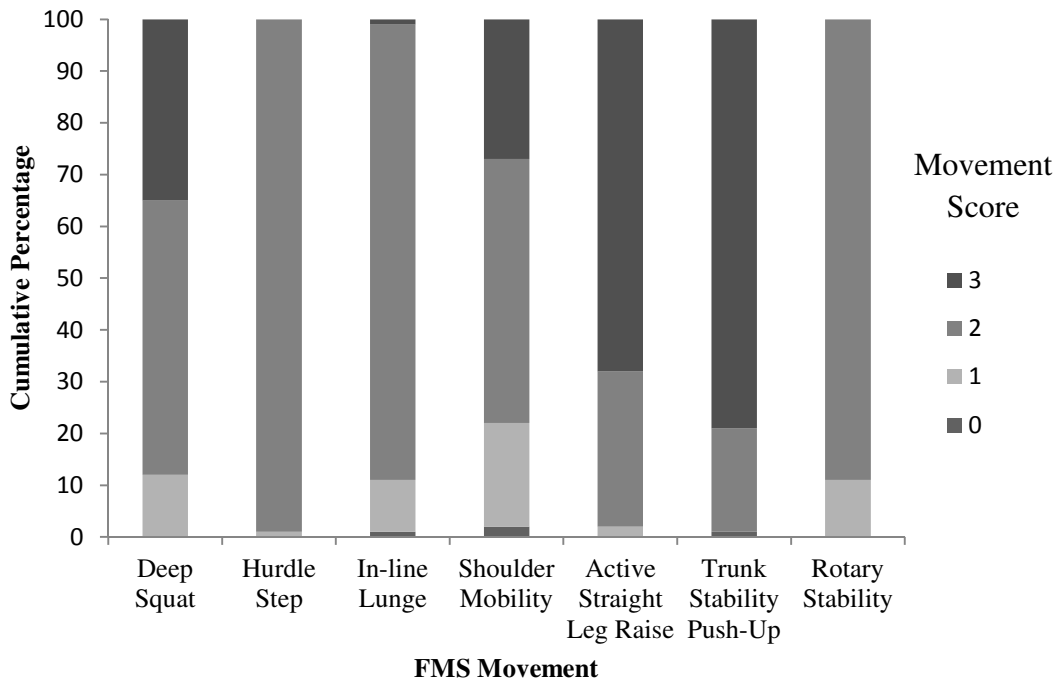


Figure 1
Cumulative Percentage Distribution of Scores on Each FMS Movement

Injuries

Injury data were available on 78 participants, as 3 participants did not complete the season as team members. A total of 43 musculoskeletal injuries were reported to 31 participants (which represented 40% of the sample). Eleven players were injured twice and one player was injured three different times. Participants missed a total of 390 practices resulting in 9.1 (\pm 14.0) practices missed per injury. Participants missed a total of 61 games resulting in 1.4 (\pm 2.8) games

missed per injury. Seventeen of the injuries were a result of direct contact, 12 were a result of indirect contact, 11 were non-contact injuries, and 2 injuries were due to overuse. One mechanism of injury was unknown.

Bilateral Body Mass Asymmetry Measures

Results of the two bilateral body mass asymmetry measures can be found in Table 6. For the shoulder width difference, 16 participants (20% of the sample) had a difference of 10 kg or higher between feet. Eleven participants (14% of sample) had a difference of 10% or more of their body mass. For the standardized difference, four participants (5% of sample) had a difference of 10 kg or higher between feet and two players (3% of sample) had a difference of 10% or more of their body mass.

Table 6
Bilateral Body Mass Asymmetry Measures

	<i>Mean ± S</i>	Minimum Score	Maximum Score
Shoulder Width Difference (kg)	5.5 ± 5.9	0	31.6
Standardized Difference* (kg)	3.9 ± 3.5	0	19.3
Shoulder Width Difference (% of body mass)	5 ± 5%	0%	23%
Standardized Difference* (% of body mass)	4 ± 3%	0%	16%

Note: Standardized Difference is the difference between two scales that were placed a standardized difference (1/3 of the individual's height) apart.

*n = 81; * n = 78*

Sensitivity and Specificity

Tables 7-11 provide the breakdown of the number of participants that met the cutoff for various tests. Table 7 displays the breakdown of the 14-point FMS cutoff. There was no significant relationship between composite FMS scores categorized with the 14-point cutoff and injury status ($\chi^2 (1) = 0.15, p = .70$). Eight participants (10% of the sample) had a composite FMS score of 14 or lower and experienced an injury. Thirty-three participants (42% of the sample) had a composite FMS score of 15 or higher and did not experience an injury.

Table 7
2 × 2 Contingency Table for 14-point FMS Cutoff

Cutoff	Injury Status		Total
	Injured	Not Injured	
Composite FMS Score ≤ 14	8	14	22
Composite FMS Score > 14	23	33	56
Total	31	47	78

Table 8 displays the breakdown for the 15-point FMS cutoff. There was no significant relationship between composite FMS scores categorized with the 15-point cutoff and injury status ($\chi^2 (1) = 0.37, p = .54$). Thirteen participants (17% of the sample) had a composite FMS score of 15 or less and experienced an injury. Twenty-four participants (31% of the sample) had a composite FMS score of 16 or more on the FMS and did not experience an injury.

Table 8
2 × 2 Contingency Table for 15-point FMS Cutoff

Cutoff	Injury Status		Total
	Injured	Not Injured	
Composite FMS Score ≤ 15	13	23	36
Composite FMS Score > 15	18	24	42
Total	31	47	78

Table 9 depicts the breakdown for the BMI 30 kg•m⁻² cutoff. There was no significant relationship between BMI categorized with the 30 kg•m⁻² cutoff and injury status ($\chi^2 (1) = 0.10, p = .75$). Thirteen participants (17% of the sample) had a BMI of 30 kg•m⁻² or higher and experienced an injury. Thirty participants (38% of the sample) had a BMI of less than 30 kg•m⁻² and did not experience an injury.

Table 9
2 × 2 Contingency Table for BMI Cutoff

Cutoff	Injury Status		Total
	Injured	Not Injured	
BMI ≥ 30 (kg•m ⁻²)	13	17	30
BMI < 30 (kg•m ⁻²)	18	30	48
Total	31	47	78

Table 10 depicts the breakdown of the shoulder width difference bilateral body mass asymmetry measure using the ≥5% of body mass cutoff. There was no significant relationship between bilateral body mass asymmetry measure using a shoulder width difference of ≥ 5% of body mass and injury status ($\chi^2 (1) = 3.03, p = .08$). Sixteen participants (21% of the sample) had

a bilateral body mass shoulder width difference of 5% of body mass or greater and experienced an injury. Thirty-two participants (41% of the sample) had a bilateral body mass shoulder width difference of less than 5% of body mass and did not experience an injury.

Table 10
2 × 2 Contingency Table for Bilateral Body Mass Asymmetry Measure: Shoulder Width Difference Cutoff

Cutoff	Injury Status		Total
	Injured	Not Injured	
Bilateral Body Mass Asymmetry Measure: Shoulder width difference $\geq 5\%$ of body mass	16	15	31
Bilateral Body Mass Asymmetry Measure: Shoulder width difference $< 5\%$ of body mass	15	32	47
Total	31	47	78

Table 11 depicts the breakdown of the standardized difference bilateral body mass asymmetry measure using the $\geq 5\%$ of body mass cutoff. There was not a significant relationship between the bilateral body mass asymmetry measure using the standardized difference of $\geq 5\%$ of body mass and injury status ($\chi^2 (1) = 0.37, p = .54$). Nine participants (12% of the sample) had a bilateral body mass standardized difference of 5% of body mass or greater and experienced an injury. Thirty-four participants (43% of the sample) had a bilateral body mass standardized difference of less than 5% of body mass and did not experience an injury.

Table 11
2 × 2 Contingency Table for Bilateral Body Mass Asymmetry Measure: Standardized Difference Cutoff

Cutoff	Injury Status		Total
	Injured	Not Injured	
Bilateral Body Mass Asymmetry Measure: Standardized difference $\geq 5\%$ of body mass	9	12	21
Bilateral Body Mass Asymmetry Measure: Standardized difference $< 5\%$ of body mass	20	34	54
Total	29	46	75

n = 75; Standardized difference not available on three players

Table 12 depicts sensitivity and specificity results for different FMS, BMI, and bilateral body mass asymmetry measure cutoffs. Composite FMS scores categorized based on cutoff scores of 14 and 15 resulted in similar but low values for sensitivity and specificity. The bilateral body mass asymmetry measure with shoulder width difference (with a cutoff of $\geq 5\%$ of body mass) had the highest value for sensitivity, while the same test with standardized difference (with a cutoff of $\geq 5\%$ of body mass) had the highest value for specificity. BMI had the second highest value of sensitivity, but that value was still low.

Table 12
Sensitivity and Specificity Values for Various Tests

	Cutoff	% of sample with positive test*	Sensitivity	Specificity
FMS Score	≤ 14	28%	.26	.70
FMS Score	≤ 15	47%	.42	.51
BMI (kg•m ⁻²)	≥ 30.0	39%	.42	.64
Bilateral Body Mass Asymmetry: Shoulder Width Difference	≥ 5% of body mass	40%	.52	.68
Bilateral Body Mass Asymmetry: Standardized difference	≥ 5% of body mass	28%	.31	.74

*Note: A positive test indicates that the participant scored below the cutoff for FMS or above the cutoff for BMI and bilateral body mass asymmetry tests.

Chapter V: Discussion

The purpose of the study was to determine the ability of the Functional Movement Screen™ (FMS), Body Mass Index (BMI), and two bilateral body mass asymmetry measures to accurately predict injury in intercollegiate football players. The FMS can be used reliably with intercollegiate football players, but the validity of the FMS to predict injury is questionable. The current study found that the FMS did not accurately predict injury over the course of a season in collegiate football players. In addition, sensitivity and specificity values for the FMS were similar to comparable values for the anthropometrically derived measurements.

The sensitivity findings in the current study are similar to or slightly higher than values reported in previous research (Chorba et al., 2010; Kiesel et al., 2007; O'Connor et al., 2011). Sensitivity is an epidemiological statistic that identifies a test's ability to correctly identify a condition. In the current study, sensitivity refers to the proportion of participants that experienced an injury and had positive tests. FMS cutoff scores of 14 and 15, along with BMI and two bilateral body mass asymmetry measures, were examined for their ability to predict injury. All of the sensitivity values in the current study were $\leq .52$. Chorba et al. (2010) reported a sensitivity value of .58 in a sample of intercollegiate female athletes using the FMS cutoff score of 14. Kiesel et al. (2007) reported a sensitivity value of .54 in professional football players using the FMS cutoff score of 14. O'Connor et al. (2011) reported sensitivity values ranging from .12 to .45 for different injury types using the FMS cutoff score of 14. The findings of the current study are in agreement with previous research and demonstrate that a cutoff of 14 or less on the FMS does not result in high sensitivity values. McClure (2001) stated that sensitivity values should be above .80 to be considered high.

Specificity is an epidemiological statistic that is used to determine the ability of a test to correctly exclude a condition. In the current study specificity refers to the proportion of participants that did not experience an injury and had negative tests. The specificity findings in the current study are lower than values reported in previous research (Chorba et al., 2010; Kiesel et al., 2007; O'Connor et al., 2011). Specificity values in the current study ranged from .51 to .74. Chorba et al. (2010) reported a specificity value of .74, while Kiesel et al. (2007) reported a specificity value of .91. O'Connor et al. (2011) reported an overall specificity of .92, with values ranging from .78 to .94 for different injury types. The values in the current study may differ from previous findings because of the injury definition used. Various injury definitions have been used in previous studies (Chorba et al., 2010; Kiesel et al., 2007; O'Connor et al., 2011) and these definitions were less robust than the injury definition used in the present study.

The sensitivity and specificity values for the FMS in the current study were no better than the sensitivity and specificity values for BMI or the two bilateral body mass asymmetry measures. Determining BMI and using the two bilateral body mass asymmetry tests are more feasible and can be measured faster than the FMS can be completed. The FMS cutoff score of 14 had a lower value of sensitivity than BMI and the two bilateral body mass asymmetry measures. The FMS, BMI, and the bilateral body mass asymmetry measures were unable to identify a large proportion of participants who were likely to be injured or not injured.

Because the mechanism of injury may impact the predictive ability of the FMS, analyses were replicated with direct contact injuries removed. Overall, results were similar when direct contact injuries were removed from the analysis. The FMS cutoff score of 14 produced a lower value of sensitivity than BMI and the two bilateral body mass asymmetry measures. Even with the direct contact injuries removed from the analysis, the FMS, BMI, and the bilateral body mass

asymmetry measures were unable to identify a large proportion of participants who were likely to be injured or not injured.

The mean composite FMS score in the current study is similar to that reported by Schneiders et al. (2011), but different than that reported by Kiesel et al. (2007). Kiesel et al. did not report descriptive statistics, but did report a mean composite FMS score of 16.9 (\pm 3.0). This is higher than the mean composite FMS score of 15.4 (\pm 1.7) found in the current study. Without descriptive statistics from the study by Kiesel et al., a comparison between the sample in their study and the sample in the current study is difficult. Both studies examined the relationship between composite FMS score and injury over the course of one football season. Twenty-eight percent of the sample in the study by Kiesel et al. was injured, while 40% of the sample in the current study was injured.

Reliability results in the current study demonstrate that the FMS can be used reliably in a sample of intercollegiate football players. These results are similar to some previous research (Minick et al., 2010; Onate et al., 2012; Schneiders et al., 2011) and dissimilar to other previous research (Teyhen et al., 2012). Onate et al. (2012) reported intraclass correlation coefficient (*R*) values of .92 and .98 for intrarater and interrater composite FMS score, respectively. Onate et al. utilized a certified FMS rater and a non-certified FMS rater, similar to the design of the current study. The *R* value for interrater reliability in the current study (.92) was similar to that reported by Onate et al.

Minick et al. (2010) and Schneiders et al. (2011) reported proportion of agreement (*Pa*) values as evidence of criterion-referenced reliability. These values indicated the agreement of two raters for classifying participants similarly. Minick et al. (2010) reported interrater *Pa* values ranging from .69 to 1.0, which were similar to those reported in the current study. Schneiders et

al. (2011) reported *Pa* values ranging from .86 to 1.0, which were slightly better than those found in the current study.

Teyhen et al. (2012) reported *Pa* values ranging from .68 to .88 for intrarater reliability and .68 to .92 for interrater reliability. Teyhen et al. also reported *R* values of .74 and .76 for intrarater and interrater reliability, respectively. These results may be slightly lower than those found in the current study for a few reasons. Multiple raters were used for intrarater reliability evidence in the study by Teyhen et al. Each rater scored between 14 and 18 participants twice in real time. Intrarater reliability evidence in the current study was provided by one rater who was FMS certified. The multiple raters in the study by Teyhen et al. were not certified FMS raters. For interrater reliability evidence, Teyhen et al. used more than two raters and not every rater viewed every participant. Two raters were randomly assigned to view a participant. The current study used the same two raters to provide evidence of interrater reliability, which may have resulted in higher agreement than that seen with multiple raters.

The limitations in the current study include: not testing players in their protective equipment, an inability to determine “limited” practice participation, a small sample on which interrater reliability was evaluated, and limited generalizability to other sports. Since players were tested at various times throughout the day (i.e., not immediately before practice), they were not wearing the protective equipment that they may have worn during a practice or competition. Such protective equipment may include ankle and knee braces or similar equipment. Further research should examine the impact of protective equipment on composite FMS scores. Another limitation in the current study was an inability to determine “limited” practice participation. It is possible that some injuries impaired performance past the date in which the participant returned to practice. Future research should attempt to determine limited practice participation in addition

to considering time lost to injury. A third limitation in the current study is the small sample on which interrater reliability was evaluated. Caution should be taken when interpreting correlations that are calculated on small samples.

A strength of the current study was the injury definition used. The injury definition used in the current study was the National Collegiate Athletic Association (NCAA) Injury Surveillance System (ISS) injury definition. This definition has been used in previous research (Agel & Schisel, 2013; Dick et al., 2007; Dragoo et al., 2012a; Dragoo, et al., 2012b; Hootman et al., 2007; Hunt et al., 2013), but has not been utilized in the FMS literature. Dragoo et al. (2012a) described the ISS as "...a powerful resource for monitoring injuries in NCAA sports" (p. 991). In a sample of men's and women's collegiate soccer players, Kucera, Marshall, Bell, DiStefano, Goerger, and Oyama (2011) determined that the NCAA ISS captured 88% of all time-loss injuries and they concluded that that the NCAA ISS can provide reliable and valid injury data. Kiesel et al. (2007) used inclusion on the injured reserve and time loss of three weeks as an injury definition. Kiesel et al. did not include injuries that resulted in less than three weeks of time lost. Kiesel et al. indicated that future research should include a "more robust injury definition" (p. 151) and that the injury criteria in their study may not have detected all meaningful injuries. Chorba et al. (2010) defined injury as a musculoskeletal injury that occurred in an intercollegiate game or practice and required medical attention. Chorba et al. did not include a time loss component in their definition. Fifty percent of the sample studied by Chorba et al. experienced an injury, while 40% of the sample in the current study experienced an injury. O'Connor et al. (2011) defined injury as sustaining physical bodily damage secondary to physical training that required medical care one or more times during the study. Time loss was not included in the definition, so injuries such as blisters, abrasions, and lacerations were

included in their results. The injury definition used in the current study was supported by previous literature (Agel & Schisel, 2013; Dick et al., 2007; Dragoo et al., 2012a; Dragoo, et al., 2012b; Hootman et al., 2007; Hunt et al., 2013) and has some validity evidence. Previous injury definitions used in the FMS literature have been inconsistent and may have been limited in their ability to detect meaningful injuries.

Another strength of the current study is the reliability evidence provided. Bretnall and Bundy (2009) stated that it is important (but not sufficient) to provide evidence of reliability to support the credibility of observational assessments. Bretnall and Bundy also stated that failing to provide reliability evidence limits the interpretations that can be placed on scores. Kiesel et al. (2007) did not include any evidence of reliability (interrater or intrarater) and although O'Connor et al. (2007) discussed maximizing reliability, they provided no evidence of interrater or intrarater reliability. Chorba et al. (2010) provided some evidence of interrater reliability, but this was completed as a pilot study on a sample of eight participants. The current study provided evidence of high intrarater and interrater reliability, strengthening the credibility of the findings.

Additional strengths of the current study include: the prospective design of the study, the sample size, and the comparison methods. The prospective design of the study allowed the researchers to evaluate the ability of the FMS to accurately predict injury. The sample size is substantial relative to previous studies that examined the predictive ability of the FMS in athletic populations. The addition of comparison methods (i.e., BMI and bilateral body mass asymmetry measures) in the study design allowed comparison of the FMS to other means of predicting injury and aided interpretation of the values found for sensitivity and specificity. The purpose of including comparison methods in the design was not to suggest that these methods should be used as a replacement for FMS testing, but to examine whether the FMS is more accurate at

predicting injury than more easily obtained anthropometric measures. Findings of the current study demonstrated that the FMS does not perform better than these anthropometrically derived measures at identifying football players who are likely to be injured over the course of a season.

In summary, the FMS is a tool that can be used reliably with intercollegiate football players. However, the validity of the FMS to accurately predict injury is questionable. Categorizing participants with FMS cutoff scores of 14 or 15 did not predict injury any better than anthropometric measurements. The bilateral body mass asymmetry measures and BMI, although at least as accurate as the FMS, did not accurately predict injury. Further research is needed to determine the validity of the FMS to accurately predict injury in athletic populations.

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Appendix A: IRB Approval

3/23/2014

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EAST CAROLINA UNIVERSITY
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Notification of Initial Approval: Expedited

From: Biomedical IRB
To: [Tyler Hall](#)
CC: [Matthew Mahar](#)
Date: 6/7/2013
Re: [UMCIRB 13-000693](#)
Assessment of Functional Movement

I am pleased to inform you that your Expedited Application was approved. Approval of the study and any consent form(s) is for the period of 6/6/2013 to 6/5/2014. The research study is eligible for review under expedited category #4 and 6. The Chairperson (or designee) deemed this study no more than minimal risk.

Changes to this approved research may not be initiated without UMCIRB review except when necessary to eliminate an apparent immediate hazard to the participant. All unanticipated problems involving risks to participants and others must be promptly reported to the UMCIRB. The investigator must submit a continuing review/closure application to the UMCIRB prior to the date of study expiration. The Investigator must adhere to all reporting requirements for this study.

Approved consent documents with the IRB approval date stamped on the document should be used to consent participants (consent documents with the IRB approval date stamp are found under the Documents tab in the study workspace).

The approval includes the following items:

Name	Description
FMS Consent Form	Consent Forms
FMS Study Protocol	Study Protocol or Grant Application
Thirty Day Physical Activity Recall	Surveys and Questionnaires

The Chairperson (or designee) does not have a potential for conflict of interest on this study.

IRB00000705 East Carolina U IRB #1 (Biomedical) IORG0000418
IRB00003781 East Carolina U IRB #2 (Behavioral/SS) IORG0000418