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Can a Preseason Screen Predict Injury or Performance over Three Years of College Football?

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Doctor of Philosophy

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ABSTRACT

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Purpose: To investigate if the Functional Movement Screen (FMS™) Total score, individual component test scores or number of asymmetries can predict noncontact injury risk or player performance over three consecutive seasons of NCAA Division I football.

Methods: As football teams are comprised of individuals with vastly different physical characteristics and playing responsibilities, we divided the subjects into three homogeneous groups based on position (Big, Combo and Skill). Each FMS™ score was assessed with regard to the total team score as well as by individual position groups. For our injury analysis we also controlled for exposure. For player performance we controlled for plays played.

Participants: 286 NCAA Division I athletes participated over three consecutive seasons, yielding a total of 344 observations.

Results: We found no significant relationship between Total FMS™ score and likelihood of injury when analyzed by the total team or by position group. These findings were the same for all groups, for both the total number of injuries as well as injuries weighted by injury exposure. The only significant findings occurred when we considered individual Test Item Scores to injury by position group. We only found a significant relationship in the expected direction with Push-Up Stability in the Combo group. Regarding performance, Total FMS™ was only significant for the Big group, but this effect was not practically significant.

Conclusion: FMS™ was not a good predictor of noncontact injury or performance based on possible playing time.

Key Words: Functional Movement Screen, injury prediction, FMS™, sports performance

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I would like to thank my wife and children for supporting me in my return to school with all the associated late nights of homework and studying. I would like to thank my committee for taking the time to work with a "nontraditional" student who chose a project that literally required three years of work just to complete the data collection.

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INTRODUCTION

Participation in athletics has always carried an inherent risk for injury. American football is not only noted as the most popular high school and collegiate sport with a total overall participation of 9 million athletes, but it is also the leading cause of sports related injuries (1). Intercollegiate football has been shown to have the highest injury rate of NCAA sports, with a reported 35.9 injuries per 1000 injury exposures (IE) (2,3). Likewise, studies estimate high school football players suffer between 300,000 and 1.2 million football related injuries annually. A recent study placed the mean cost for care of 397,363 visits to the emergency room (ER) due to football injury at $1,941 per injury (1,3). This same study estimated the total cost of football related ER visits in the United States over a 2-yr period to be $771,299,862. Due to a concern for athlete safety, the NCAA and its member institutions have studied and changed practice policies such as limiting the number and nature of practices, changing the rules and ball placement on kickoffs as well as mandating improved equipment standards (2,4-9).

Due to the frequency of injury in athletics, the costs associated with caring for those injuries and the fact that teams with fewer injuries tend to be more successful (10), there is a need for clinical tools to identify predisposing risk factors. Researchers have identified a variety of factors which can help predict injury, some of which include body composition (11,12), previous injury (13), and overuse (14).

Currently teams evaluate a wide variety of characteristics such as power, speed, flexibility, and endurance (15,16). Over the past 10 years it has become common for many teams to utilize the Functional Movement Screen (FMS™). The FMS™ is an inexpensive, quick, and easy-to-administer set of 7 tests that are designed to identify restrictions or alterations to normal basic movement patterns (17,18). Scoring ranges from 0–3. A score of 0 indicates pain was associated with the movement. Otherwise a score of 1 to 3 is given based on the quality of movement. A maximum score on the 7 Test Items is 21.

When the FMS™ was introduced it was touted as a clinical tool, which focused on whole-body movement patterns in order to assess risk of injury and performance. Over the past 11 years, numerous studies have attempted to establish the efficacy of the FMS™ to injury and performance prediction. Results to this point have been mixed. Some studies have reported an association in an athlete's FMS™ score and the athlete's chance of injury (19-21). Conversely, other studies have reported no relationship between scores and their chance of injury (22-25). Additionally, FMS™ research typically used to discuss football injuries is based on a small sample of professional players from 1 or 2 teams over a season or preseason (19,20). As only 1.5% of all NCAA football players go on to participate in the NFL, the previously cited studies are not a representative sample of the typical NCAA-level football athlete (26).

To date there has been little research investigating if the FMS™ can be used to predict athletic performance. The limited research that exists has looked at the relationship between FMS™ scores and individual performance tests such as linear speed, 1RM squat strength, sit and reach, flexibility and jump tests (27,28). Results are also mixed regarding whether an FMS™ score is able to predict different components of athletic performance. There is some support for the idea of performance prediction in youth soccer players (29) and with regards to performance tests such as hopping distance, strength, speed, agility and power (16,30), while other studies have argued against using the FMS™ to predict performance on the same or similar tests (21,23,28,30-32).

Because the FMS™ was introduced as a way to systematically assess basic movement pattern quality with regard to movements which are less than optimal or problematic (17), we decided to concentrate on the correlation of the FMS™ with noncontact injury. We did this on the basis that movement quality likely has considerably less to do with contact injuries resulting from the high-speed collisions common in football. In focusing on noncontact injuries, we agree with Crouse when he concluded that, “future research should involve a prolonged study that can differentiate between contact and non-contact injuries” (16). We assessed the mechanism of all injuries over the duration of the study and included in our analysis only those we deemed to be noncontact in nature.

The purpose of this study was to determine, over three consecutive collegiate football seasons: First, does a preseason total FMS™ score, the individual FMS™ Test Item scores or the number of asymmetries predict noncontact injury by position group. Second, does a preseason total FMS™ score, the individual FMS™ Test Item scores or number of asymmetries predict player performance?

METHODS

Participants

Participants included all members of a Division I NCAA football team that were on the roster for one or more of the three consecutive years that this study was conducted. This study included 207 male athletes. Mean age was 21.4 ± 1.84 with a range of 18–26 years old. Participation per year: Year 1 n = 108, (height 1.90 ± 0.06 m, weight 105.19 ± 19.68 kg). Year 2 n = 119, (height 1.88 ± 0.06 m, weight 103.72 ± 19.53 kg). Year 3 n = 117, (height 1.87 ± 0.07 m, weight 104.05 ± 19.62 kg). As this study covered 3 consecutive years, some subjects were observed over multiple years resulting in 344 total observations. The number of subjects observed for only 1 season was 99, subjects included for 2 years was 79 and 29 subjects were observed over the entire 3 years of this study. This study was approved by Brigham Young

University's Institutional Review Board and was determined to be exempt from requiring written informed consent.

Design

This was a 3-year prospective descriptive epidemiology study, which evaluated the relationship between the total FMS™ score with injury and football game performance. Performance was based on the number of plays an athlete participated in, out of the total number possible. Secondary analysis utilized the scores found on the 7 individual FMS™ Test Items and the number of asymmetries and correlated them with injury and football game performance. We collected data from all eligible members of a Division I intercollegiate football team (2014, 2015 and 2016).

Procedures

To be rostered each participant had to pass a preparticipation physical as well as have any previous injuries reviewed by the sports medicine staff, who also performed a thorough musculoskeletal screen. Any individuals with orthopedic injuries over the prior year, or who demonstrated asymmetries in range of motion or strength were additionally screened by an orthopedic surgeon to be cleared for unrestricted participation and be added to the roster.

All participants were divided into groups based on their playing position. This was done as there is a large difference in size, strength, speed and the level of contact in the various position groups during both practice and games. Groups with similar demands were combined and all results were expressed in terms of these more homogeneous groups. These groups are labeled as Big, Combo, and Skill. The Big group consisted of subjects playing on the Offensive and Defensive Lines. The group labeled Combo included those athletes playing Linebacker and

Tight End. The remaining Skill group included Defensive Backs, Kickers, Receivers, Quarterbacks and Running Backs.

The day after being cleared, all rostered players were assigned a time for FMS™ testing. All testing occurred on the same day, 1 day prior to the start of fall camp practice. Testing was done in groups using the standard 4-point scoring system with a range of 0–3 for the entire FMS™ screen using the protocol established by Cook (17,18,33). The FMS™ has been reported to demonstrate moderate to excellent intrarater (ICC = .74–.92) and interrater (ICC = .76–.98) reliability for testers ranging from novice to expert for each of its measured components and in both live and videotaped analysis (34-38).

All measurements for hand length, footedness and tibial tuberosity height were performed by the primary investigator prior to testing and were prepopulated on each subject's data collection sheet. Each year, seven certified FMS™ testers performed one of the seven FMS™ screens on all subjects for that year. All testers had multiple years of experience performing these tests on athletic populations. This method has been found to be the most efficient way of testing large groups (39-41). Tests were all administered in the order that they are presented on the standard FMS™ scoring sheet (33).

We tracked participation in practice or games each day for all participants for the 2014, 2015 and 2016 collegiate football seasons. Injuries were recorded daily after each practice or game for the duration of this study. When data collection concluded, each of the three seasons injuries were coded using the appropriate ICD 10 code (42) for any injuries incurred. Mechanisms for all injuries were reviewed by the athletic trainers covering the practice or game to differentiate between contact and noncontact injuries. Data were coded and added to an encrypted database. We used season-long data in aggregate form to report team and group averages to examine the relationship between FMS™ scores, injuries and game performance. The total score, as well as each individual test item score, was used to see if correlations existed with the noncontact injuries sustained over the course of each competitive season. Total injuries were reported and then assessed based on whether the injury was noncontact in nature. The number of IEs was adjusted to reflect any decreases in participation during practices or games due to things such as contact injuries, disciplinary measures, athletes transferring, not playing in games or sickness.

Operational Definitions

Injury. A musculoskeletal noncontact injury that met each of the following criteria:

1. The injury occurred as a result of participation in an organized on- or off-field practice or competition.
2. The injury required consultation with a certified athletic trainer, physical therapist, or physician.
3. The injury resulted in the inability to fully participate in a subsequent practice or competition.

Injury types. Injuries were classified as contact or noncontact based on their mechanism.

Contact – an injury that occurs with the mechanism being primarily a collision with another player or object.

Noncontact – any injury that occurs where the mechanism or primary force causing the injury is of an intrinsic nature.

Injury Exposure (IE). One IE represents one athlete participating in either one practice or game regardless of the time associated with that participation (1,43-45).

Injury Exposure Rate. IE Rate is the percentage of possible practices and games participated in divided by the total possible number of practices and games.

Player Game Performance. Player game performance is based on participation in games only and is calculated as:

$$\frac{\#\ of\ plays\ participated\ in}{total\ number\ of\ plays\ possible\ for\ that\ position}$$

Positional Groupings of Players.

Big = Offensive and Defensive Linemen.

Combo = Linebackers and Tight Ends.

Skill = Receivers, Quarterbacks, Running Backs, Defensive Backs and Kickers.

Statistical Analysis

We used a generalized linear mixed model methodology as implemented in the glmer() function from the lme4 package of R to analyze the data. These were generalized linear models since the data were not distributed normally. For the percentage-of-plays and number-of-injuries-per-exposure response variables, we used the binomial family with the logit link function. For the raw number-of-injuries response variable, we used the Poisson family with a log link function. Mixed model methodology was necessary since many players played more than one season, thus we needed to account for both within-subject and between-subject variability.

This study was essentially a hypothesis generating study, rather than a hypothesis testing study. That is, there have been real questions about the efficacy of FMS™, and this was the first large scale study to address a number of those questions. Because we performed so many tests, the alpha-levels reported in the analyses are clearly too small. We made no attempt to correct for this problem since we were more interested in seeing if there were any consistent trends which could then be addressed in more detail in future studies.

Because statistical significance is related to sample size, and the sample size for our data set was quite large, it was likely that we would get results that were statistically significant but that had no practical significance. That is, we might show a statistically significant relationship that was meaningless for use in a practical or clinical application.

Going into the study we expected a negative relationship between FMS™ scores and injury, meaning that an increase in an FMS™ score would correspond with a decreased injury rate. Regarding performance, we anticipated a positive relationship, where an increase in an athlete's FMS™ score would be accompanied with a corresponding improvement in player performance.

RESULTS

The purpose of this study was to determine: First, does a preseason total FMS™ score, the individual FMS™ Test Item scores or the number of asymmetries predict noncontact injury by position group. Second, does a preseason Total FMS™ score, the individual FMS™ Test Item scores or number of asymmetries predict player performance?

Total number of players by year and position are listed in Table 1. Demographics of all subjects are noted in Table 2. Additional data including yearly total team FMS™ scores are included in Table 3. Table 4 gives the yearly noncontact injury data presented as a team as well as by position group.

Table 5 displays the number of injuries observed each year by group. Overall, we found that total FMS™ score for the total team was not a significant indicator of the number of injuries that were experienced over the 3 years studied ($P = .130$). As noted in Table 6 Total FMS™ score was also not a significant indicator of injury for the Big (P = .196), Combo (P = .172) or Skill (P = .190) groups.

FMS™ as a Predictor of Injury

Does a preseason Total FMS™ score predict noncontact injury for the total team or by position group? Table 7 presents the relationship between the total number of injuries when IE was taken into consideration. The number of exposures to injury was adjusted for each subject subtracting exposures for days missed due to injury, disciplinary measures, sickness, and in several cases not participating due to transferring to another school. Again, we found that if we looked at the relationship between total FMS™ score and injury for the total team, there was no significant correlation (P =.128). When we considered each of the 3 position groups, there was also no significant relationship between position group total FMS™ score and the number of injuries, as a percentage of total practices and games. See Table 7.

Do preseason individual FMS™ Test Item scores predict noncontact injury by position group? As we found that Total FMS™ score was not a significant indicator of injury risk in our 3 groups of interest, it was logical to see if any of the individual Test Item scores were helpful tools in predicting noncontact injury. Again, we answered this question with regard to both total number of injuries and when corrected for IE. In our Big group, we found none of the 7 individual Test Items to be significant with respect to the total number of injuries as seen in Table 8.

In Table 8 we present the relationship of individual FMS™ Test Item scores to the number of injuries observed. No individual Test Item was significant in the Big group. In the Combo group, only the Push-Up Stability score was found to be significant with respect to the total number of injuries. Only the Rotary Stability Test Item score was found to be significant with respect to the total number of injuries in the Skill group as well as for the Total Team. As we considered the relationship of individual FMS™ Test Item scores with the overall number of injuries in the Skill group, we noted that none of the 7 Test Items that make the FMS™ are significant predictors of the number of injuries in the anticipated direction.

When we considered the ability of the individual FMS™ Test Item scores to predict injury after correcting for IE, we found a significant relationship for Push-Up Stability for the Combo group. It should be noted that the relationship is negative, and thus what we expected. Meaning that an increase in the Push-Up Stability score would predict a decrease in the number of injuries. Rotary Stability for both the Skill and Total Team showed a significant relationship. However, our model predicts a positive relationship, meaning an improved score in the Rotary Stability test is associated with an increased frequency of injury. This relationship is opposite of what would be expected from the FMS™.

Does the number of asymmetries in the FMS™ predict noncontact injury by position group? We considered the effect of the number of asymmetries on injury for the entire team including all practices and games, as well as a separate analysis including only those players that played in the games. This was done to see if there was a difference in the results based on which players did and did not play. The number of Total Team asymmetries by year is presented in Table 10.

Results of our analysis of the relationship between Total Team number of asymmetries and total number of asymmetries by group reveal no significant relationships between these items and injury as noted in Table 11.

Additional analysis of the relationship between the number of FMS™ asymmetries and the number of injuries (Table 12), corrected for IE for each of the position groups, revealed that there are still no significant correlations between any of the three position groups or the Total Team and the number of asymmetries.

FMS™ as a Predictor of Performance

This research question is addressed in Tables 13–16. Since player performance was based on the number of plays an athlete participated in out of the total number possible, all results in the performance section were based on those players who played in the games. Thus, the number of observations drops from n = 344 used in the injury section to a sample of n = 211. This represents those athletes that played in at least one game over the course of the three years of the study.

Does a preseason Total FMS™ score predict player performance? Results of our regression of player performance as a function of the Total FMS™ score for the Total Team as well as by position group are presented in Table 13. There was a significant relationship between all three position groups and the Total Team FMS™ Total score and the likelihood of playing ($P < .001$ in all cases). However, for the Combo and Skill groups and for the Total Team, our model demonstrated a negative relationship, meaning that an increase in Total FMS™ score in each of these instances would predict less playing time with increasing Total FMS™ scores. The Big group not only demonstrated a significant P value of < .001 but the relationship was in the expected direction. That is, our model predicted that as Total FMS™ score increased so did their playing time as anticipated.

Do preseason individual FMS™ Test Item scores predict player performance? As we considered the presence of significant relationships between each of the 7 Test Item scores of the FMS™ and Total Team player performance in Table 14, we found the In-Line Lunge and Active Straight Leg Raise tests to be significant in the expected direction. Meaning, that an increase in each of these scores is correlated with an increase in playing time. All the other tests had a significant P value with the exception of Push-Up Stability (P = .207) but the predicted direction of the relationship indicated that an increase in the individual test score would result in a lower participation rate.

Results of modeling the 7 Test Items of the FMS™ with player performance for all 3 groups is presented in Table 15. For the Big group: Deep Squat, Hurdle Step, In-Line Lunge, Active Straight Leg Raise and Push-Up Stability all are significant and in the expected direction. In the Combo group the only test that is statistically significant and in the expected direction is In-Line Lunge. The same analysis was performed on the Skill group and In-Line Lunge and Active Straight Leg Raise were both noted to be significant and in the expected direction.

Does the number of asymmetries found in a preseason FMS™ test predict player performance? Results of our analysis of the relationship between the number of asymmetries and player performance for all 3 groups and Total Team is noted in Table 16. Significant relationships are noted for the Total Team as well as for the Big and Combo groups. For the Total Team our model predicted as expected, that an increase in the number of asymmetries will result in a decrease in playing time. For the Big and Combo groups an increased total FMS™ score was related to increased playing time.

DISCUSSION

Our study is largely exploratory in nature, in that it is the first multi-year retrospective study designed to assess the ability of the FMS™ to predict noncontact injury and performance in Division I NCAA football players. For this reason, and because we are making multiple statistical comparisons, it is a hypothesis-generating study. Thus, our discussion is largely descriptive in nature, rather than explanatory, with our results compared to previously published studies when applicable. We will first summarize our results in relation to our stated purposes.

The purpose of this study was to determine over 3 consecutive collegiate football seasons: First, does a preseason total FMS™ score, the individual FMS™ scores, or the number of asymmetries predict noncontact injury by position group. Second, does a preseason total FMS™ score, the individual FMS™ test scores, or number of asymmetries predict player performance as defined by the percentage of plays a player participates in compared to the total number of plays available over the same time span?

Relationship Between Total FMS™ Score and Injury

Our data demonstrated a lack of any significant correlation between Total FMS™ score and total number of injuries as well as when we controlled for IE. Additionally, no correlations were noted for the Big, Combo or Skill groups for total injuries or when exposure was controlled.

Relationship Between FMS™ Test Item Scores and Injury

When we considered how individual FMS™ Test Item scores predicted injury by group, we found that the Big group had no significant correlations between individual tests and injury. This held true for the total number of injuries as well as when we controlled for IE.

In the Combo group, the only test that was statistically significant was Push-Up Stability for both the total number of injuries as well as injuries weighted for IE. Risk analysis was performed on these two significant tests to determine the expected change in risk associated with a 1-unit change in the Push-Up Stability test score. In the case of total number of injuries as a function of Push-Up Stability score, the two possible scores that corresponded with the risk of injury was a score of 2 or 3. When the score was 2, the risk of injury was 13.44%; when the score improved to a 3, risk was reduced to 3.67%. When we looked at the same test in relation to the number of injuries, controlled for IE, we found a risk of 11% associated with a score of 2 and a reduction in risk to 3.2% with a score of 3.

In our analysis of the Skill group, we found that there was one statistically significant relationship between the number of injuries and individual FMS™ Test Item scores. Rotary Stability was noted to be statistically significant but not in the expected direction. The positive relationship we found suggests that as the Rotary Stability test score increases the frequency of injury increases as well. Such a relationship is contrary to the underlying premise of the FMS™. When we considered the Skill group and their number of injuries, when we controlled for IE we again found that no tests were significant in the expected direction.

Ford followed an NCAA football team over 1 season (n = 92) and focused on determining if the FMS™ was a predictor of lower extremity injury among Division I collegiate athletes. (23) He reported on both contact and noncontact injuries and was unable to find a statistically significant difference between those athletes who were injured and those who were not. He also separated subjects into skilled and nonskilled groups to try and assess the influence that different positions might have on injury rates. Although he only used 2 groups, he reported that the skill position athletes had higher total FMS™ scores over that season. Similar to Ford, we found the highest Total FMS™ score existed in the Skill group, followed by the Combo and then Big groups (Year 1 Skill = 16.63 ± 1.62, Combo = 15.71 ± 1.52, Big = 15.31 ± 1.49; Year 2 Skill = 17.20 ± 1.51, Combo = 17.03 ± 1.68, Big = 15.77 ± 1.80; Year 3 Skill = 15.33 ± 1.87, Combo = 14.86 ± 1.89, Big = 13.75 ± 1.76). It should be noted that the strength staff during years one and two of our study were focused on flexibility, explosiveness and body weight exercises. After the second season, a new staff placed greater emphasis on sheer strength and heavy lifting. The corresponding changes seen in the groups' Total FMS™ scores associated with the differing approaches to training seem to agree with the findings of Kiesel (46) who reported that FMS™ scores changed with specific training.

Relationship Between Number of FMS™ Asymmetries and Injury

Multiple authors have suggested that the number of asymmetries demonstrated in the 5 individual tests that measure both sides of the body is an additional predictor of injury (20,22). Our analysis revealed no statistically significant relationship between the total number of injuries and the number of asymmetries for the total team or by group. When we considered the number of injuries based on the number of asymmetries and controlled for IE, we also found no significant relationships. It is worth noting that the majority of our findings were negative relationships, suggesting that more asymmetries lead to a decreased risk of injury.

Relationship Between FMS™ and Performance

Our study presented a novel way of measuring performance to see the correlation between a player's preseason FMS™ score, and the amount of time played. Previous studies have typically judged performance not on actual playing performance but by how well they performed on various physical tests (28,32). We proposed a method of evaluating performance based on the premise that in a competitive environment coaches will play those players they feel are their best performers to increase the likelihood of winning. Therefore, we defined player performance as the percentage of plays participated in, divided by the number of plays available on offense and defense per season. By definition then we only assessed those players that played in games when we assessed performance.

Relationship Between Total FMS™ and Performance

Our analysis of whether a preseason Total FMS™ score predicted performance showed that the 3 position groups and the estimate for the Total Team were all statistically significant. However, models for the Total Team, Skill and Combo groups all were in an unexpected direction. Our models predicted that an increase in Total FMS™ score is associated with decreased playing time, which is opposite what we expected. The only group that showed statistical significance in the expected direction was the Big group. Due to this significant relationship in the expected direction, we analyzed the chance of playing based on different possible Total FMS™ scores. We determined that a subject with a Total FMS™ score of 10 has a 7.8% chance of playing; improving that score to 15 increased the likelihood of playing to 11.7%. A further increase of Total FMS™ score to 19 resulted in a likelihood of playing of 15.9%. The standard error of measurement for the Total FMS™ is reported to generally be < 1.0 point (36,40), and further research by Kiesel et al. (46) reported that an entire off-season training program yielded an average improvement in a person's Total FMS™ score of 11%. It is estimated that with an average FMS™ score for the team of 15.8, an entire off-season of training with an individualized FMS™-based program, in addition to the required strength and conditioning program, would yield approximately a 1.3-point improvement on the FMS™ score. Given the time and effort involved to enhance a score by just over 1 point, our results demonstrate that, although statistically significant, in reality, such a change is not practically significant with regard to the player increasing their playing time.

Relationship Between FMS™ Test Item Scores and Performance

The relationship between players in the Big group and their playing time as a function of individual component FMS™ Test Item scores shows statistical significance in the expected direction for the following tests: Deep Squat, Hurdle Step, In-Line Lunge, Active Straight Leg Raise and Push-Up Stability. The relative frequency of playing associated with each possible score on the tests is summarized in Table 17.

For the Combo group for players who played at least once, the only individual FMS™ Item Test score that showed significance in the expected direction was the In-Line Lunge test. The changes in the likelihood of participating with improvement to a score of 2 is 2.6% with further improvement to a score of 3 increasing the likelihood of playing by 3.9%. The Skill group saw significance in the expected direction in only two tests: In-Line Lunge and Active Straight Leg Raise. In-Line Lunge where the likelihood of playing with a score of 2 is 5.7%, which is improved to 6.6% with additional improvement to a score of 3; the Active Straight Leg Raise was also significant in the expected direction where the likelihood of playing with a score of 1 was 6.6% which increased to 7.1% with a score of 2 and further to 7.7% with additional improvement to a score of 3.

For all groups, it should be noted that a 1-point change (which is a 25% change in FMS™ scoring) in the FMS™ Test Item score results in very little predicted change in the player's likelihood of playing in the game. Once again, we see that what might be a significant statistical relationship may not be practically significant.

Relationship Between FMS™ Asymmetries and Performance

Finally, we considered the effect of the number of asymmetries on the percentage of plays participated in for Total Team and those in the Big, Combo and Skill groups, respectively. The only one of these four groups that was significant in the expected direction was the Total Team. This relationship was significant and the model predicted that an increased number of asymmetries is associated with a decrease in playing time.

A frequently cited study by Kiesel et al. (19) assessed the relationship between injuries and a Total FMS™ score in a small number of NFL professionals (n = 46) over a single preseason. This initial professional football study was the first to suggest that an FMS™ score of 14 or lower demonstrated a higher likelihood of suffering an injury. Unfortunately, membership on the injured reserve and loss of 3 weeks playing time was utilized as the only definition of injury. Consequently, the data were skewed to only include significant injuries rather than less severe injuries that are more commonly encountered by an athlete and that result in missing only a single training or competitive session. Although it has been reported by several authors that the FMS™ demonstrates predictive value with regards to injuries in professional football (19,20), our results do not support a similar relationship between Total FMS™ score and injury in collegiate football players over 3 seasons. We found no significant relationship between Total FMS™ score and likelihood of injury when considering the entire team collectively or when we assessed the team by group.

Several possible reasons may exist for this discrepancy between our findings and those presented by Kiesel et al (19). The most likely reason is the difference in the definition of injury between his first study and ours. In the original study, an injury was not considered to have occurred unless the athlete was placed on injured reserve and missed at least 3 weeks of participation. In a subsequent larger study using one NFL team's preseason (n = 81), and a different NFL team for 2 consecutive preseasons (year 1 n = 77, year 2 n = 80) (20), the definition of injury was changed. The revised definition utilized the common practice of counting an injury if there was any time lost from practice or game, which agrees with our definition.

Their initial study also did not differentiate between contact and noncontact injuries in their assessment. We considered only those injuries that were determined by our assessment to be noncontact. We decided to concentrate on the correlation of the FMS™ with noncontact injury as movement quality likely has less to do with contact injuries resulting from the high-speed collisions common in football. Shankar supported our use of noncontact injury when he postulated that the increased rigor of training and the year round nature of collegiate athletics may contribute to the increases in frequency, severity and types of injuries seen at higher levels of competitions(1). He noted that NCAA athletes had more injuries that were attributable to overuse and noncontact mechanisms.

One other notable difference between our study and Kiesel et al. (19) was the average Total Team FMS™ score: 16.9 for the professional athletes compared to our 3-year average of 15.8. This basic difference between collegiate and professional athletes in the same sport highlight the difference in athletic attributes between NCAA and NFL players. Thus, there is a need for a different set of normative injury and FMS™ data when assessing how well the FMS™ predicts injury in different populations.

LIMITATIONS

One potential limitation is that our data was collected over three consecutive seasons, and the coaching staff changed after 2 years. Furthermore, the strength and conditioning staff changed each of the 3 years studied. This resulted in a change in the off-season training and in-season practice characteristics from year to year. Specifically, for the first 2 years of this study the team utilized a “Go Hard, Go Fast” mentality in both games and practice settings. The third year was based on a more traditional, slower paced game where the players saw significantly fewer overall plays in both the practice and game settings. This could be construed as a limitation; however in the normal year-to-year flow of collegiate football it is common for coaching staffs and philosophies to change. For example, there was an average of just over 23 head coaching changes per year over the past 7 years among the Division I Football Bowl Series teams (47). While a coaching change might be considered a limitation, the fact that it happened during the course of this study actually gives a more realistic picture of the changes collegiate athletes face over the course of their collegiate football careers.

Another limitation is that not all subjects had the same number of exposures to injury, even if they were healthy throughout the entire season. Some players were not on the travel list and thus did not travel or participate in away games. Other athletes who did travel did not all play the same number of plays. So even though all subjects had the same exposure to injury during the week of practice, their actual number of plays and exposure could vary significantly based on if, and how much, they played during games. Since it has been reported that over a 16-year period the game injury rate was noted to be over 9 times higher than the injury rate noted in regular season practices, (48) we attempted to offset some of this increased exposure to injury in our analysis. For this reason, we did not count games as an exposure unless the subject participated in the game. This methodology matches that employed in many epidemiological studies to differentiate between practice and game injuries (1,45,49). Our analysis of performance, by definition, was based on the percentage of plays the subject participated in out of the total available. Thus, the number of subjects used in assessing the ability of FMS™ to predict performance was decreased from our overall number of subjects (n = 344) to include only those who played in games (n = 207).

One additional limitation was the prophylactic use of braces and taping among the athletes may have influenced the number of injuries. In our study, all Offensive Linemen wore bilateral knee braces during every exposure, and all subjects in each group were required to either tape their ankles or wear ankle braces for every practice or game. It is felt, however, that although this may limit some chance of injury, it is a fairly standard precaution across all athletes in Division I football where all players are typically treated with the appropriate prophylactic procedures.

CONCLUSIONS

While the FMS™ can be used to assess the quality of fundamental movement and demonstrate asymmetries for 5 of the 7 Item Tests, overall our data suggest that it is not a valid tool for predicting either noncontact injury or performance based on playing time in NCAA Division I football. We established normative data for multiple seasons of intercollegiate football for Total FMS™ and individual Test Item scores. Although we found several measures that seemed to display statistical significance, the relationship between statistical significance and practical significance must be taken into consideration. The majority of the models from our analysis did not predict any statistical significance. They also predicted outcomes contrary to what would be expected when using the Total FMS™ score, individual Item Test scores or number of asymmetries as predictors of injury or performance. Our analysis showed that those models that did indicate statistically significant relationships, in almost every case, had an effect size or probability of change that was very small and did not demonstrate practical significance.

Based on our findings we suggest that other assessment tests be developed that better predict injury and/or performance capability of intercollegiate football players. With regards to the FMS™, future research is needed to improve the scoring of the individual tests that comprise the FMS™ to improve their ability to make better distinctions between scoring, particularly for scores of 1, 2 and 3.

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Table 1. Group size and observations by year

Years Observed	# Players Observed	# Total Observations	Group			Total Subjects
			Big	Combo	Skill	
1	99	99	35	24	49	108
2	79	158	35	29	55	119
3	29	87	32	22	63	117
Total	207	344	102	75	167	344

Table 2. Demographics by position group and whole team

	Big		**Combo**		**Skill**		**Team**	
	Height (m)	**Mass (kg)**	**Height (m)**	**Mass (kg)**	**Height (m)**	**Mass (kg)**	**Height (m)**	**Mass (kg)**
Mean	1.92 ± .05	130.31	1.90 ± .05	104.72	1.85 ± .06	90.02	1.88 ± .07	103.98
Count	94.00	94.00	72.00	72.00	181.00	181.00	344.00	344.00

Table 3. Team FMS™ scores by year scores by year

2014 Team FMS™ Total Score		2015 Team FMS™ Total Score		2016 Team FMS™ Total Score	
Mean	16.0	Mean	16.7	Mean	14.8
Standard Deviation	1.7	Standard Deviation	1.7	Standard Deviation	1.9
Count	108	Count	119	Count	117

Table 4. Test Item FMS™ scores by group and total team

		Big	Combo	Skill
2014	Players	35	24	49
	Deep Squat	2.14 ± .43	2.13 ± .34	2.18 ± .44
	Hurdle Step	1.94 ± .42	2.04 ± .36	2.22 ± .47
	In-Line Lunge	2.11 ± .32	2.13 ± .34	2.25 ± .43
	Shoulder Mobility	2.00 ± .69	2.08 ± .88	2.22 ± .74
	Active Straight Leg Raise	2.51 ± .56	2.42 ± .50	2.78 ± .42
	Push-Up Stability	2.66 ± .64	2.88 ± .34	2.90 ± .31
	Rotary Stability	1.91 ± .37	2.04 ± .36	2.08 ± .28
	FMS™ Total	15.31 ± 1.49	15.71 ± 1.52	16.63 ± 1.62
2015	Players	**35**	**29**	**55**
	Deep Squat	2.14 ± .43	2.59 ± .50	2.55 ± .50
	Hurdle Step	2.31 ± .47	2.17 ± .38	2.26 ± .44
	In-Line Lunge	2.63 ± .49	2.55 ± .51	2.73 ± .45
	Shoulder Mobility	2.11 ± .72	2.35 ± .72	2.27 ± .71
	Active Straight Leg Raise	2.31 ± .47	2.48 ± .51	2.62 ± .53
	Push-Up Stability	2.51 ± .70	2.86 ± .35	2.82 ± .39
	Rotary Stability	1.74 ± .44	2.03 ± .19	1.96 ± .19
	FMS™ Total	15.77 ± 1.80	17.03 ± 1.68	17.20 ± 1.51
2016	Players	**32**	**22**	**63**
	Deep Squat	1.81 ± .54	1.96 ± .38	2.05 ± .49
	Hurdle Step	2.03 ± .31	2.00 ± .31	2.19 ± .40
	In-Line Lunge	1.91 ± .39	2.27 ± .46	2.18 ± .38
	Shoulder Mobility	2.03 ± .82	2.18 ± .85	2.19 ± .72
	Active Straight Leg Raise	2.00 ± .84	2.09 ± .81	2.41 ± .71
	Push-Up Stability	2.81 ± .40	2.91 ± .29	2.89 ± .32
	Rotary Stability	1.16 ± .37	1.46 ± .51	1.429 ± .50
	FMS™ Total	13.75 ± 1.76	14.86 ± 1.89	15.33 ± 1.87
Total Team	Players	**102**	**75**	**167**
	Deep Squat	2.04 ± .49	2.25 ± .50	2.25 ± .52
	Hurdle Step	2.10 ± .43	2.08 ± .36	2.22 ± .43
	In-Line Lunge	2.223 ± .51	2.33 ± .48	2.38 ± .49
	Shoulder Mobility	2.05 ± .74	2.21 ± .81	2.23 ± .72
	Active Straight Leg Raise	2.28 ± .67	2.35 ± .63	2.59 ± .59
	Push-Up Stability	2.66 ± .61	2.88 ± .33	2.87 ± .34
	Rotary Stability	1.62 ± .51	1.87 ± .45	1.80 ± .46
	FMS™ Total	14.98 ± 1.88	15.97 ± 1.90	16.33 ± 1.86

Table 5. Number of injuries per year by position and total

Year	Big	Combo	Skill
2014	35	24	49
2015	35	29	55
2016	32	22	63
Total	102	75	167

Table 6. Relationship between total injuries and group FMS™ scores

Total FMS™ Scores	**P Value Group**	**Relationship**
Big	0.196	(+)
Combo	0.172	(−)
Skill	0.190	(+)
Total Team	0.130	(+)

Table 7. Relationship between Total FMS™ and participation

Total FMS™ Scores	P Value	Relationship
Big	0.253	(+)
Combo	0.237	(−)
Skill	0.187	(+)
Whole Team	0.128	(+)

Table 8. Relationship between Test Item FMS™ scores and number of injuries by group and total team

Total Scores	Big P Value	Combo P Value	Skill P Value	Total Team P Value
Deep Squat	0.087 (+)	0.515 (−)	0.197 (+)	0.054 (+)
Hurdle Step	0.739 (+)	0.904 (−)	0.071 (+)	0.062 (+)
In-Line Lunge	0.179 (+)	0.148 (−)	0.543 (+)	0.396 (+)
Shoulder Mobility	0.210 (−)	0.224 (−)	0.550 (−)	0.123 (−)
Active Straight Leg Raise	0.358 (+)	0.996 (−)	0.862 (−)	0.537 (+)
Push-Up Stability	0.933 (−)	0.001* (−)	0.943 (+)	0.678 (−)
Rotary Stability	0.054 (+)	0.297 (+)	0.011* (+)	< 0.001* (+)

**denotes significance*
(+) or (−) denotes direction of the relationship

Table 9. Relationship of FMS™ Test Item and number of injuries corrected for exposure by group and total team

Total Scores	**Big P Value**	**Combo P Value**	**Skill P Value**	**Total Team P Value**
Deep Squat	0.103 (+)	0.627 (−)	0.170 (+)	0.054 (+)
Hurdle Step	0.785 (+)	0.990 (+)	0.069 (+)	0.062 (+)
In-Line Lunge	0.191 (+)	0.204 (−)	0.509 (+)	0.396 (+)
Shoulder Mobility	0.201 (−)	0.272 (−)	0.574 (−)	0.123 (−)
Active Straight Leg Raise	0.427 (+)	0.939 (+)	0.813 (−)	0.537 (+)
Push-Up Stability	0.934 (−)	0.001* (−)	0.931 (+)	0.678 (−)
Rotary Stability	0.070 (+)	0.332 (+)	0.016 (+)	< 0.001* (+)

**denotes significance*
(+) or (−) denotes direction of the relationship

Table 10. Number of asymmetries per group by year

2014 # Team Asymmetries	
# Asymmetries	109
Big	36
Combo	30
Skill	43
Mean	1.01
Std. Deviation	0.766
Minimum	0
Maximum	3
Subjects	108

2015 # Team Asymmetries	
# Asymmetries	118
Big	38
Combo	30
Skill	50
Mean	1.025
Std. Deviation	0.961
Minimum	0
Maximum	4
Count	119

2016 # Team Asymmetries	
# Asymmetries	148
Big	37
Combo	34
Skill	77
Mean	1.256
Std. Deviation	1.018
Minimum	0
Maximum	4
Count	117

Table 11. Relationship between number of asymmetries and number of injuries (by group)

Total Scores	**P Value**	**Relationship**
Big	0.148	(−)
Combo	0.475	(−)
Skill	0.792	(+)
Total Team	0.472	(−)

Table 12. Relationship between number of asymmetries and injuries corrected for participation (by group)

Total Scores	P Value	Relationship
Big	0.129	(−)
Combo	0.464	(−)
Skill	0.707	(+)
Total Team	0.508	(−)

Table 13. Relationship between Total FMS™ score and performance

Total FMS™ Group and Total Team	P Value	P Value All	Relationship
Big	< 0.001*	< 0.001*	(+)
Combo	< 0.001*	< 0.001*	(−)
Skill	< 0.001*	< 0.001*	(−)
Total Team	< 0.001*	NA	(−)

*****_denotes significance_

Table 14. Relationship between individual FMS™ Test Items and performance (total team)

Test Item	**P Value**	**Relationship**
Deep Squat	< 0.001*	(−)
Hurdle Step	< 0.001*	(−)
In-Line Lunge	< 0.001*	(+)
Shoulder Mobility	< 0.001*	(−)
Active Straight Leg Raise	< 0.001*	(+)
Push-Up Stability	0.207	(+)
Rotary Stability	< 0.001*	(−)

**denotes significance*

Table 15. Relationship between FMS™ Test Item scores and performance

Test Item	Big P Values	Combo P Values	Skill P Values
Deep Squat	< 0.001* (+)	< 0.001* (−)	< 0.001* (−)
Hurdle Step	< 0.001* (+)	< 0.001* (−)	< 0.001* (−)
In-Line Lunge	< 0.001* (+)	< 0.001* (+)	< 0.001* (+)
Shoulder Mobility	< 0.001* (−)	0.578 (+)	< 0.001* (−)
Active Straight Leg Raise	< 0.001* (+)	< 0.001* (−)	0.005 (+)
Push-Up Stability	< 0.001* (+)	0.899 (−)	0.334 (+)
Rotary Stability	0.110 (−)	< 0.001* (−)	< 0.001* (−)

**denotes significance*

(+) or (−) displays direction of relationship

Table 16. Relationship between asymmetries and player performance

	P Value	**Relationship**
Big	< 0.001*	(+)
Combo	< 0.001*	(+)
Skill	0.132	(+)
Total Team	< 0.001*	(−)

**denotes significance*

Table 17. Likelihood of participation at different individual test scores (Big)

Test Item	Score of 0	Score of 1	Score of 2	Score of 3
Deep Squat	5.60%	8.00%	11.4	15.9
Hurdle Step	NA	6.30%	8.5	11.3
In-Line Lunge	6.60%	8.5	10.9	14.0
Active Straight Leg Raise	6.20%	8.3	10.9	14.1
Push-Up Stability	2.70%	4.8	8.2	13.7