12-17-2015

Functional Movement Screen Score by Somatotype Category

Amanda Kelch
Grand Valley State University

ScholarWorks Citation

Kelch, Amanda, "Functional Movement Screen Score by Somatotype Category" (2015). *Masters Theses*. 791.
https://scholarworks.gvsu.edu/theses/791

Functional Movement Screen Score by Somatotype Category

Amanda Kelch

A Thesis Submitted to the Graduate Faculty of

GRAND VALLEY STATE UNIVERSITY

In

Partial Fulfillment of the Requirements

for the Degree of

Master of Health Science

In Biomedical Sciences

December 2015

Acknowledgments

I would like to express my sincerest gratitude to my thesis committee members Dr. Debra Burg, Dr. Heather Gulgin, and Dr. Sango Otieno, without whom this research project would not be possible. Thank you for your expertise, your constant encouragement, and your guidance. Thank you for the time that you invested into this research study as well as the time you invested into my personal development. I feel very fortunate to have had each one of you as a member of my thesis committee. I would also like to thank Brady and Megan Cone for their assistance in data collection. Thank you for your dedication, positive attitudes, and for all the long hours spent together in the lab. I would also like to express my gratitude to the Exercise Science Program for allowing me the privilege of using the Human Performance Laboratory for data collection. I would like to acknowledge Grand Valley State University for their support through a Presidential Grant and thank the University for granting me this award. With the grant I was able to purchase the equipment necessary to conduct this research study. Lastly I would like to thank my husband Tim and my parents for their constant support and encouragement.

Abstract

Background: The Functional Movement Screen (FMS) is a tool used by fitness and health professionals to assess the quality of movement patterns in active populations. The literature has established descriptive values for FMS scores in various populations. However there has not yet been a study establishing the descriptive values of FMS score based on the somatotype categories. Establishing these descriptive values may provide a better understanding of how an individual's somatotype affects their ability to move. Purpose: The purpose of this study was to establish FMS scores for the four simplified somatotype categories (normal, endomorph, mesomorph, and ectomorph). Methods: Participants were healthy college students between the ages of 18-25 years old (male = 29, female = 52, age = 20.48 yrs ± 1.44; height = 170.46 cm ± 10.26; weight = 67.22 kg ± 16.06). Ten basic anthropometric measures were taken on each of the participants to determine somatotype category according to the Heath-Carter Somatotype Method. Following the initial measurements each of the participants completed the FMS evaluation, which consisted of 7 functional movement patterns. Movement patterns were scored (by a certified FMS evaluator) using the 3-point scale. Results: Of the 81 participants, somatotypes were identified as follows: 33 mesomorphs, 16 endomorphs, 8 ectomorphs, 24 as central, and 2 were dropped from study for falsifying information. There was no significant difference between mean overall FMS scores for each category (endomorph 17.63±1.09, mesomorph 17.64±1.11, ectomorph 17.63 ± 1.06, central 17.58 ± 1.25). Conclusion: In the case of healthy young adults there appears to be very little variance in overall FMS scores between the four simplified somatotype categories.

Table of Contents

Manuscript

Extended Review of Literature

Appendices

List of Tables

List of Figures

Manuscript

Abstract

Background: The Functional Movement Screen (FMS) is a tool used by fitness and health professionals to assess the quality of movement patterns in active populations. The literature has established descriptive values for FMS scores in various populations. However there has not yet been a study establishing the descriptive values of FMS score based on the somatotype categories. Establishing these descriptive values may provide a better understanding of how an individual's somatotype affects their ability to move. Purpose: The purpose of this study was to establish FMS scores for the four simplified somatotype categories (normal, endomorph, mesomorph, and ectomorph). Methods: Participants were healthy college students between the ages of 18-25 years old (male = 29, female = 52, age = 20.48 yrs ± 1.44; height = 170.46 cm ± 10.26; weight = 67.22 kg ± 16.06). Ten basic anthropometric measures were taken on each of the participants to determine somatotype category according to the Heath-Carter Somatotype Method. Following the initial measurements each of the participants completed the FMS evaluation, which consisted of 7 functional movement patterns. Movement patterns were scored (by a certified FMS evaluator) using the 3-point scale. Results: Of the 81 participants, somatotypes were identified as follows: 33 mesomorphs, 16 endomorphs, 8 ectomorphs, 24 as central, and 2 were dropped from study for falsifying information. There was no significant difference between mean overall FMS scores for each category (endomorph 17.63±1.09, mesomorph 17.64±1.11, ectomorph 17.63 ± 1.06, central 17.58 ± 1.25). Conclusion: In the case of healthy young adults there appears to be very little variance in overall FMS scores between the four simplified somatotype categories.

Introduction

Somatotyping is a technique that provides a numerical summary of an individual's physique and is used to classify individuals by body type. [1]The three main components measured in somatotyping include endomorphy, mesomorphy, and ectomorphy. Endomorphy is a measure of relative fatness, mesomorphy is a measure of relative musculo-skeletal robustness, and ectomorphy is a measure of proportionality between body weight and height. [2] Measures for each of these components are determined through the use of several anthropometric measures including skinfolds, girth measurements, height, weight, and limb length. An individual's somatotype is expressed as a three number rating of the three main components; endomorphy, mesomorphy, and ectomorphy respectively. [1] The number expressed for each of these main components represents the magnitude of each component. A rating between 2 to 2 1/2 is consider low, a rating of 3 to 5 is considered moderate, a rating of 5 1/2 to 7 is considered high, and a rating above 7 1/2 is considered very high. [2] After obtaining a three number rating for an individual, the individual is further classified into a somatotype category. There are four simplified somatotype categories named based on the dominant component in the three number rating. The four categories are central (no dominance), endomorph, mesomorph, and ectomorph (See Figure 1). [1]

Somatotype ratings and somatotype categories are used in various settings in which evaluation of physique is beneficial. Somatotyping is widely used in sports performance for comparing athletes at various levels of competition, and is ideal for any setting in which changes in physique in over the course of growth, aging, and training are recorded. Additionally relationships between somatotype category and rate of injury, measures of performance, and sports position have all been examined. [3–12] However very little research however, has been done on the relationship between somatotype category and movement abilities. More specifically there appears to be a deficit in knowledge about the relationship between somatotype category and fundamental movement abilities.

Movement is simply the act of carrying out motion. When discussing movement in regards to the human body, movement refers to a physical change in location or position. Movement is accomplished by the body through movement patterns. Movement patterns are intentional groupings of mobile and stable elements of the body working in coordination to produce efficient and effective movement sequences. [6] In other words, during movement some parts of the body remain stable to aid in posture while other parts are mobile, allowing for a change in position. It is through movement sequences that an individual is able to change position as well as able to move through the environment. [13] Fundamental movement patterns then, are movement sequences that allow an individual to carry out fundamental movements such as walking, running, jumping, pushing, and pulling. Fundamental movement is observed as having three purposes: stability, locomotion, and manipulation. [14] Each of these purposes plays a significant role in allowing an individual to survive, navigate, and excel in a given environment. In order to understand the significance of functional movement, the process of motor development must first be understood.

Motor development refers to the development of movement abilities over the course of a lifetime. While there are numerous theories associated with motor development, most experts would agree that the development of movement abilities and observable movement behavior happens in phases. [14] Motor development is thought to have four phases that occur in the following order: reflexive movement, rudimentary movement (first form of voluntary movement), fundamental movement, and specialized movement. [15] Motor development begins with reflexive or involuntary movement in early infancy and progresses to specialized movement in adulthood. Fundamental movement then occurs in the progression of movement development in between rudimentary movement in infancy and specialized movement in adolescence and adulthood. Fundamental movement builds on rudimentary movement and is the foundation of specialized movement. Therefore appropriate and efficient fundamental movement patterns are crucial in the development of specialized movement.

One theory in motor development suggests that movement develops out of an interaction between constraints of an individual, the environment the individual is in, and the task to be performed by the individual. [16] (See Figure 2). This theory proposes that there are three major constraints that interact during the performance of movement. These constraints include: individual constraints, task constraints, and environmental constraints. [15] Environmental constraints are external and can be either physical or cultural. Task constraints are also external and are specific to the goal of the movement task. Individual constraints are internal and are either structural or functional. Functional constraints are related to an individual’s behavior patterns while structural constraints derive from an individual’s physical body structure. It has been established that body composition serves as a structural constraint. [15] It is likely then that somatotype would also serve as a structural constraint affecting the movement patterns of an individual. For this reason it is important to evaluate the movement patterns of each somatotype category. Fundamental movement patterns would be of particular interest in that functional movement patterns are the foundation of more advanced specialized movement patterns and that evaluation of fundamental movement patterns would provide a better understanding of the relationship between somatotype category and movement patterns.

The Functional Movement Screen (FMS™) is a pre-participation and pre-performance evaluation used by fitness and health professionals to examine movement quality in active populations. [13] The FMS was developed to fill a void in pre-participation and pre-performance evaluations. Before beginning physical activity it is often recommended that an individual to first gain medical clearance by completing a physical with a physician. Upon gaining medical clearance often an individual will go through several different performance tests examining strength, flexibility, power, agility, body composition and cardiorespiratory fitness. These performance tests are used to establish a baseline in performance ability. The void noticed by the creators of FMS falls between gaining medical clearance and before completion of performance evaluations. There is a need to examine movement quality before progressing to performance evaluation because any dysfunction in movement patterns may need to be brought to attention and corrected before building on these movement patterns. By examining the quality of movement patterns and whether an individual is able to carry out a movement pattern without compensation, it may be possible to decrease the risk of injury due to dysfunctional movement patterns. Individuals performing beyond their movement abilities and are thought to be at greater risk for injury.[17,18]

The FMS consists of evaluations of seven fundamental movement patterns and is designed to test both mobility and stability. [17,18] In the original scoring system set out by Cook[17,18], movement patterns are scored on a rudimentary scale with scores ranging from zero to three. A score of zero would imply that an individual experienced pain at some point during the movement being assessed. A score of one would indicate that an individual did not experience pain but was unable to complete the movement. A score of two indicates that an individual was able to carry out the movement but not without some form of compensation in the movement pattern. A score of three would indicate that the individual was able to carry out the movement correctly with no compensation. Using this scoring system, a higher score implies more functional movement and a lower score implies dysfunction in movement.

A great deal of research has gone into investigating correlations between factors such as risk of injury and performance abilities, to both FMS scores and somatotyping. Studies are unclear on the association between FMS score and performance, but suggest that lower FMS scores tend to be associated with greater risk of injury. [19–21] Studies investigating somatotyping and performance suggest that different somatotypes display varying levels of performance for different tasks. [3–6,8–10] Ectomorphs appear to achieve higher aerobic capacities in relation to their body mass than either endomorphs or mesomorphs, while endomorphs and mesomorphs tend to achieve higher levels of strength. [4,5] Studies investigating correlation between somatotype and risk of injury have all been sport specific and therefore have shown varying results. [7–10] Although research has been done investigating FMS scores and somatotyping regarding risk of injury or performance, no correlation between these two measures has been investigated. Using FMS to evaluate functional movement patterns of the simplified somatotype categories would provide a better understanding of the relationship between somatotype classification and fundamental movement abilities.

The purpose of this study is to establish normative reference values for functional movement screening scores for the four simplified somatotype categories (central, endomorph, mesomorph, and ectomorph). In addition, the predictive ability of the somatotype categories to account for any variance in functional movement screening scores will be analyzed . The hypothesis of this study is that the somatotype categories will be shown to be good predictors for variance in composite functional movement scores.

Methods

Experimental Design

This descriptive study had the purpose of establishing normative reference values for functional movement screening scores for the four simplified somatotype categories. Prior to participation by human subjects, the study was approved by the Institution Review Board at Grand Valley State University. Before participating, every subject was informed of all procedures and was provided an informed consent form. Participants were also assigned an identification number to ensure identity protection and were asked to complete a short questionnaire. All data collection for a participant took place in one 30-45 minute session at the Human Performance Lab at Grand Valley State University. Researchers first took anthropometric measurements on participants to determine each participant's somatotype rating and then functional movement abilities were assessed in real-time using the FMS. In order to ensure there was no bias in the scoring of the FMS, the researcher responsible for the

FMS scoring was blinded to somatotype ratings and classification. The blinded researcher conducted the FMS evaluation using a standardized set of instructions for all participants and scored the movement patterns according to the grading criteria established by Cook[13].

Subjects

A convenience sample of students was taken from Grand Valley State University. Eighty one participants were assessed for somatotype rating and FMS composite score (Male = 29, Female = 52, age = 20.48yrs ± 1.44, height = 170.46cm ± 10.26 , and weight = 67.22kg ± 16.06). This study included male and female participants of all activity levels. Inclusion criteria for participation in this study required participants to be healthy adults between the ages of 18 and 25 years of age. Participants were excluded from this study if obvious constraints to movement were exhibited or if any constraints to movement were self-reported. Participants were also excluded if they were not injury free at the time of testing or if they had undergone lower extremity surgery in the past six months. Two participants were dropped from this study for falsifying information with regard to injuries.

Somatotyping

The Heath-Carter method was used for somatotyping as described in Heath and Carter's instruction manual. [1] Basic anthropometric measurements such as height, weight, skinfold measurements, breadth measurements, and girth measurements were taken. Height measurements were taken using a standard stadiometer . Mass measurements were taken using a standard sliding scale. Participants were asked to remove their shoes and shirt before stepping on the scale. Skinfold measurements were taken at triceps, subscapular, supraspinale, and calf skinfold sites as described by Heath and Carter, using Harpenden Skinfold Calipers (West Sussex, United Kingdom). The biepicondylar breadth measurement of the right humerus and the biepicondylar breadth measurement of the right femur were taken using a Lafayette Small Anthropometer (Orlando, Florida). Lastly girth measurements were taken at the upper right arm, and the right calf using a Guilk tape measure (Knoxville, Tennessee). Based on the data collected, subjects were assigned to a somatotype category. Additionally, pictures of each subject were taken for classification purposes. Pictures were taken with minimal clothing as examining physique was the primary purpose of taking the pictures. For a man this involved being photographed in a pair of athletic shorts and no shirt. For a woman this involved being photographed in a sports bra and a pair of athletic shorts. To protect the identities of subjects, the eyes, the mouth, and any other identifying features were covered with a black box in their digital photo.

FMS

Functional movement screening was completed as described by Cook [17,18]. FMS involves the assessment of seven movements including deep squat, hurdle step, in-line lunge, single leg raise, shoulder mobility, trunk stability push-up, and rotary stability. FMS also includes three clearance tests including shoulder clearance, spinal extension clearance, and spinal flexion clearance. Participants completed these in movements in the order and with the standardized instructions provided by Cook [17,18]. In addition, the official FMS kit was used for testing (Cranston, Rhode Island). Movements were scored on a three-point grading scale as set by Cook [17,18]. Subjects were given up to three trials for each movement pattern assessed and scores were given based on FMS grading criteria for each individual movement pattern. [17,18] For consistency purposes only one rater carried out the FMS testing. This rater was certified in FMS and had six months of experience using the tool.

Statistical Analysis

Data was analyzed using SAS 9.4 (Cary, North Carolina). Normative data was reported for each of the simplified somatotype categories. The relationship between functional movement score and somatotype category was analyzed using multiple linear regression. The independent variables (central category, endomorph category, mesomorph category, and ectomorph category) were assessed to determine if these variables were predictors of functional movement score. The level of significance that was used is $p < 0.05$. To ensure a power level of 0.80 with a medium effect size and three predictors, sample size was calculated using Cohen's power analytic approach. [15] It was determined that the sample size needed to consist of at least 77 participants. [15] Additionally, the relationship between FMS composite score and the individual somatotype component ratings, BMI, sex, and physical activity level were assessed. Correlations between composite FMS score and each of the somatotype ratings were calculated using Pearson Correlation Coefficients and the magnitudes of the correlations of the somatotype groups were compared using the approach described by Zou.[22]

Results

In total, eighty-three subjects participated in this study. The data of two subjects was not included in this study as these two subjects were dropped from the study for falsifying information. Of the remaining eighty-one subjects, the number of participants in each somatotype category is reported in Table 1. The minimal composite score recorded was a 15 and the maximum composite score recorded was a 20. Descriptive information for the overall sample is reported in Table 2. The mean composite score for the somatotype categories were found to be: 17.63 ± 1.09 for endomorphs, 17.64 ± 1.11 for mesomorphs, 17.63 ± 1.06 for ectomorphs, and 17.58 ± 1.25 for participants in the central category. Looking at Table 2 it is apparent that there is no difference in mean or variance of composite FMS score between the simplified somatotype categories. Due to unequal group size and extremely little variance in mean composite score between somatotype categories, it was determined that it was not appropriate to use multiple linear regression to determine whether the simplified somatotype categories were good predictors of variance in composite FMS score. The independent variables of central category, endomorph category, mesomorph category, and ectomorph category, physical activity, sex and BMI were found to be non-predictive variables of composite FMS Score. Like the somatotype categories, the mean composite FMS scores did not vary between sexes or by level of physical activity. (Table 3 and Table 4)

In addition to comparing mean composite FMS scores between the somatotype categories, relationships between all of the endomorphy rating, mesomorphy rating, and ectomorphy rating and composite FMS score were also analyzed. The Pearson Correlation Coefficients for endomorphy rating, mesomorphy rating, and ectomorphy rating were r= -0.15 (p= 0.16), -0.10 (p=0.37), and 0.008 (p=0.94) respectively. Looking at Figure 4-6, it is apparent that there is no relationship between the individual somatotype components and composite FMS score. The comparisons made between the magnitude of the correlations for the somatotype group were as follows: endomorph to mesomorph (Z = -0.30, p =0.76), endomorph to ectomorph (z = 0.15, p = 0.87), and mesomorph to ectomorph (z= 0.22, p = 0.82). Based on these findings, the magnitude of correlations of the somatotype groups do not differ.

Discussion

The FMS is commonly used as part of a battery of tests during pre-participation screens in athletic populations. It is thought to be able to detect dysfunctional movement patterns, assess injury risk, and potentially assess athletic performance [23,24]. Somatotype category has been found to be related to athletic performance [4,5]. The purpose of this study was to establish normative values of FMS composite score for the Heath Carter simplified somatotype categories and determine whether the somatotype categories were predictive of variance in the composite FMS score. The hypothesis of this study was that the simplified somatotype categories would be predictive of variance in composite FMS score. This hypothesis was based on the evidence that BMI and composite FMS score have been shown to be related [25,26] as well as somatotype and athletic performance having been shown to be related. [4,5] Normative values were established for each of the somatotype categories. However, extremely little variance was observed in mean FMS composite score between the somatotype categories. Therefore, the somatotype categories do not appear to be predictive of FMS composite score.

The normative values established for FMS composite score in this study were higher than those established in previous studies. In this study the composite FMS score established for college students between the ages of 18 and 25 years old, was 17.62 ± 1.12. In a similar study comparing general college students to collegiate athletes, the mean composite score reported for both general college students and to collegiate athletes was much lower, 14.1 ±

0.2 and 14.2 ± 0.2 respectively [27]. It appears that the normative values established in this study were more similar to those established in physically active individuals between the ages of 18 and 40 years of age with a composite score of 15.7 ± 0.2 [28], and those established in military service members with a composite score of 16.2 ± 2.2 [29]. To the best of the author's knowledge, the normative values established for composite score in this study are the highest to ever be reported. One possible explanation for this finding may be that the rater responsible for scoring the FMS sessions in this study is a relatively novice rater. While the rater obtained a Level 1 Certification in FMS, the rater also only had six months of experience using the tool. It is possible that this relative lack of experience played a role in the higher scores that were reported. However, it has been previously established that novice raters with little to no experience with the FMS are reliable raters when compared to expert raters having significantly more experience [30,31]. Another factor that may have influenced the higher composite score reported in this study is that all scoring of the FMS was done in real-time versus being assessed from a video recording that could be replayed. While there is some evidence to suggest that grading the FMS from a pre-recorded video session is reliable when compared to real-time scoring [32], it is likely that there is an observable difference in scoring between real-time scoring and scoring a videotaped session. The choice to perform real-time scoring in this study was an intentional choice in order to more closely replicate how the FMS is used in the field. The FMS was designed to be a simple and effective tool for experts in athletics and human movement to assess functional movement in athletic populations with minimal equipment.

The hypothesis of this study was based on the premise that composite FMS score may predict athletic performance. As somatotype category has been shown to influence athletic performance, it is logical to suspect that if FMS score is predictive of athletic performance then it is likely that there is a relationship between these two assessments. The literature is still unclear on whether FMS is a good predictor of athletic performance. In one study performed on professional football players, individualized training interventions were shown to improve composite FMS score and reduce risk of injury [33]. However, the study failed to investigate whether other measures of performance also improved with movement specific interventions. Similarly, a study performed on mixed martial arts athletes showed movement specific interventions improved composite FMS score in as little as four weeks [34]. Again, the study failed to investigate the effect of this intervention on other measures of performance. Overall, studies comparing composite FMS score to specific performance measures have been in agreement that there is a minimal relationship between composite FMS score and athletic performance [19,20,35,36]. This in part, may account for the lack of variance seen in composite FMS score between the simplified somatotype categories in this study.

The only previous study that connected composite FMS score to a measure of longitudinal performance was that of Chapman et al. In this study, elite track athletes scoring higher on composite FMS score had greater longitudinal positive performance changes than those scoring lower on the FMS. [37] This may suggest that while composite FMS score does not appear to be related to specific measures of performance, such as sprint times or vertical jump, that individuals scoring higher do appear to perform better overall. More research is necessary to determine the relationship between composite FMS score and overall sport specific performance and other variables that may be influencing both of these measures. Composite FMS scores have been established as a predictor of injury risk [38]. While there appears to be some debate over the true cutoff point at which specificity and sensitivity of injury detection are maximized, there does appear to be a moderate amount of evidence suggesting that lower FMS score increases risk of injury [39–41]. It is possible that rate of injury is the influencing factor in the connection between composite FMS score and longitudinal sport specific performance. The reasoning behind this is that athletes that spend less time injured have the advantage of more time for training and more opportunities to compete. However in this present study, on average, participants had higher composite scores and none of the participants scored below a 14, which is commonly used as the cutoff point for risk of injury.

Recently there has been debate over what the FMS composite score represents. It is thought to represent overall quality of functional movement. However, recent studies suggest that the composite score of the FMS is not the uni-dimensional construct it was thought to be and that more attention should be paid to individual movement patterns rather than composite scores [42,43]. The present study was conducted under the assumption that the FMS composite score is a uni-dimensional construct. When individual movement patterns were assessed more closely only one weak correlation was found between endomorphy rating and deep squat score (r= -0.32). There were no other correlations found between any of the movement patterns and somatotype ratings. From this observation it is likely there is minimal relationship between somatotype rating and movement pattern score. It is possible that no correlation was observed because the original three point grading scale is not sensitive enough to differentiate between the number and patterns of compensation. Modified grading scales have been created for the FMS screen in an attempt to rectify this issue [44,45]. However, little is known about the validity of these new grading scales. As new grading scales are established and validated, more investigation of the possible relationship between movement patterns and somatotype should take place.

In the current study no correlation was found between BMI and composite FMS score. This is in contrast to previous studies, where BMI was found to be negatively correlated with composite FMS score [25,26]. In one of these studies, it was determined that BMI and amount of physical activity accounted for 60.2% of the variance in FMS composite score [25]. It should be noted that these studies were performed on children and the relationship found between BMI and composite score may not reflect reality for adult populations. One study investigating the relationship between BMI and composite FMS score in children found that there was no correlation between BMI and composite FMS score. The authors speculated that this was partly because few of the participants were classified as overweight [46]. Similarly in this present study, 14% participants were classified as overweight and 3% of participants were obese. Additionally, as many of these participants were mesomorphs, it is likely that the observed higher BMI ratings are due to increased muscle density rather than increased fat mass.

Limitations of this study must be acknowledged. The first limitation being an unanticipated participation bias. The researchers anticipated that near equal group sizes would be obtained for the simplified somatotype categories from a convenience sample. However, it was observed by the researchers that participants belonging to the mesomorph and central category classifications were far more likely to participate than participants belonging to the endomorph and ectomorph classifications. This may have been due to the nature of measurements taken. Participants with higher fat mass may have been uncomfortable with the body composition measurements taken and therefore may have chosen not to participate. Another limitation is the homogeneity of the participants. It is likely that the somatotype categories were only minimally different in regards to body composition as, on average, participants scored low to moderate in all the somatotype rating components. It is acknowledged that it is possible yet unlikely, that with a more diverse population, the results of this study may have been different.

In conclusion, the results of this research show that there is virtually no difference in composite FMS score between the Heath-Carter simplified somatotype categories. Due to this observed lack of variance in composite FMS score, it is likely that the simplified somatotype categories do not account for the variance in FMS score. Additionally, no relationships were observed between composite FMS score and BMI, sex, or physical activity level. Any further research on this subject should examine the relationship between somatotype ratings and individual movement patterns. A weak negative relationship was observed between the deep squat movement and endomorphy rating. It seems likely that increased fat mass may impact certain functional movement patterns. The researchers would be interested to know if this finding could be replicated in a more diverse population.

Acknowledgements

This research study was made possible through funding received from a Presidential Research Grant awarded by Grand Valley State University

References

1. Carter JE, Heath BH. The heath-carter anthropometric somatotype. 2002.

2. Norton K, Olds T. *Anthropometrica: A Textbook of Body Composition Measurement for Sports and Health Courses*. Sydney, Australia: UNSW Press; 1996.

3. Ayan V, Bektas Y, Erol AE. Anthropometric and performance characteristics of Turkey National U-14 volleyball players. *Afr J Phys Health Educ Recreat Dance*. 2012;18(2):395-403.

4. Bale P. Relationships among physique, strength, and performance in women students. *J Sports Med Phys Fitness*. 1985;25(3):98; 98-103; 103.

5. Bale P, Colley E, Mayhew J. Size and somatotype correlates of strength and physiological performance in adult male students. *Aust J Sci Med Sport*. 1984;16(4):2-6.

6. Garganta J, Maia J, Pinto J. Somatotype, body composition and physical performance capacities of elite young soccer players. In: United Kingdom; 1993. http://articles.sirc.ca/search.cfm?id=318734; http://ezproxy.gvsu.edu/login?url=http://search.ebscohost.com/login.aspx?direct=true&db=s3h&AN=SPH318734&site=ehost-live&scope=site; http://articles.sirc.ca/search.cfm?id=318734.

7. GREENLEE G. The relationship of somatotype and isokinetic strength measures to lower extremity injuries in female athletes (Mise en relation du somatotype de la force isocinetique avec les blessures des extremites inferieures chez les femmes sportives). *Relatsh Somatotype Isokinetic Strength Meas Low Extrem Inj Female Athletes Mise En Relat Somatotype Force Isocinetique Avec Blessures Extrem Inferieures Chez Femmes Sport*. 01 1986.

8. Hopper DM. Somatotype in high performance female netball players may influence player position and the incidence of lower limb and back injuries. / Le somatotype des joueuses de netball de haut niveau peut influer sur la position occupee par les joueuses et l â�™ incidence des blessures des membres inferieures et de la region lombaire. *Br J Sports Med*. 1997;31(3):197-199.

9. Reilly T. Somatotype and injuries in adult student rugby football. *J Sports Med Phys Fitness*. 1981;21(2):186; 186-191; 191.

10. Carlson BR, Carter JEL, Patterson P, Petti K, Orfanos SM, Noffal GJ. Physique and motor performance characteristics of US national rugby players. *J Sports Sci*. 1994;12(4):403-412.

11. Salokun SO. Minimizing injury rates in soccer through preselection of players by somatotypes. / Minimiser l â�™ incidence des blessures en football par la preselection des joueurs d â�™ apres leur somatotype. *J Sports Med Phys Fitness*. 1994;34(1):64-69.

12. Wilsmore RG. The body type of female hockey players involved in different playing positions and levels of competition. *Aust J Sci Med Sport*. 1987;19(4):26-28.

13. Cook G. *Movement Functional Movement Systems: Screening, Assessment, and Corrective Strategies*. Aptos, CA: On Target Publications; 2010.

14. Gallahue DL. *In Adapted Physical Education and Sport. 3rd Ed, Champaign, Ill., Human Kinetics, c2000*.; 2000.

15. Haywood N Kathleen & Getchell. *Life Span Motor Development*. 5th ed. Champaign, IL: Human Kinetics; 2009.

16. Utley A, Astill S. *Motor Control, Learning and Development*. New York: Taylor & Francis; 2008.

17. Cook G, Burton L, Hoogenboom B. Pre-participation screening: the use of fundamental movements as an assessment of function - part 1. *North Am J Sports Phys Ther NAJSPT*. 2006;1(2):62-72.

18. Cook G, Burton L, Hoogenboom B. Pre-participation screening: the use of fundamental movements as an assessment of function - part 2. *North Am J Sports Phys Ther NAJSPT*. 2006;1(3):132-139.

19. Frost DM, Beach TA, Callaghan JP, McGill SM. Using the Functional Movement Screen to evaluate the effectiveness of training. *J Strength Cond Res Natl Strength Cond Assoc*. 2012;26(6):1620-1630.

20. Parchmann CJ, McBride JM. Relationship between functional movement screen and athletic performance. *J Strength Cond Res Natl Strength Cond Assoc*. 2011;25(12):3378-3384.

21. Lisman P, O’Connor FG, Deuster PA, Knapik JJ. Functional movement screen and aerobic fitness predict injuries in military training. *Med Sci Sports Exerc*. 2013;45(4):636-643.

22. Zou GY. Toward using confidence intervals to compare correlations. *Psychol Methods*. 2007;12(4):399-413. doi:10.1037/1082-989X.12.4.399.

23. Cook G, Burton L, Hoogenboom BJ, Voight M. Functional movement screening: the use of fundamental movements as an assessment of function - part 1. *Int J Sports Phys Ther*. 2014;9(3):396-409.

24. Cook G, Burton L, Hoogenboom BJ, Voight M. Functional movement screening: the use of fundamental movements as an assessment of function-part 2. *Int J Sports Phys Ther*. 2014;9(4):549-563.

25. Duncan MJ, Stanley M. Functional movement is negatively associated with weight status and positively associated with physical activity in british primary school children. *J Obes*. 2012;2012:697563.

26. Duncan MJ, Stanley M, Wright SL. The association between functional movement and overweight and obesity in British primary school children. *BMC Sports Sci Med Rehabil*. 2013;5(1):11.

27. Engquist KD, Smith CA, Chimera NJ, Warren M. Performance Comparison of Student-Athletes and General College Students on the Functional Movement Screen and the Y Balance Test. *J Strength Cond Res Natl Strength Cond Assoc*. 2015;29(8):2296-2303. doi:10.1519/JSC.0000000000000906.

28. Schneiders AG, Davidsson A, Horman E, Sullivan SJ. Functional movement screen normative values in a young, active population. *Int J Sports Phys Ther*. 2011;6(2):75-82.

29. Teyhen D. Normative data and the influence of age and gender on power, balance, flexibility, and functional movement in healthy service members. *Mil Med*. 2014;179(4):413-420.

30. Onate JA, Dewey T, Kollock RO, et al. Real-time intersession and interrater reliability of the functional movement screen. *J Strength Cond Res Natl Strength Cond Assoc*. 2012;26(2):408-415. doi:10.1519/JSC.0b013e318220e6fa.

31. Elias JE. The Inter-rater Reliability of the Functional Movement Screen within an athletic population using Untrained Raters. *J Strength Cond Res Natl Strength Cond Assoc*. July 2013.

32. Shultz R, Anderson SC, Matheson GO, Marcello B, Besier T. Test-retest and interrater reliability of the functional movement screen. *J Athl Train*. 2013;48(3):331-336.

33. Kiesel K, Plisky P, Butler R. Functional movement test scores improve following a standardized off-season intervention program in professional football players. *Scand J Med Sci Sports*. 2011;21(2):287-292.

34. Bodden JG, Needham RA, Chockalingam N. The Effect of an Intervention Program on Functional Movement Screen Test Scores in Mixed Martial Arts Athletes. *J Strength Cond Res Natl Strength Cond Assoc*. July 2013.

35. Clifton DR, Harrison BC, Hertel J, Hart JM. Relationship between functional assessments and exercise-related changes during static balance. *J Strength Cond Res Natl Strength Cond Assoc*. 2013;27(4):966-972.

36. Hartigan EH. Relationship of the Functional Movement Screen In-Line Lunge to Power, Speed, and Balance Measures. *Sports Health*. 2014;6(3):197-202.

37. Chapman RF, Laymon AS, Arnold T. Functional movement scores and longitudinal performance outcomes in elite track and field athletes. *Int J Sports Physiol Perform*. 2014;9(2):203-211.

38. Kiesel K, Plisky PJ, Voight ML. Can Serious Injury in Professional Football be Predicted by a Preseason Functional Movement Screen? *North Am J Sports Phys Ther NAJSPT*. 2007;2(3):147-158.

39. Letafatkar A, Hadadnezhad M, Shojaedin S, Mohamadi E. Relationship between functional movement screening score and history of injury. *Int J Sports Phys Ther*. 2014;9(1):21-27.

40. Butler RJ, Contreras M, Burton LC, Plisky PJ, Goode A, Kiesel K. Modifiable risk factors predict injuries in firefighters during training academies. *Work Read Mass*. 2013;46(1):11-17.

41. Kiesel KB, Butler RJ, Plisky PJ. Prediction of Injury by Limited and Asymmetrical Fundamental Movement Patterns in American Football Players. *J Sport Rehabil*. 2014;23(2):88-94.

42. Kazman JB, Galecki J, Lisman P, Deuster PA, O'connor FG. Factor Structure of the Functional Movement Screen in Marine Officer Candidates. *J Strength Cond Res Natl Strength Cond Assoc*. August 2013.

43. Li Y, Wang X, Chen X, Dai B. Exploratory factor analysis of the functional movement screen in elite athletes. *J Sports Sci*. December 2014:1-7. doi:10.1080/02640414.2014.986505.

44. Jill N. Hickey BAB. Reliability of the Functional Movement Screen Using a 100-point Grading Scale: 1765. *Med Sci Sports Exerc - MED SCI SPORT Exerc*. 2010;42. doi:10.1249/01.MSS.0000384722.43132.49.

45. Butler RJ. Interrater Reliability of Videotaped Performance on the Functional Movement Screen Using the 100-Point Scoring Scale. *Athl Train Sports Health Care*. 2012;4(3):103; 103-109; 109.

46. Mitchell UH, Johnson AW, Adamson B. Relationship between Functional Movement Screen Scores, Core Strength, Posture, and BMI in School Children in Moldova. *J Strength Cond Res Natl Strength Cond Assoc*. February 2015. doi:10.1519/JSC.0000000000000722.

47. Gribble PA, Brigle J, Pietrosimone BG, Pfile KR, Webster KA. Intrarater reliability of the functional movement screen. *J Strength Cond Res Natl Strength Cond Assoc*. 2013;27(4):978-981.

48. Minick KI, Kiesel KB, Burton L, Taylor A, Plisky P, Butler RJ. Interrater reliability of the functional movement screen. *J Strength Cond Res Natl Strength Cond Assoc*. 2010;24(2):479-486.

49. Gulgin H, Hoogenboom B. The functional movement screening (fms)^{TM}: an inter-rater reliability study between raters of varied experience. *Int J Sports Phys Ther*. 2014;9(1):14-20.

50. Smith CA, Chimera NJ, Wright NJ, Warren M. Interrater and Intrarater Reliability of the Functional Movement Screen: *J Strength Cond Res*. 2013;27(4):982-987. doi:10.1519/JSC.0b013e3182606df2.

51. Teyhen DS, Shaffer SW, Lorenson CL, et al. The Functional Movement Screen: a reliability study. *J Orthop Sports Phys Ther*. 2012;42(6):530-540.

52. Kraus K, Schütz E, Taylor WR, Doyscher R. Efficacy of the functional movement screen: a review. *J Strength Cond Res Natl Strength Cond Assoc*. 2014;28(12):3571-3584. doi:10.1519/JSC.0000000000000556.

53. Beardsley C, Contreras B. The Functional Movement Screen: A Review. *Strength Cond J Lippincott Williams Wilkins*. 2014;36(5):72-80.

54. Frost DM, Beach TA, Callaghan JP, McGill SM. FMS scores change with performers' knowledge of the grading criteria - Are general whole-body movement screens capturing "dysfunction"? *J Strength Cond Res Natl Strength Cond Assoc*. November 2013.

55. Frost DM, Beach TAC, Campbell TL, Callaghan JP, McGill SM. An appraisal of the Functional Movement Screen^{TM} grading criteria - Is the composite score sensitive to risky movement behavior? *Phys Ther Sport Off J Assoc Chart Physiother Sports Med*. February 2015. doi:10.1016/j.ptsp.2015.02.001.

56. Sprague PA, Monique Mokha G, Gatens DR, Rodriguez R. The relationship between glenohumeral joint total rotational range of motion and the functional movement screen^{TM} shoulder mobility test. *Int J Sports Phys Ther*. 2014;9(5):657-664.

57. Whiteside D, Deneweth JM, Pohorence MA, et al. Grading the Functional Movement Screen^{TM}: A Comparison of Manual (Real-Time) and Objective Methods. *J Strength Cond Res Natl Strength Cond Assoc*. August 2014. doi:10.1519/JSC.0000000000000654.

58. Chorba RS, Chorba DJ, Bouillon LE, Overmyer CA, Landis JA. Use of a functional movement screening tool to determine injury risk in female collegiate athletes. *North Am J Sports Phys Ther NAJSPT*. 2010;5(2):47-54.

59. O'Connor FG, Deuster PA, Davis J, Pappas CG, Knapik JJ. Functional movement screening: predicting injuries in officer candidates. *Med Sci Sports Exerc*. 2011;43(12):2224-2230.

60. Wiese BW, Boone JK, Mattacola CG, McKeon PO, Uhl TL. Determination of the Functional Movement Screen to Predict Musculoskeletal Injury in Intercollegiate Athletics. *Athl Train Sports Health Care J Pract Clin*. 2014;6(4):161-169.

61. Lockie RG, Schultz AB, Callaghan SJ, Jordan CA, Luczo TM, Jeffriess MD. A preliminary investigation into the relationship between functional movement screen scores and athletic physical performance in female team sport athletes. *Biol Sport*. 2015;32(1):41-51.

62. Lockie RG, Schultz AB, Jordan CA, Callaghan SJ, Jeffriess MD, Luczo TM. Can selected functional movement screen assessments be used to identify movement deficiencies that could affect multidirectional speed and jump performance? *J Strength Cond Res Natl Strength Cond Assoc*. 2015;29(1):195-205. doi:10.1519/JSC.0000000000000613.

63. Okada T, Huxel KC, Nesser TW. Relationship between core stability, functional movement, and performance. *J Strength Cond Res Natl Strength Cond Assoc*. 2011;25(1):252-261.

64. Chimera NJ, Smith CA, Warren M. Injury History, Sex, and Performance on the Functional Movement Screen and Y Balance Test. *J Athl Train Allen Press*. 2015;50(5):475-485.

65. Perry FT, Koehle MS. Normative data for the functional movement screen in middle-aged adults. *J Strength Cond Res Natl Strength Cond Assoc*. 2013;27(2):458-462.

66. Agresta C, Slobodinsky M, Tucker C. Functional Movement Screen ™ - Normative Values in Healthy Distance Runners. *Int J Sports Med*. 2014;35(14):1203-1207.

67. Fox D, O'Malley E, Blake C. Normative data for the Functional Movement Screen in male Gaelic field sports. *Phys Ther Sport Off J Assoc Chart Physiother Sports Med*. November 2013.

68. Parenteau-G E, Gaudreault N, Chambers S, et al. Functional movement screen test: A reliable screening test for young elite ice hockey players. *Phys Ther Sport Off J Assoc Chart Physiother Sports Med*. October 2013.

69. Abraham A, Sannasi R, Nair R. Normative values for the functional movement screentm in adolescent school aged children. *Int J Sports Phys Ther*. 2015;10(1):29-36.

70. Anderson BE, Neumann ML, Huxel Bliven KC. Functional movement screen differences between male and female secondary school athletes. *J Strength Cond Res Natl Strength Cond Assoc*. 2015;29(4):1098-1106. doi:10.1519/JSC.0000000000000733.

71. Wright MD, Portas MD, Evans VJ, Weston M. The effectiveness of 4 weeks of fundamental movement training on functional movement screen and physiological performance in physically

active children. *J Strength Cond Res Natl Strength Cond Assoc*. 2015;29(1):254-261. doi:10.1519/JSC.0000000000000602.

72. Bardenett SM, Micca JJ, DeNoyelles JT, Miller SD, Jenk DT, Brooks GS. Functional movement screen normative values and validity in high school athletes: can the FMS^{TM} be used as a predictor of injury? *Int J Sports Phys Ther*. 2015;10(3):303-308.

73. Frohm A, Heijne A, Kowalski J, Svensson P, Myklebust G. A nine-test screening battery for athletes: a reliability study. *Scand J Med Sci Sports*. 2012;22(3):306-315. doi:10.1111/j.1600-0838.2010.01267.x.

74. Tarara DT, Hegedus EJ, Taylor JB. Real-time test-retest and interrater reliability of select physical performance measures in physically active college-aged students. *Int J Sports Phys Ther*. 2014;9(7):874-887.

75. Comerford MJ. Screening to identify injury and performance risk: movement control testing – the missing piece of the puzzle. *SportEX Med*. 2006;(29):21-26.

76. Mischiati CR, Comerford M, Gosford E, et al. Intra and inter-rater reliability of screening for movement impairments: movement control tests from the foundation matrix. *J Sports Sci Med*. 2015;14(2):427-440.

77. Olds T, Daniell N, Petkov J, David Stewart A. Somatotyping using 3D anthropometry: a cluster analysis. *J Sports Sci*. 2013;31(9):936-944.

78. Wilmore JH. Validation of the first and second components of the Heath-Carter modified somatotype method. *Am J Phys Anthropol*. 1970;32(3):369-372. doi:10.1002/ajpa.1330320306.

79. Carter JE. The somatotypes of athletes--a review. *Hum Biol*. 1970;42(4):535-569.

80. Martín-Matillas M, Valadés D, Hernández-Hernández E, et al. Anthropometric, body composition and somatotype characteristics of elite female volleyball players from the highest Spanish league. *J Sports Sci*. 2014;32(2):137-148.

81. Aerenhouts D, Delecluse C, Hagman F, et al. Comparison of anthropometric characteristics and sprint start performance between elite adolescent and adult sprint athletes. *Eur J Sport Sci*. 2012;12(1):9-15.

82. Barlow MJ, Findlay M, Gresty K, Cooke C. Anthropometric variables and their relationship to performance and ability in male surfers. *Eur J Sport Sci*. 2014;14:S171-S177.

83. Dewit O, Fuller NJ, Fewtrell MS, Elia M, Wells JC. Whole body air displacement plethysmography compared with hydrodensitometry for body composition analysis. *Arch Dis Child*. 2000;82(2):159-164.

84. Toombs RJ, Ducher G, Shepherd JA, De Souza MJ. The impact of recent technological advances on the trueness and precision of DXA to assess body composition. *Obes Silver Spring Md*. 2012;20(1):30-39. doi:10.1038/oby.2011.211.

Tables

Table 1. Descriptive Data of Sample Population	
Age (yrs)	20.48±1.44
Height (cm)	170.46 ± 10.26
Weight (kg)	67.22 ± 16.06
Endomorph Rating	3.86 ± 1.65
Mesomorph Rating	4.59 ± 1.54
Ectomorph Rating	2.34 ± 1.28

Table 2. Number of Participants in each Somatotype Category	
Endomorph	16
Mesomorph	33
Ectomorph	8
Central	24

Table 3. Mean Composite FMS Score between the Sexes

Sex	Mean Composite Score	95% Confidence Interval
Male	17.65 ± 1.14	17.34-17.97
Female	17.55 ± 1.12	17.13 - 17.98

Table 4. Mean Composite FMS Score by Physical Activity Level

Hours of Physical Activity per Week	Mean Composite Score	95% Confidence Interval
0 to 4	17.39 ± 0.98	16.90-17.88
5 to 8	17.70 ± 1.02	17.34 - 18.06
9 to 12	17.58 ± 1.46	16.87 - 18.29
>12	17.82 ± 1.08	17.09 - 18.54

Figures

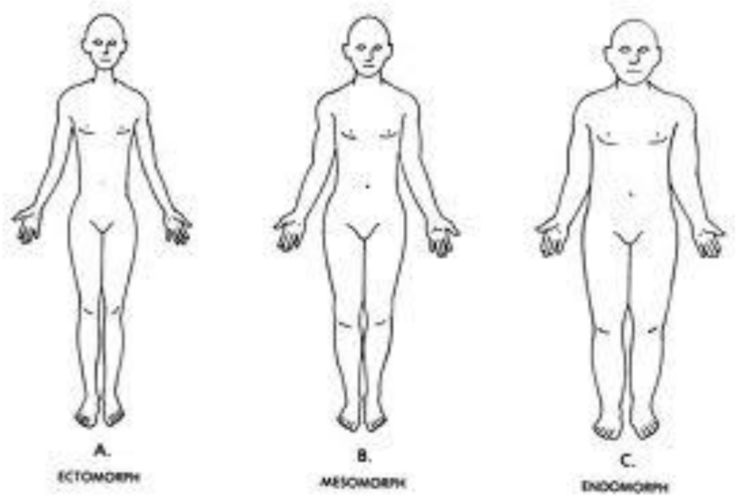


Figure 1. Somatotype Categories. This image shows a physical representation of each somatotype category.

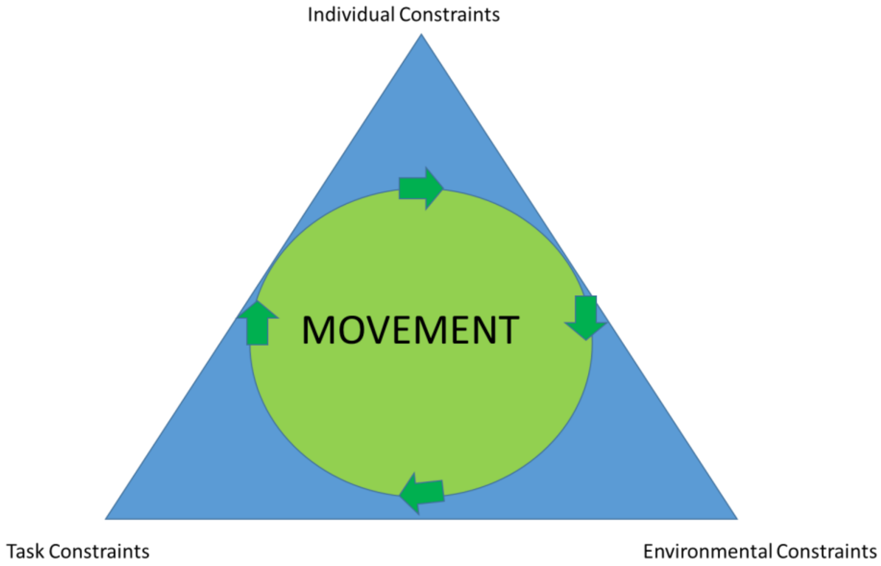


Figure 2. Newell's Model of Movement Constraints. Image adapted from Motor Control, Learning, and Development.[29] Looking at this figure it is clear that individual constraints such as physique play an important role in the development of movement.

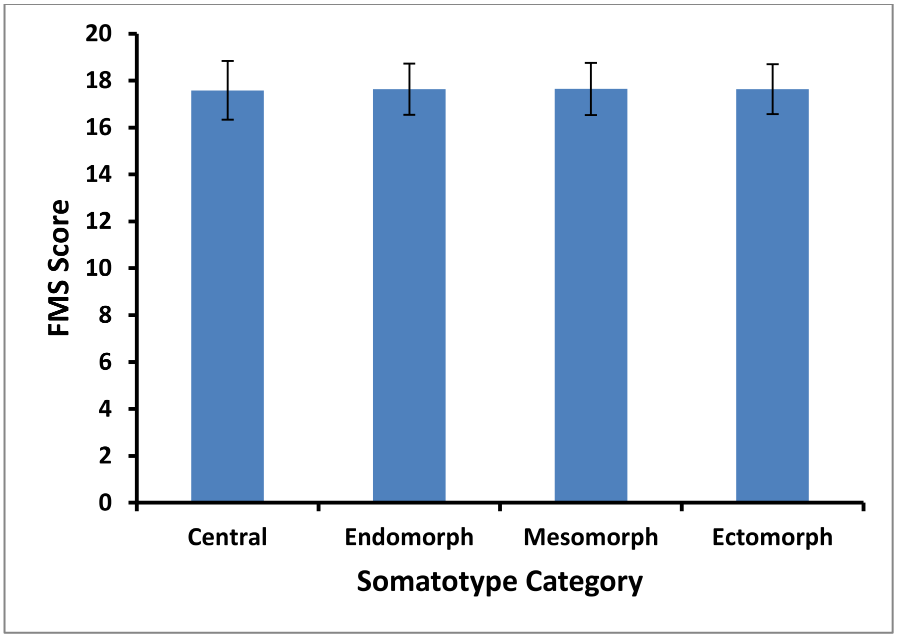


Figure 3. Mean composite FMS score by somatotype category. Looking at this graph it is clear that there is very little variance between the somatotype categories. The mean composite scores as well as the standard deviation are essentially identical.

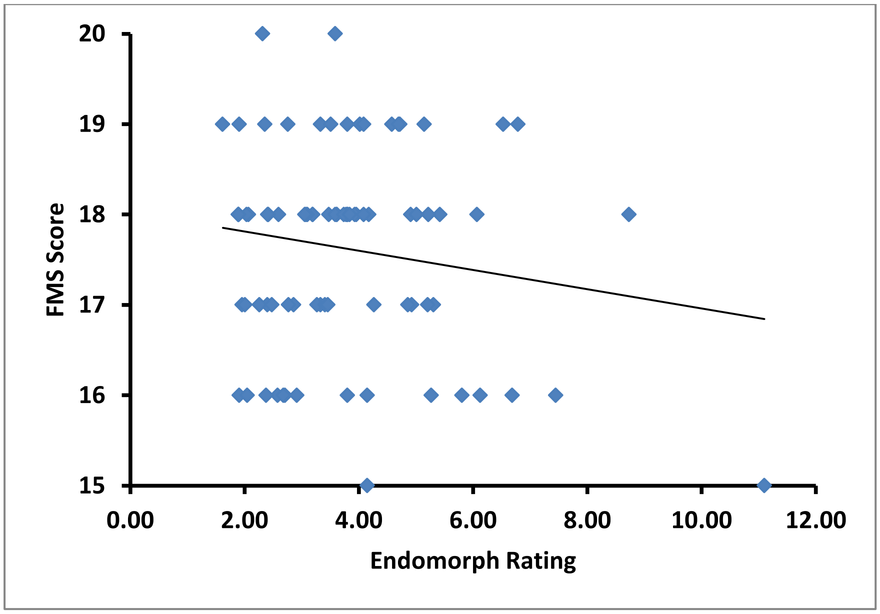


Figure 4. Correlation between endomorphy rating and composite FMS score. (r=-0.15, p=0.16). Looking at this scatter plot graph it is clear there was no association between composite FMS score and endomorph rating found in the sample.

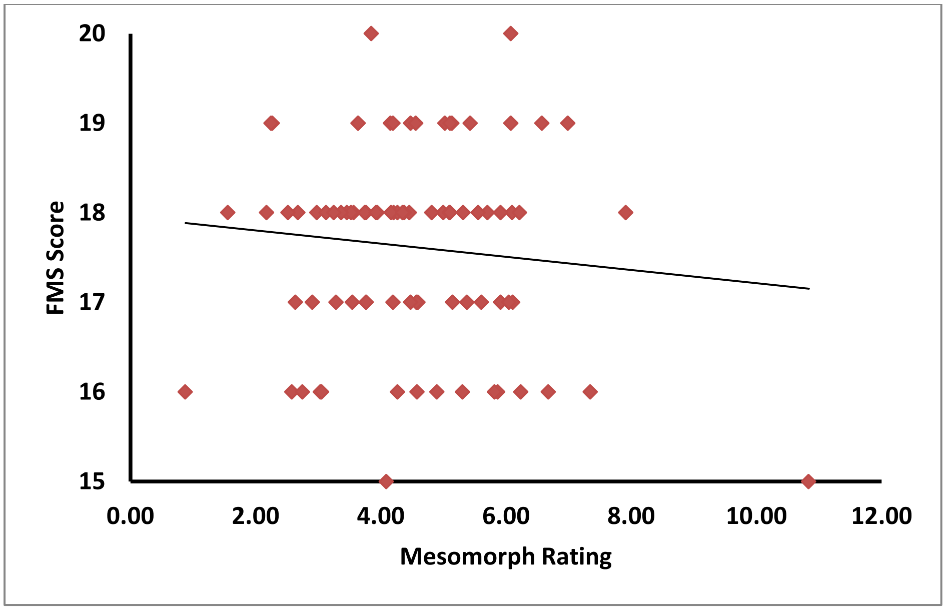


Figure 5. Correlation between mesomorphy rating and composite FMS score. (r=-0.10, p=0.37) Looking at this scatter plot graph it is clear there was no association between composite FMS score and mesomorph rating found in the sample.

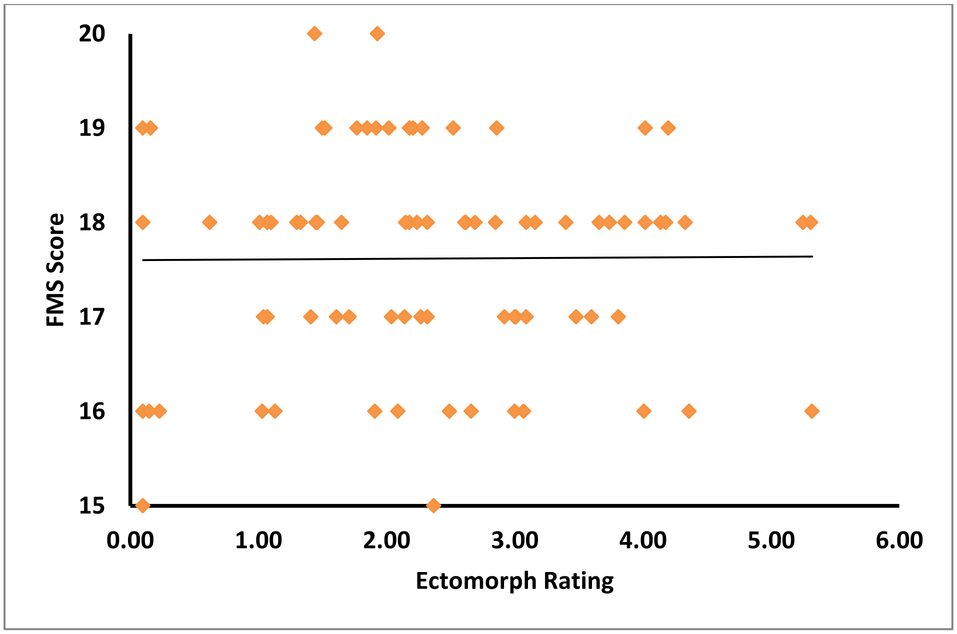


Figure 6. Correlation between ectomorphy rating and composite FMS score. (r=0.01, p=0.94) Looking at this scatter plot graph it is clear there was no association between composite FMS score and ectomorph rating found in the sample.

Extended Review of Literature

The Functional Movement Screen™ (FMS) tool was originally created to serve as an assessment of the quality of functional movement in athletic and active populations. [13] The purpose of this tool was to establish an evaluation standard that would assess movement patterns prior to participation in athletic and exercise activities. This screening instrument is designed to identify weaknesses or compensations during movement that are thought to be dysfunctional. Once identified, these weaknesses and compensations can, in theory, be addressed and possibly corrected. This may improve the efficiency of an individual's movement and reduce risk of injury. The creators of the FMS believe that this tool will be specifically useful in making return to sport decisions, in injury prevention, and in performance predictability [23], but should be used only as part of a comprehensive assessment [23]. Therefore, the creators are not advocating for the FMS to be used as a standalone evaluation. This is an important consideration to keep in mind when reviewing the current literature on the FMS. Since the creation of the FMS, there has been a considerable amount of research evaluating the reliability and validity of the tool.

Reliability of The Functional Movement Screen

In the past decade, there has been a considerable amount of research investigating the reliability of the FMS. The majority of this research has focused on the inter-rater and intra-rater reliability when scoring the FMS [30–32,47–51]. Overall, the FMS appears to have moderate to excellent inter-rater and intra-rater reliability. However, there is less agreement regarding the amount of formal training and clinical experience that is necessary for a rater to be consider reliable. Additionally, some studies have investigated the reliability of raters using real-time or live action scoring versus scoring from a pre-recorded video of subjects performing the FMS. [31,32,47–49] As real-time assessment and videotaped assessments differ in the number of times a rater is able to observe each movement, these approaches should be evaluated independently of each other in regards to reliability.

In an assessment of intra-rater reliability, Gribble et al. compared raters with different levels of clinical experience and experience with FMS, to determine intra-rater reliability of videotaped assessment [47]. The researchers recruited three individuals to be videotaped while performing the FMS test. Thirty-eight raters then watched the videos of the three individuals performing the FMS in a randomized order and assigned a score. One week later the raters watched the videos for a second time and assigned a score. The raters were divided into three groups based on clinical experience and experience with FMS: athletic trainers with at least 6 months of experience working with FMS, athletic trainers with no experience working with FMS, and athletic training students with no experience working with FMS. The interclass correlation coefficients (ICC) between sessions were ICC = 0.946, ICC = 0.758, and ICC = 0.372 respectively. The authors concluded that overall intra-rater reliability appeared to be strong and that it appeared to be stronger in individuals with clinical experience and experience using the FMS [47]. This study suggests that experience with FMS testing is important to the reliability of the instrument.

A similar study done by Shultz et al. found that inter-rater reliability was poor between raters with different levels of experience [32]. In this study, six raters of different experience levels evaluated 39 National Collegiate Athletic Association Division IA varsity athletes (21 female, 18 male) performing the FMS test by assessing the video tape recordings. One rater was responsible for evaluating all the athletes in live time as well as from video tape. The remaining five raters only evaluated the athlete's performance from videotape. The inter-rater reliability between the six raters was found to be poor ($K\alpha = 0.38$). For the one rater evaluating the live time performances and video tapes of the performance the test-retest reliability was determined to be good (ICC= 0.6) and the reliability between live and video sessions was determined to be excellent (ICC = 0.92). The authors concluded that the FMS is reliable tool when used with one rater. The authors suggested that due to the poor inter-rater reliability that the FMS may not be an appropriate test for detecting dysfunctional movement patterns that place an athlete at greater risk for injury [32]. This study brings into question whether the amount of experience really affects inter-rater reliability, as the inter-rater reliability was reported to be the lowest between the two most experienced raters. In order to understand the implications of these findings more must be known about the reliability of novice raters and the criteria for being a novice rater.

A research study done by Minick et al looked at the reliability of the FMS comparing expert and novice raters using videotaped assessment [48]. There were two expert raters and two novice raters. The expert raters each had been instrumental to the development of the FMS and had more than ten years of experience. The novice raters completed a standardized introductory course and had less than one year of experience. The raters assessed videos of thirty-nine healthy college students completing the FMS. Instead of looking at reliability by overall score values, this study examined reliability of each individual test component. It was determined that novice raters showed excellent reliability on 6 out of the 17 components (κ= 0.8-1.0), substantial reliability on 8 of the 17 components (κ= 0.65-0.77), and moderate reliability on 3 out of the 17 components (κ= 0.53-0.54). It was determined that expert raters showed excellent reliability on 4 out of the 17 components (κ= 0.84-0.95), substantial reliability on 9 of the 17 components (κ= 0.60-0.78), and moderate reliability on 4 out of the 17 components (κ= 0.40-0.59). In comparing novice and expert raters it was determined that the inter-rater reliability was excellent for 14 of the 17 components, and substantial for 3 of the 17 components. From this the authors concluded that with proper training the FMS is a reliable measure. This study is unique in that the expert raters were involved in the collaborative effort of creating the FMS. For this reason the expert raters in this study have more experience than the expert raters in similar studies.

Another study comparing experienced and novice raters, was a research study performed by Gulgin and Hoogenboom [49]. In this study, three novice raters and one expert rater scored videos of twenty college-aged students performing the FMS. The three novice raters were third year physical therapy students and were each recently certified in FMS. The expert rater had formal training before FMS certification existed and had 3 years of experience using it regularly. The raters assessed the movements by watching video recordings, but were required to watch it at normal speed to replicate real-time scoring. The percent agreement was found to be excellent (100%) for six of the twelve movements, moderate (66%) for three of the twelve movements, and poor for three of the twelve movements. Using a one-way ANOVA it was determined that there were no significant differences in mean overall score between raters (p=0.14). Also it was determined that there was good to excellent rater reliability in regards to mean overall score (ICC= 0.88). From these results it would appear that raters with little experience but formal training and certification are reliable raters.

In contrast, a research study performed by Jade Elias [31] suggests that no formal training is necessary for a rater to be reliable in scoring the FMS. In this study, twenty Level 2(4-8 years of clinical experience) and Level 3 (8-12 years of clinical experience) physiotherapists served as raters, scoring five elite athletes on six of the seven functional movement components. Athletes were assessed from video-tape from three different views. The raters were sent the videos of each athlete along with grading criteria and were allowed to watch the videotaped sessions as many times as necessary to determine a score. The overall mean score for each athlete was determined for Level 2 and for Level 3 physiotherapists. These scores were compared between the two groups of physiotherapist and it was determined there was no significant difference in overall score between the two groups (p=0.52). It was also determined that the overall score had excellent reliability between raters (ICC= 0.906). This would suggest that clinical experience does not affect a clinician's reliability in scoring. One limitation to this study is that it lacked a comparison of the untrained raters to expert raters.

Overall it appears that inter-rater and intra-rater reliability for videotaped assessment of the FMS appears to be good. There is some disagreement about the requirements for a reliable rater. However, the majority of the evidence for reliability of scoring the FMS using videotaped assessment appears to suggest that formal training is beneficial for a rater and that proper training increases rater reliability. [31,32,47–49] One study supports the notion that reliability was similar between videotaped assessment and real-time assessment. This is an important implication, and for this reason further investigation between videotaped assessment and real-time assessment should take place.

In contrast to the previous studies, a study done by Smith et al. [50] examining inter-rater reliability and intra-rater reliability during real time testing appears to suggest that experience with FMS testing is not important for good intra-rater reliability. In this study, four raters, with different degrees of clinical experience and experience with FMS testing, examined twenty subjects (22-44 years old) performing the FMS test. Two of the raters had no previous experience with the FMS. The four raters simultaneously examined each of the participants using real-time administration. The inter-rater reliability of the four raters was determined to be strong in both sessions (session 1 ICC = 0.89; session 2 ICC = 0.87). The intra-rater reliability of each of the four raters was also determined to be strong with interclass correlation coefficients of 0.90, 0.81, 0.91, and 0.88 respectively. Interestingly the rater with the lowest intra-rater reliability was the rater with the most experience as well as FMS certification. The authors speculated that this may be because the rater with the FMS certification may have been more sensitive to subtle changes in movement between sessions. It is also likely that this rater was better able to identify errors in movement when compared to the other raters that had no previous experience with the FMS. Nonetheless it was concluded that overall the intra-rater and inter-rater reliability for the FMS test was good when scored by raters of various levels of experience with the FMS.

One study performed by Teyhen et al. looked at the reliability of real-time FMS scoring using only novice raters [51]. The eight raters were first year physical therapy students that had received twenty hours of training with the FMS. The participants of this study were 64 active duty service members who completed two FMS tests. Four of the raters were randomly selected to assess a group of the participants for both FMS tests. The other four were paired with one of the first four raters to assess a group of participants on the second day. It was determined that both the inter-rater reliability and intra-rater reliability was moderate to good (ICC=0.76 and ICC=0.74 respectively). The authors concluded that the FMS had adequate reliability in the assessment of active service members by novice raters. This study would suggest that the reliability of the FMS is moderate to good even when conducted with less experienced raters. It should be noted that novice raters in this study received more education and training on the FMS than novice raters in similar studies. This suggests that twenty hours of training is sufficient for reliable real-time grading of the FMS.

Onate et al performed a study examining the intra-rater and inter-rater reliability of real-time scoring of both overall FMS score and individual components [30]. This study involved an expert rater for both the intra-rater and inter-rater reliability portions, and a novice rater for the inter-rater reliability portion. The expert rater had four years of experience as a Certified Athletic Trainer and a Certified Strength and Conditioning Specialist (CSCS), and was FMS certified. The novice rater had three years of experienced as a CSCS, but no prior experience or training with the FMS. The subjects in this study consisted of 19 physically active adults recruited from a local university. The intra-rater or intersession reliability was determined to be excellent for overall score (ICC = 0.92) and poor to good for individual components ($\kappa = 0.16$ - 0.84). The inter-rater reliability was determined to be excellent for overall score (ICC = 0.98) and fair to excellent for individual components ($\kappa = 0.33$ - 1.00). The researchers concluded that overall FMS score and six out of the seven movement patterns appeared to be reliable between sessions and between raters. This study is interesting in that it proposed that as a novice rater, reading over the FMS instruction manual once was sufficient to be a reliable rater. In contrast, Teyhen et al. suggested more training is necessary. It is significant that the novice rater in this study, was not a clinician but a Certified Strength and Conditioning Specialist. This study seems to suggest that raters certified in strength and conditioning along with clinicians are reliable raters in scoring the FMS. This is important in considering the reliability of use of the FMS by coaches, trainers, and strength and conditioning experts that work with athletic and active populations. No studies have been performed on raters lacking experience in working with athletic populations. However it is likely that a background in athletics and movement analysis is necessary for a rater to be reliable.

The literature appears to support the notion that the FMS tool is a reliable screening tool between raters when real-time scoring is used. However, it is still unclear what qualifies an individual as a reliable rater, or how much training is necessary for that individual to be reliable in rating. Several studies using videotaped assessment suggest that with proper training a rater is deemed reliable [50,51], while other studies using real-time scoring suggested novice raters with little to no training were reliable raters [30]. There appears to be a difference in the requirements of a reliable rater between these two scoring methods. For this reason more research should be done to compare the reliability of real-time scoring to the reliability of scoring from video recordings. This is important as the FMS tool is intended to be used as a real-time tool. However, if real-time scoring is not considered reliable when compared to scoring from video recordings, this may suggest that dysfunctions in movement or compensations are being missed in real-time scoring. This would be concerning as the foremost aim of the FMS is to identify and address these compensations.

Reliability of New Grading Criteria

The original 21-point grading scale for FMS is a three point grading scale in which participants can score a three, two, one, or zero on each movement pattern (7 total) for a possible sum of 21 points. Participants scoring a three exhibit no compensations in their movement. Participants scoring a two exhibit one or more compensations or dysfunctions in movement, but are able to complete the movement pattern. Participants scoring a one exhibit one or more compensations or dysfunctions in movement and are not able to complete the movement pattern. A score of zero is reserved for those exhibiting pain during the movement pattern [17]. Researchers have argued that this grading scale is not sensitive enough to distinguish between a participant with several compensations during a movement pattern and a participant with fewer compensations during a movement pattern. For this reason Hickey et al. established a new 100 point grading scale focused on precision [44]. One study performed by Butler et al. looked at the reliability of raters using Hickey's 100-point grading scale rather than the original 21-point grading scale [45]. This new grading scale was created to address concerns about the precision of the 21-point grading scale and ideally improve the predictive value of the FMS tool. To examine the reliability of this new grading scale, two experienced raters watched the video recordings of 39 middle school aged children performing the FMS and rated each performer using the 100-point scale. Raters were able to review the videotape as many times as necessary and were blinded to one another's scoring. The result was that each individual movement component and overall score were determined to have excellent reliability (ICC= 0.91-1.0). There were several limitations, to this study including choice of subject population, lack of real-time scoring, and lack of comparison to the original 21-point scale. Overall the authors concluded that the 100-point scale was reliable and encouraged its use among fellow researchers. However, there appears to be a deficit in further investigation of this new grading scale in the literature.

Validity of the Functional Movement Screen

Validity of the FMS has gained a considerable amount of attention from the research community. The creators of the FMS suggest that the tool is able to detect dysfunctional movement and that it may be used in making return to sport decisions, for predicting injury, and performance predictability. When assessing the validity of these claims in the literature, there is a considerable amount of disagreement. An expert review by Kraus et al. concluded that there was only limited evidence to support the validity of the FMS [52]. Interestingly though, the authors also suggested that as part of a battery of screening examinations it may be a "meaningful start in musculoskeletal screening" in lower level athletic populations [52]. In higher level athletic populations, the authors advocate for more "sophisticated methods" [52]. An expert review article written by Beardsley and Contreras suggests that while the FMS has some degree of predictability for injuries, that overall there is a lack of validity of the FMS [53]. It should be acknowledged that these are expert reviews and therefore, have the potential for bias. In order to have a clearer understanding of the validity of the FMS tool, the primary literature must be consulted. The literature has concentrated on the validity of the FMS in three main areas: the construct validity of the FMS to detect dysfunctional movement patterns, the validity of the FMS to predict injury, and the validity of the FMS to assess athletic performance.

Different approaches were taken to understand what the FMS is truly measuring. In one study, by Kazman et al., the researchers investigated the internal consistency and factor structure of the FMS [42]. Given that the seven movement pattern scores are summed to equate a single overall score, this overall score has been assumed to be a uni-dimensional construct. This uni-dimensional construct is thought to be a measure of movement quality as a whole. The authors assessed this assumption by computing Cronbach's alpha and conducting an exploratory analysis on the FMS scores of 934 Marine officer candidates. The results of this study showed that the FMS is not the uni-dimensional construct it was assumed to be, and that there was poor internal consistency for the seven tasks in the FMS (Cronbach's alpha = 0.39). The authors of this study have suggested that each of the seven movement patterns may be a separate construct. However if each movement is a separate construct, then the meaning of the overall FMS score becomes unclear.

A similar study performed by Li et al. investigated the internal consistency and factor structure of the FMS using elite athletes in China [43]. Likewise, this study found the internal consistency of the seven FMS movement patterns to be low and through factor analysis determined the seven movement patterns were not indicative of a single factor. This finding may suggest that more attention should be paid to individual movement pattern scores rather than overall FMS score. Interestingly, this finding is consistent with the notion that the FMS should not be used as a standalone evaluation but as part of a more complete screen. This was not a completely unexpected result, as the FMS was created to assess the quality of individual movement patterns, providing information on compensations and errors. However, the finding that the FMS tool is likely not a uni-dimensional construct, still leaves the question unanswered concerning the meaning and appropriate use of the overall FMS score. It appears that more research is necessary to draw conclusions on this topic.

A study performed by Frost et al took a very different approach to examining the validity of the FMS. These researchers examined the role that the participants' knowledge of the grading criteria played on the overall FMS score [54]. Twenty-one firefighters completed the FMS once with no knowledge of the grading criteria and again after receiving knowledge of the grading criteria. The result was that overall FMS scores significantly improved with knowledge of the grading criteria ($p <0.001$). The authors interpreted this result to mean that "it would be inappropriate to assume that someone's movement patterns are a direct result of specific "dysfunction" or "impairment" that could be rectified via "corrective" exercise"[54]. Since this is the basis of the FMS, the authors' suggestion directly challenges the validity of the assessment. One major limitation of this study was that there was no control group. Having a control group that had not received information about specific grading criteria but did completed the FMS for a second time with little or no change in score, would have allowed the authors of this study to make a stronger argument against the validity of the FMS. However, this study does suggest that there is a learning component to movement patterns that should be considered. One conclusion that can be drawn from this study is that a participant's knowledge of the grading criteria appears to affect their overall score. This is crucial for clinicians to keep in mind when administering the FMS screen.

Interestingly, in a previous study by Frost et al., the researchers examined participants' frontal plane knee and spine motion in comparison to overall FMS score [55]. The researchers examined a group of high scoring participants, individuals scoring a 14 or above, and a group of low scoring participants, scoring a 13 or below. It was determined that on average participants in the high scoring group had less spine and frontal plane motion during the movement patterns when compared to their matched lower scoring counterparts, . This would appear to suggest a higher quality of movement was observed in the higher scoring group of participants. Assuming this finding is legitimate, then this would imply that the FMS may be a valid assessment. However, the authors concluded that due to substantial variability of motion in both groups "that current FMS scoring criteria may be insensitive to potentially risky movement behavior"[55], questioning the validity of the assessment's ability to predict injury.

In a different approach, one study by Sprague et al. examined the relationship between asymmetries in glenohumeral joint range of motion (ROM) and asymmetries in score on the shoulder mobility component of the FMS, in overhead athletes [56]. The researchers hypothesized that the FMS would not be sensitive enough to detect an asymmetry in glenohumeral joint ROM. This results of this study proved the hypothesis to be correct. However it is important to consider that completing the shoulder mobility test of the FMS requires more than just adequate glenohumeral joint ROM, but also adequate scapulothoracic rhythm and ROM, and adequate flexibility as well. The shoulder mobility component of the FMS is meant to detect dysfunction in gross shoulder mobility and likely is not specific enough to detect all clinically significant asymmetries in ROM in overhead athletes. The authors of this study concluded that while the FMS is capable of providing information about a participant's gross shoulder mobility it does not appear to be related to passive rotational ROM of the glenohumeral joint. This appears to neither confirm nor refute the validity of the FMS, but underlines the importance of using the FMS as part of a battery of examinations prior to physical activity participation.

The most objective study examining the validity of the FMS in detecting dysfunction in movement was a study performed by Whiteside et al. that compared manual scoring of the FMS by a certified expert with scoring based on an inertia-based motion (IMU) capture system [57]. The aim of the study was to compare manual scoring of the seven FMS components to the IMU system with preset kinematic thresholds that were determined based on the grading criteria. The study found poor to fair reliability between six of the seven test components. The only test component that was determined to have moderate to good reliability was the hurdle step. Assuming the IMU system is objective and accurate and the grading criteria of the FMS allow the IMU system to detect dysfunctional movement, then the results of this study appear to challenge the validity of manual real-time scoring of the FMS.

Overall there does not appear to be enough evidence to validate the FMS as a measure of dysfunctional movement. While it seems that the FMS meets face validity in that it appears to be widely accepted by movement experts, the present research appears to suggest that the FMS is not the one-dimensional construct it has been assumed to be. For this reason, future research should continue to examine the construct validity of the individual functional movement patterns rather than the composite score and the screen as a whole.

Aside from construct validity, researchers have also tried to validate the various claims of the creators of the FMS, such as the screen's ability to predict injury. This is crucial in that the ability of the FMS to be able to predict injury suggests that the screen is in fact identifying dysfunctional movement patterns that place individuals at risk for injury. The first group of researchers to examine the relationship between FMS score and risk of injury was Kiesel et al.[38]. It is important to note that Kiesel was part of the collaborative effort of creating the FMS. The researchers performed a preliminary study with professional football players, having the athletes participate in the FMS as a part of pre-participation screening and then comparing scores to injuries that occurred during the season. Using a receiver-operator characteristic (ROC) curve for overall FMS score and injury status, it was determined that individuals scoring a 14 or below were at greatest risk for injury. This was the point that was determined to maximize the specificity and sensitivity of the FMS to predict injury. In response to the research study performed by Kiesel, Chorba et al. performed a follow-up study examining the ability of the FMS to predict injury in female athletes [58]. The researchers used a cutoff point of 14 based on the findings of Kiesel et al.. Chorba et al too, determined that individuals scoring below a 14 on the FMS were at greater risk for injury (OR= 3.85, sensitivity = 0.579, specificity = 0.737).

Lisman et al. also examined the relationship between overall FMS score and risk of injury. This study involved 874 men enrolled in Marine Corps officer candidate training. [21] Participants completed physical fitness tests, the FMS, and a questionnaire for self-reported physical fitness and prior injury history. Injury data was then collected throughout training. It was determined that three mile run time and overall FMS score below 14 were both risk factors for injury. In addition, combining slower run time and low FMS score increased the predictive value for injury. This appears to suggest that the FMS may be useful in injury prediction. This is significant in that if injuries are able to be predicted, then it is possible that with corrective exercise these injuries might be avoided. A very similar research study using Marine Officer candidates performed by O'Connor et al. found that there was no point on a ROC curve that maximized specificity and sensitivity. [59] This is in contradiction to Kiesel et al. that found that a score of 14 maximized the sensitivity and specificity of the FMS in injury prediction. This study was in agreement with Lisman et al., in that an overall FMS score below 14 displayed an increased odds ratio for injury and that participants scoring low on physical fitness were at greater risk for injury. However unlike Lisman et al. combining FMS scores and physical fitness scores did not improve injury prediction. A unique result from this study was that individuals scoring above an 18 on the FMS also were at greater risk for injury. This is important in that it seems to contradict the entire premise of the FMS in that dysfunctional movement can be identified and corrected to reduce risk of injury. If this premise were accurate then high scoring participants should be at lower risk of injury.

Another study that identified a FMS score of 14 as the point where sensitivity and specificity for injury were maximized, was one performed by Butler et. al [40]. This study assessed the ability of the FMS and physical fitness tests to predict injuries in fire-fighter trainees. The only individual test components that were identified as being predictive of injury were the sit and reach test (OR= 1.24), FMS deep squat (OR=1.21), and FMS push-up (OR= 1.30). The ROC curve created in this study found that sensitivity (0.83) and specificity (0.62) were maximized at an overall FMS score of 14. However, a similar study performed on active fire-fighters by Peate et al. found that individuals with previous injury were more likely to achieve an overall score below 16 on the FMS. The odds of scoring below a 16 on the FMS were 1.68 times more likely for individuals with a history of injury. It appears there are discrepancies in determining a cutoff point in composite FMS score that detects risk of injury.

In contrast to previous studies, where a score of 14 was found to be the cutoff point, or no cut off point was found, Letafaker et al. identified a FMS score of 17 as the cutoff point [39]. This study involved male and female competitive and recreational athletes for Iran. Using a ROC curve the researchers found that the sensitivity (0.645) and specificity (0.780) were greatest at an overall FMS score of 17. The odds ratio at this point was determined to be 4.7. As the overall mean score for this population was found to be 16.7 ± 1.8, this finding is concerning. A research study performed by Wiese et al. also identified a FMS score of 17 to be the cut off point for risk of injury [60]. In this study performed on Division I College Football players, it was determined through ROC analysis that sensitivity (0.4) and specificity (0.4) were maximized at a score of 17. However contrary to Letafaker, with a lower odds ratio of 1.425, the researchers concluded that there was little evidence that the FMS was useful in prediction of injury.

Presently, there appears to be moderate evidence to support the use of FMS in prediction of injuries. The disagreement in the actual cutoff point used to determine the risk of injury may be explained by different participant populations. However, based on the current literature the cutoff point for athletic populations is most likely between a score of 14 and 17 [21,38–40]. More research should be conducted to determine the sensitivity and specificity of the FMS to detect risk of injury in different athletic populations. Additionally researchers should evaluate whether specific movement patterns are more likely to predict injuries in different populations.

Researchers have also attempted to validate the claim that the FMS is capable of predicting athletic performance ability. One of the first research studies examining the whether an intervention program could change FMS score was performed by Kiesel et al [33]. The researchers developed individualized interventions for each participant, all of which were professional football players, based on initial performance of the FMS. Participants then completed the individualized training program and were re-evaluated at the conclusion of the training program using the FMS. Using chi-squared, it was determined that more participants were scoring higher than the injury threshold after the intervention as compared to before the intervention. The authors the study concluded that an individualized training program can improve FMS scores. This would appear to suggest that if the FMS is truly identifying dysfunctional movement, that an individualized training program may be helpful in correcting movement patterns. However, one major limitation of this study is the lack of a control group. Therefore it cannot be concluded that the difference in score after invention was due to the individualized training program intervention.

Bodden et al. performed a research study on semi-professional mixed martial arts athletes to determine if an eight-week training intervention would improve FMS score [34]. In contrast to Kiesel, Bodden et al. used a control group. The researchers created a corrective exercise program for the intervention group, while the control group was asked to refrain from changing training strategies for the duration of the study. It was found that there were significantly different scores between the intervention group and the control group at four weeks and at eight weeks of intervention. The intervention group was also found to have fewer participants score below 14 on the FMS, and overall less asymmetrical movement patterns were found. The researchers concluded that the corrective exercises appeared to improve FMS score in mixed martial arts athletes in as little as four weeks. One weakness of this study is that the FMS is the only measure of performance that was used to evaluate the outcome of the intervention program. This study suggests that corrective exercises may improve overall FMS score and decreases asymmetrical movement patterns, but fails to provide evidence that overall athletic performance has changed.

Frost et al. also performed a study that attempted to answer whether the FMS is a valid measure for change in performance [19]. This study included sixty firefighters that were evenly divided into three groups: 2 intervention groups, and a control group. The intervention groups consisted of different training programs, one focusing on exercises for injury prevention and another focusing purely on physical fitness. The control group did not participate in a training program. FMS scores were recorded before and after the intervention programs. The researcher evaluated a recorded video of each participant using the original 3 point scale, the research standard 100 point scale, and a modified 100 point scale. From this it was determined that there was no significant difference in the overall FMS scores in any of the groups post-intervention for any of the grading scales. From this it would appear that the FMS is incapable of detecting changes in movement patterns , or that the interventions were unsuccessful at improving movement patterns.

Some research studies focused on comparing performance on the FMS to different established measures of athletic performance. A preliminary study performed by Lockie et al. investigated the relationship between FMS and athletic performance in nine female athletes [61]. The study compared FMS scores to several different performance tests. The researchers concluded that there were likely limitations in using the FMS to evaluate performance. A secondary study performed by Lockie et al. investigated the relationship between FMS score and performance looking specifically at the lower body screens and tests of multidirectional speed and jumping ability [62]. Some moderate correlations were found between individual FMS components and performance measures, but overall the researchers concluded the relationship between FMS and athletic performance in this population was minimal.

Similarly, Okada et al performed a research study using recreational athletes to determine if there was a relationship between core stability, functional movement, and performance [63]. Researchers found there were a few significant correlations between the core stability test scores and scores on performance measures. No significant correlations were found between core stability and FMS score. This is a surprising result as two of the FMS movement patterns that were tested are measures of core stability. Using multiple linear regression it was determined that 86% of the variability in performance scores could be accounted for by flexion and lateral flexion core stability endurance tests and the shoulder mobility component of the FMS which is an unlikely predictor of performance. This would appear to suggest that the FMS as a whole is not a good predictor of variability in performance.

Parchmann and McBride examined the relationship between FMS score and athletic performance in collegiate Division I golf players [20]. The researchers compared both composite FMS score and individual movement pattern scores to measures of performance such as sprint, jump, and agility tests. There were no significant correlations found. The researchers also compared a one repetition maximum strength test to these same measures of performance and found several significant correlations. This is expected as strength is general thought to be a measure of athletic performance. It is surprising that none of the FMS movement pattern scores were related to any of the measures of performance, as the FMS is thought to be predictive of athletic performance. This research study is in agreement with the previous studies in suggesting that the FMS may not be useful in measuring athletic performance.

In a research study performed by Clifton et al., the relationship between functional movement and static balance was measured before and after exercise [35]. The researchers hypothesized that there would be a relationship between static balance measures and FMS score. Additionally, the researchers hypothesized since exercise related fatigue has been shown to impact static balance ability, it is likely it will also affect FMS score. While individual components of the FMS including the hurdle step, inline lunge, and active straight leg raise showed moderate correlation with the static balance measures before exercise, the overall FMS score and other components did not. Additionally while static balance measures decreased with exercise, the overall FMS score and component scores remained the same. This is a surprising result as the FMS is thought to identify dysfunctions in stability as well as mobility. It is possible that since the FMS movement patterns require more dynamic stability in contrast to static stability, that this may explain the unchanged score after exercise. It is also possible that the order the testing was done, in which the FMS testing was after the static balance measures, allowed the participants to begin recovering from fatigue.

Similar to the research study performed by Clifton et al., is a research study performed by Hartigan et al [36]. This research study looked more specifically at the relationship between the Inline lunge movement pattern of the FMS, and balance, sprint time, and jumping abilities.

It was determined that the FMS did not have a significant correlation with any of these measures (r= -0.293-0.101). This is partially in contradiction to previous studies showing a significant correlation between the inline lunge and balance. This study is different however in that balance was measured during the movement pattern as opposed to separately. This study would appear to support the notion that the FMS may not be sensitive enough to detect deficiencies in balance, and is likely not useful to measure athletic performance.

Rather than using performance tests, Chapman et al. performed a research study on elite track athletes to determine if there were differences in longitudinal performance based on FMS score [37]. The researchers divided the athletes into a high scoring group, individuals scoring a 15 or above, and a low scoring group, individuals scoring below a 15. The researchers found that athletes in the high scoring group had greater positive performance changes than athletes in the lower scoring group. An interesting and unexpected result, was that this was true for the group of athletes as a whole and the subgroup of male athletes, but there was no difference in longitudinal performance change by FMS for female athletes. This brings to question the role sex plays in the ability of the FMS to predict athletic performance.

To determine what role sex and previous injury played on FMS score and Y- Balance Test score, Chimera et al. performed a research study on Division I male and female athletes [64]. In this study, participants self-reported injury history through a questionnaire and performed the FMS and Y-Balance test. Interestingly overall FMS score was the same between the sexes, however scoring on individual movement patterns was different, with females scoring lower on the two core related movement patterns. Also found was that previous hip, elbow, hand, and shoulder injuries were all shown to have an adverse effect on overall FMS score. It is very interesting that no relationship between previous lower body injury and overall FMS score was found.

There appears to be moderate evidence to support the notion that the FMS may not be suitable as a predictor or measure of athletic performance. While a few studies showed that FMS score increased with specific exercise intervention, these studies failed to show that athletic performance increased with the same specific exercise intervention. The majority of studies revealed that there appeared to be no relationship between athletic performance measures and performance on the FMS, or a very minimal relationship. From these results it is likely the FMS alone is not a good predictor of athletic performance, and should be used with caution and as part of a battery of performance tests, when evaluating an athlete's performance abilities.

Another current area of interest for many researchers is the normative values of the FMS when used on different populations. Upon being accepted as a reliable tool for general athletic populations, there has been a great deal of interest in looking at the use of the FMS with specific populations. Some populations that have been studied are military, Division I collegiate athletes, elite athletes, runners, and the general population. Researchers have also been interested in identifying factors that may explain variance in FMS score. Suggested factors potentially explaining the variance in score are age, gender, and body mass index (BMI).

Schneider et al. examined two hundred and nine physically active individuals between the ages of 18 and 40 to determine normative values for FMS composite score in healthy young individuals [28]. The researchers found that the mean composite score for participants as a whole was 15.7± 1.9. The researchers also calculated the mean composite score for male and female participants separately, finding the mean composite for males to be 15.6 ± 2.0 and females to be 15.8 ± 1.8. From this it appears there is no difference in composite scores between the sexes in this population. A very similar research study was performed by Perry and Koehle in which normative values of FMS composite score were determined for middle aged adults [65]. The participants were six hundred and twenty-two individuals between the ages of 21 and 82. The researchers did not report a mean composite score for the group as a whole, but reported mean composite scores for different age groups. Participants between the ages of 20-39 scored the highest with a mean composite score of 15.17 ± 2.44, while participants between the age of 60-64 scored the lowest with a mean composite score of 12.89 ± 3.23. Using multiple linear regression the researchers also determined that age, BMI, and physical activity level were all significant predictors of FMS composite score. Additionally, negative correlations were found between the factors of BMI and age with FMS composite score.

FMS was originally developed to be used in athletic populations. While the previous two studies developed normative values for general populations, technically the FMS was not created for this purpose. A research study performed by Engquist et al compared mean composite scores between Division I collegiate athletes to general college students that were the same age and attended the same university [27]. The researchers found there was no difference in mean composite score between the two groups. The mean composite score for student athletes was 14.2 ± 0.2, while the mean composite score for general students was 14.1 ± 0.2. Also, the only individual movement pattern student athletes scored significantly higher on was the deep squat. The results of this study seem to suggest that movement patterns are fairly similar between the general population and athletic populations.

Normative values for mean FMS composite score have been established for many specific athletic populations. One of these populations was active military service members, in which normative values were determined by a research study performed by Tehyen et al [29]. It was determined that the mean composite score for active military service members was 16.2 ± 2.2. Another active population that FMS normative values have been established for is distance runners. A study by Agresta et al. established normative values for FMS composite score for novice distance runners and expert distance runners, but excluded professional distance runners [66]. The mean FMS composite score for all distance runners in this study was 13.13 ± 1.8. This is a concerning result for this population, as the mean composite score is lower than the composite score that is thought to be predictive of injury. Interestingly, there was no difference in mean FMS composite score between novice and distance runners, runners with or without a history or injury, or male or female runners. The only significant differences found for male and female runners were mean scores on the deep squat, trunk stability push-up, and active straight leg raise movement patterns. Men scored higher on the deep squat and the trunk stability push-up while women scored higher on the active straight leg raise.

Another research study that determined normative values for an athletic population based on skill level was that of Fox et al [67]. In this study, normative values were established for male elite and sub-elite hurling and soccer players . The overall mean composite score for hurlers was found to be 15.51 ± 1.52 and the overall mean composite score for soccer players was found to be 15.67 ±1.35. There were no significant differences found between skill levels. Given the results of Enquist et al. that there is no difference in score between athletic and general populations, this is not a surprising result. What is a surprising result is that there was no significant relationship found between age or BMI and composite FMS score in this population. As this is in contradiction to Perry et al, more research should be performed to evaluate the role BMI and age have on composite FMS score.

Using the Functional Movement Screen in Adolescent Populations

The FMS was not originally created to be used in adolescent populations, however there has been a significant amount of interest in whether the FMS is an appropriate tool to be used in adolescent populations. The issue is that when it comes to motor control and movement patterns, adolescents should not be thought of as smaller versions of adults. Adolescents are still developing mature movement patterns into adulthood. For this reason it is unknown whether the FMS is an appropriate tool to measure dysfunctional movement in adolescents. Researcher have attempted to determine this by establishing normative values, examining injury prediction, and examining factors that influence score.

A recent study by Parenteau et al. examined the reliability of the FMS in adolescent elite hockey players between the age of 13-16 years old [68]. Data collection was completed in three different sessions in order to assess inter-rater reliability and intra-rater reliability of certified raters. In the first session two raters simultaneously assessed all twenty-eight participants in real-time. Videotape recordings were taken during this session to be used in sessions two and three. In sessions two and three, two raters assessed videotape footage with six weeks between viewing sessions. The inter-rater reliability for total FMS score was determined to be excellent (ICC = 0.96). The intra-rater reliability for total FMS was also determined to be excellent (ICC = 0.96). Evaluation of the individual test components showed at least good agreement between raters for five of the seven test components. The authors of this study concluded that the FMS is a reliable test in this athletic population. This appears to be consistent with previous results. Additionally this study suggests reliable use with additional populations beyond the original scope intended by the creators of the FMS.

One of the first groups of researchers to establish normative values in an adolescent population was Abraham, Sannasi, and Nair [69]. These researchers screened over one thousand students between the ages of 10 and 17 years old. The researchers found that the mean composite score for this population was 14.59 ± 2.48. An unanticipated result from this study was that female adolescents score significantly lower on composite score, the inline lunge, the trunk stability, and the rotary stability components as compared to male adolescents. A researcher study performed by Anderson, Neumann, and Huxel Bliven on adolescents between the ages of 13 and 18 years old, also found mean composite score, mean inline lunge score, and mean trunk stability score to be significantly lower for female adolescents in comparison to male adolescents [70]. These studies appear to suggest that there may be a difference in FMS score between the sexes in adolescent populations.

In contrast to the previous studies, a research study performed by Duncan, Stanley, and Wright found that in children between the ages of 7 and 10 years old, that there was no difference in mean composite FMS score between the sexes [26]. However, these researchers found a moderate negative correlation between body mass index (BMI) and composite FMS score (r= -0.57). A previous study by Duncan and Stanley found an even stronger negative correlation between body mass index (BMI) and composite FMS score (r= -0.806) in 10 to 11 year old children [25]. In this same study the researchers found a weak but statistically significant positive correlation between physical activity and composite FMS score (r= 0.301). It was determined that BMI and physical activity accounted for 60.2% of the variance in composite score.

In contrast to these previous studies, a research study performed by Mitchell, Johnson, and Adamson found that BMI was not correlated with composite FMS score in children between the ages of 8 and 11 years old [46]. The authors suggested that this may be due to the fact that only 9% of the participants were considered to be overweight, while in previous studies, as many as 33% of participants were consider overweight or obese (ref). The only correlation found in this study was a weak correlation between core stability, measured by planking and side planking performance, and composite FMS score. If in fact there is a relationship between core stability and composite FMS score, this would suggest that the FMS may be a valid measure of core stability. In order to determine the validity of the FMS when used in this population, more needs to be known about the relationship between performance measures and FMS scores.

In an attempt to examine the validity of using the FMS in adolescent populations, Wright et. al examined how a four week functional intervention program influenced composite FMS score and other performance measures in physically active adolescents between the ages of 11 and 15 years old [71]. The participants were placed either in a control group participating in typical multi-sport activity or in an intervention group participating in functional movement exercises. It was determined that change in composite FMS score and sit and reach score in the intervention group were most likely trivial. Interestingly, the researchers found that the intervention was likely beneficial for planking performance, but likely harmful for side planking performance. This seems to be contradictory as both measures are thought to be markers of core stability. Based on the findings of this study it does not appear that the use of functional movement training is warranted in this population. However, before the effects of a functional movement intervention can be determined in this population, the validity of the FMS to predict performance in this population must first be addressed.

In a research study performed by Bardenett et al., the ability of the FMS to predict injury in an active adolescent population was examined [72]. Adolescents between the ages of 13 and 18 years old were screened with the FMS as part of a pre-participation examination, and then injuries for the participants were tracked throughout the athletic season. It was determined that there was no difference in mean composite score between the injured and uninjured adolescent athletes. Using a ROC curve, researchers also determined that there was not a cutoff point where sensitivity and specificity were maximized. Based on the results of this study it does not appear that the FMS is an appropriate tool for predicting risk of injury in adolescent athletes.

Other screens

With the great amount of interest in identifying impaired movement patterns, the FMS is not the only test that has been established to do so. Recently several new screens have been established in an effort to identify movement impairments. These screens include a nine-test screening battery, a sixteen item physical performance measure (16-PPM) screening battery, and The Foundation Matrix (TFM). These movement impairment screens just have begun to receive attention from researchers. The current research available for these three screens mostly focuses on inter-rater and intra-rater reliability.

The nine-test screening battery was first described by Frohm et al., and is sometimes referred to as the Frohm-9 [73]. This screening battery involves six of the seven FMS movement patterns, a one-legged squat test from the United States Tennis Association's (USTA) High Performance Profile (HPP), and a straight leg raise test and seated rotation test. The researchers made several small modifications to the FMS movement patterns, having more strict grading criteria, different standardized instructions for starting positions, and only performing portions of some of the movement patterns. In a research study using male elite soccer players and physiotherapists as raters, it was determined that this nine-test screening battery had good inter-rater reliability (ICC= 0.80) and intra-rater reliability (ICC= 0.75). Additionally, the inter-rater reliability was found to be good for each of the nine tests except the one-legged squat and the diagonal lift test. This study would appear to suggest that the nine test screening battery may be a reliable test when performed by experienced raters. Currently there is no information on the validity of the nine test screen battery or the ability of the screen to predict injury or enhance performance.

The 16-PPM screening battery was first described by Tarara, Hegedus, and Taylor [74]. This movement impairment screen is similar to the Frohm-9 in that it includes some of the movement patterns from the FMS. This screen includes modified versions of the deep squat, shoulder mobility test, and active straight leg raise. Different from the Frohm-9, this screen is broken down into quantitatively-scored tests focusing on more objective measures, and qualitatively-scored tests focusing on more subjective measures. This screen included a broad range of performance and movement strategy tests. The researchers found that inter-rater and intra-rater reliability for the majority of the sixteen tests was good, with better reliability for the performance components rather than the movement pattern components. This study suggests, that similar to other movement impairment screens, the 16-PPM may be a reliable screen in athletic populations. With the addition of performance measures in this screen, this tool may be more useful in pre-participation screening of athletic populations in comparison to previous screens only assessing movement impairments. However before this screen is accepted as a pre-participation screen more research is needed on the validity of the 16-PPM screening battery and the ability of the screen to predict injury risk and athletic performance.

The final movement impairment screen, the TFM, was created by Comerford and Mottram. This movement impairment screen is also thought to identify inefficient control of movement and dysfunctional movement patterns referred to in this screen as uncontrolled movement. Comerford and Mottram define uncontrolled movement as: "a lack of ability to cognitively coordinate and control motion efficiently to benchmark standards at a particular body segment"[75]. Similarly to dysfunctional movement patterns, uncontrolled movement is thought to increase the risk of injury. In a research study performed by Mischiati et al. the inter-rater reliability and intra-rater reliability was evaluated for the TFM [76]. Nine of the ten movement control tests were used to evaluate the reliability of the TFM. These movement control tests included five low threshold tests of alignment and coordination and four high threshold tests of strength and speed control. Researchers found that the inter-rater and intra-rater reliability for composite scores was excellent. This study would appear to suggest that the TFM is a reliable test when used by experienced raters in athletic populations. While the TFM appears to be a promising movement impairment screen, future research is still needed to assess the validity of the TFM.

Somatotyping

Somatotyping is a method for classifying human physique. It is considered to be a numerical representation of an individual's body type in a three number rating scale. Somatotyping identifies three main components to physique: endomorphy, mesomorphy, and ectomorphy. Each number in the rating scale represents one of these main components. The endomorphy rating is a measure of body fatness vs. leanness. An individual scoring high on the endomorphy rating would be considered to have a large amount of body fat, while an individual scoring lower would be considered more lean. The mesomorphy rating is a measure of muscularity. An individual scoring high on the mesomorphy rating would be considered to have a large amount of muscle mass, while an individual scoring lower would be considered to have less muscle mass. The ectomorphy rating is a measure of height in relation to weight. An individual scoring high on the ectomorphy rating would be considered to have significantly more height than weight, while an individual scoring lower would be considered to have less height and more weight.

Somatotyping was first described by W. H. Sheldon in 1940. [2] Later this method was adapted and modified by Heath and Carter. [1] It is the Heath-Carter method that is considered to be the gold standard of somatotyping today. While limitations to the Heath Carter method have been established, such as its inability to account for the expanse of the body sizes of today's population [77] and the questionable validity of one of the three components [78], it is still a very widely used field test. In the past five decades there has been a great deal of interest in identifying normative values of somatotype rating for a vast variety of different populations, and in comparing somatotype rating to measures of sports performance. Interestingly, today there is still a great deal of interest in determining normative values of somatotype rating in different athletic populations, and in comparing somatotype rating to measures of sports performance. In addition, new ways to measure an individual's physique have been compared to the Heath Carter method for validation purposes.

Somatotype Ratings in Athletic Populations and Athletic Performance

In 1970 J.E.L. Carter published a review article detailing the normative values of a wide variety of athletes [79]. In this review, several patterns between physique, skill level, and choice of sport were identified. One interesting finding was that elite athletes did not appear to differ in physique from regular athletes of the same sport. Another interesting find was that somatotype varied considerably between different sports. From this review it appears that certain body types are more likely to be involved in certain sports. Since this review article, there have been many research studies investigating somatotype ratings in athletes of different sports and different player positions. In a recent study involving volleyball players, on average, centers and hitters were characterized as belonging to the central category, setters and hitters where characterized as mesomorphs. [80] In another study on elite sprinters, females were classified as belonging to the central or ectomorph categories and males were classified as belonging to the mesomorph or ectomorph categories [81]. One study performed on intermediate and high level surfers somatotype category was able differentiate between level of performance [82]. In general, studies investigating somatotyping and performance suggest that different somatotypes display varying levels of performance for different tasks. Overall it appears that physique does seem to play a role in sport selection and success at different player positions. To understand the role somatotype plays in an individual's ability to be successful in a given sport or position, more must be known about the relationship between performance measures and somatotype.

In a research study performed on male college students, Bale, Colley, and Mayhew investigated relationships between somatotype categories and measures of physical performance. [5] While the researchers found weak to moderate correlations for the somatotype ratings and measures of performance such as grip strength, trunk extension, vertical jump, estimated VO2max, and maximum power output, the researchers did notice trends between the somatotype categories. Endo-mesomorphic and mesomorphic participants performed better in measures of strength and power, while ectomorphic participants performed better in measures of aerobic performance such as VO2max. In a very similar study performed by P. Bale, E. Colley, and J. Mayhew on female college students, the researchers again investigated relationships between somatotype categories to measures of physical performance [4]. Similar to the previous study, only weak and moderate correlations were found with performance measures. Interestingly the same trends that were noticed in the male population were found to be true of the female population as well. From this trend it appears that there is a relationship between somatotype and athletic performance.

Other Measures of Body Composition

Somatotyping is just one method used to describe human physique. There are several measures of body composition that also attempt to describe physique. The measures include hydrostatic weighing, skinfolds, bioelectrical impedance, dual energy x-ray absorption, and air displacement plethysmography. Skinfolds and bioelectrical impedance are commonly used measurements to assess percent body fat because these tests require minimal equipment. However both of these tests are indirect measures and are only able to estimate percent body fat. Another body composition test that indirectly measures percent body fat is hydrostatic weighing, in which an individual is placed on a hanging scale in a tank of water to determine underwater weight. The underwater weight of an individual can then be used to calculate fat mass and fat-free mass. Prior to the new technologies of dual energy x-ray absorption and air displacement plethysmography, hydrostatic weighing was considered to be the gold standard in assessment of body composition.

More recent studies such as one performed by Dewit et al. determined that air displacement plethysmography was as accurate as hydrostatic weighing [83]. While the study was not able to determine which technique was more accurate, it suggested that air displacement plethysmography is a "promising technique" for body composition analysis in adults and children. One disadvantage of both hydrostatic weighing and air displacement plethysmography is that both of these measures require expensive equipment (i.e. Bodpod) that is not transportable. In a research review conducted by Toombs et al., the authors suggest that according to the literature, dual energy x-ray absorption is a precise and useful tool for measuring body composition [84]. Unlike other measures, this tool is able to estimate bone mass, as well as fat free mass and fat mass. However, similar to hydrostatic weighing and air displacement plethysmography, it also requires expensive non-transportable equipment. In a study performed by Olds et al., researchers used three-dimensional whole-body scans to detect body shapes, and found body shapes incredibly similar to traditional somatotyping [77]. The researchers suggest that while 3-D body scanning offers another good approach to describing and classifying human physique, this new techniques is unlikely to replace traditional somatotyping methods due to the ease of carrying out traditional methods. It is likely for this reason exactly that somatotyping is still commonly used; somatotyping requires substantially less equipment than the previously mentioned methods and it can be performed anywhere.

Overall the literature seems to support the use of somatotyping as a valid way to assess physique. In comparison to most other methods of assessing body composition it requires less equipment and is more easily performed in field settings. Somatotyping is most useful in tracking changes in physique, and is commonly compared to athletic performance and player position.

Appendix A - Informed Consent

Research Informed Consent Form

Grand Valley State University

Functional Movement Screening Score by Somatotype Category

Purpose – What is this study for?

The purpose of this research study is to establish normative reference values for functional movement screening score based on body type category. By establishing reference norms for movement abilities by body type we will be able to know more about the relationship between the way we move and body composition. Additionally we will be able to compare functional movement screening scores between body type groups.

Reason for Invitation – Why was I invited to participate?

You have been invited to participate in this study in order to help establish reference values for functional movement screening score based on body type.

Participant Selection – Can I Participate?

To participate in this study you must be between the ages of 18-25 years and be a student enrolled at Grand Valley State University. Since this study is looking at movement abilities we must exclude individuals with known limitations to movement. In order to participate you cannot have any obvious movement limitations, self-reported or observed. Also to participate you must be free from injury at the time of the study. Additionally you may not participate if you have had any major leg injuries in the past six months or have had surgery on either leg in the past six months. Please note that your participation in this study will require attendance of one session 30-45 minutes in length.

Somatotyping – What Body Measurements are being taken?

> **Height & Weight** - The first two measurements will be height measured on a stadiometer and weight measured on a scale.
>
> **Skinfolds** - The next group of measurements will be skinfold measurements. Skinfold measurements are taken with a pair of skinfold calipers. The researcher will identify the skinfold being measured and will gently but firmly pinch just above the skinfold site using calipers to measure the thickness of the fold. There may be some slight discomfort from the pinching, but discomfort will be minimal and temporary (no more than a few seconds). There will be four sites tested: the middle of your tricep, just below your shoulder blade, just above the top of your hip bone, and the inside of your calf.

Breadth Measurements - The next set of measurements taken will be breadth measurements. Breadth measurements will involve researchers measuring the breadth (or wideness) of the widest part of you humerus (arm bone) and femur (leg bone).

Girth Measurements - The last two measurements taken will be girth measurements. These measurement will involve measuring the circumference of the widest part of your upper arm and your calf.

Photography – Additionally, somatotyping will involve the researcher taking a picture of you in order to complete your body type profile. If you are a man this will involve you being photographed in a pair of athletic shorts and no shirt. If you are a woman this will involve you being photographed in a sports bra and a pair of athletic shorts. No one but the researchers will have access to these photos. Pictures of you may be used in scientific journals or in public presentations by concealing your identity with black boxes.

Functional Movement Screening – What will I have to do?

In order to complete the functional movement screen you will need to perform seven basic movement patterns. Four of these movement patterns you will perform on both sides of your body. The seven basic movement patterns are: deep squat, hurdle step, in-line lunge, single leg raise, shoulder mobility, trunk stability push-up, and rotary stability. You will be given more specific instructions for each movement pattern during the functional movement screen. If you not able to complete a movement pattern you will in no way be penalized. If you experience pain during a movement pattern please inform the researcher immediately. Experiencing pain during these movement patterns is not an expected outcome and therefore needs to be reported to researchers.

Please note that somatotyping and functional movement screening will take place in the Human Performance Lab in the Field House at Grand Valley State University.

Risks – What Possible Harms may come from Participating?

We do not believe there is any risk to you from participating in this research. You should be aware that body composition measurements can be slightly intrusive. Researchers will act in a highly professional manner when taking your measurements and be assured that body composition data will be secure at all times. You will be given an identification number and your personal information (such as your name) will not be associated with your body composition measurements.

Potential Benefits for Society – How Does my Participation benefit others?

Establishing normative reference values for functional movement screening score for each body type category will help provide us with a better understanding of the relationship between movement abilities and body type. After establishing normative reference values we will then be able to compare these values between body types. This will help us have a better understanding of how a person's body type affects their ability to move. It may also provide information that would be helpful in trying to decrease risk of injury due to dysfunctional movement patterns.

Participation in this study is voluntary. If you decide to participate, it is important for you to understand that you may withdraw your consent at any time. This will not affect your future relationships with the Grand Valley State University, Movement Science Department, or any individual involved with the research.

As a participant in this research study you have the right to ask questions at any time concerning the procedures, as well as the right to have those questions answered. You may contact the principal investigators, Dr. Heather Gulgin as follows: gulginh@gvsu.edu (phone # 616-331-8871) or Amanda Robertson as follows: robertam@mail.gvsu.edu (248-978-5650). If you have questions about your rights as a participant in this study you may contact the Grand Valley State University Human Subjects Review Committee via phone # 616-331-3197 or email hrrc@gvsu.edu.

In the unlikely event of a physical injury resulting from your participation, the investigators will assist you in obtaining medical care (phone 911 in case of an emergency). However, payment for the medical care is your responsibility. Grand Valley State University will not provide financial compensation for the medical care.

Your signature indicates that this research has been explained to you, that your questions have been answered, and that you agree to participate in this study.

Please PRINT name ____

Signature of participant ___________________________________   Date _______________

This research protocol has been approved by the Human Research Review Committee at

Grand Valley State University. File No. 14-082-H Expiration: January 29, 2015.

Appendix B- Participant Recruitment Flyer

PARTICIPANTS NEEDED FOR RESEARCH

Functional Movement Screen Score by Body Type

Who may volunteer?
Grand Valley State University students between the ages of 18 – 25 yrs. If you currently have any injuries or have had injuries in the last six months that prevent you from physical activity or activities of daily living you may not participate.

What will you do?
You will be asked to attend one session, approximately 30 - 45 minutes in length, to have body composition measurements such as skinfolds measurements, circumferences measurements, and breadth measurements taken. Additionally during that session you will be asked to perform various functional movements involving mobility and stability. To allow for measurement, and ease of movement, we ask that you arrive in athletic shorts, a short sleeve shirt, and tennis shoes.

What will we do?
We will take your body composition measurements, as well as a body type profile photograph. Body composition measurements will involve the use of a skinfold caliper device that will require a small pinch of your skin. We will also assess functional movements by having you perform a set of 7 different movements

Benefits?
You will not benefit financially from volunteering in this study, but will help the investigators advance the scientific knowledge regarding movement and body types.

Who do I contact if I am interested?
If you meet the criteria above and are interested in volunteering in this study, then please contact the primary investigators:

Amanda Robertson	OR	Heather Gulgin
robertam@gvsu.edu		gulgin@gvsu.edu
		616-331-8871

This research protocol has been approved by the Human Research Review Committee at Grand Valley State University. File No. 14-082-H Expiration: January 29, 2015.

Appendix C- Physical Activity Questionnaire

Identification Number:_____________

Please answer the following questions to the best of your ability.

Please indicate your age: _____________

Please indicate your sex:

____ Male
____ Female

Please indicate your ethnicity:

_____Asian
_____American Indian or Alaskan Native
_____Black or African American
_____White or Caucasian
_____Hispanic or Latino
_____ I would prefer not to answer

On average how many hours a week are you physically active?

_____ 0-4 hours per a week
_____ 5 to 8 hours per a week
_____ 9 to 12 hours per a week
_____ > 12 hours per a week

What kind of physical activity do you partake in? Please explain.

____
____
____

Is there anything currently preventing you from participating in physical activity?

___ Yes
___ No
If you answered yes, please explain:

____
____
____

Is there anything that is currently preventing you from participating in activities of daily living? For instance walking, sitting, standing, attending work, or attending class.

___ Yes
___ No
If you answered yes, please explain:
____
____
____

Do you currently have or have you had any injuries in the past 6 months?

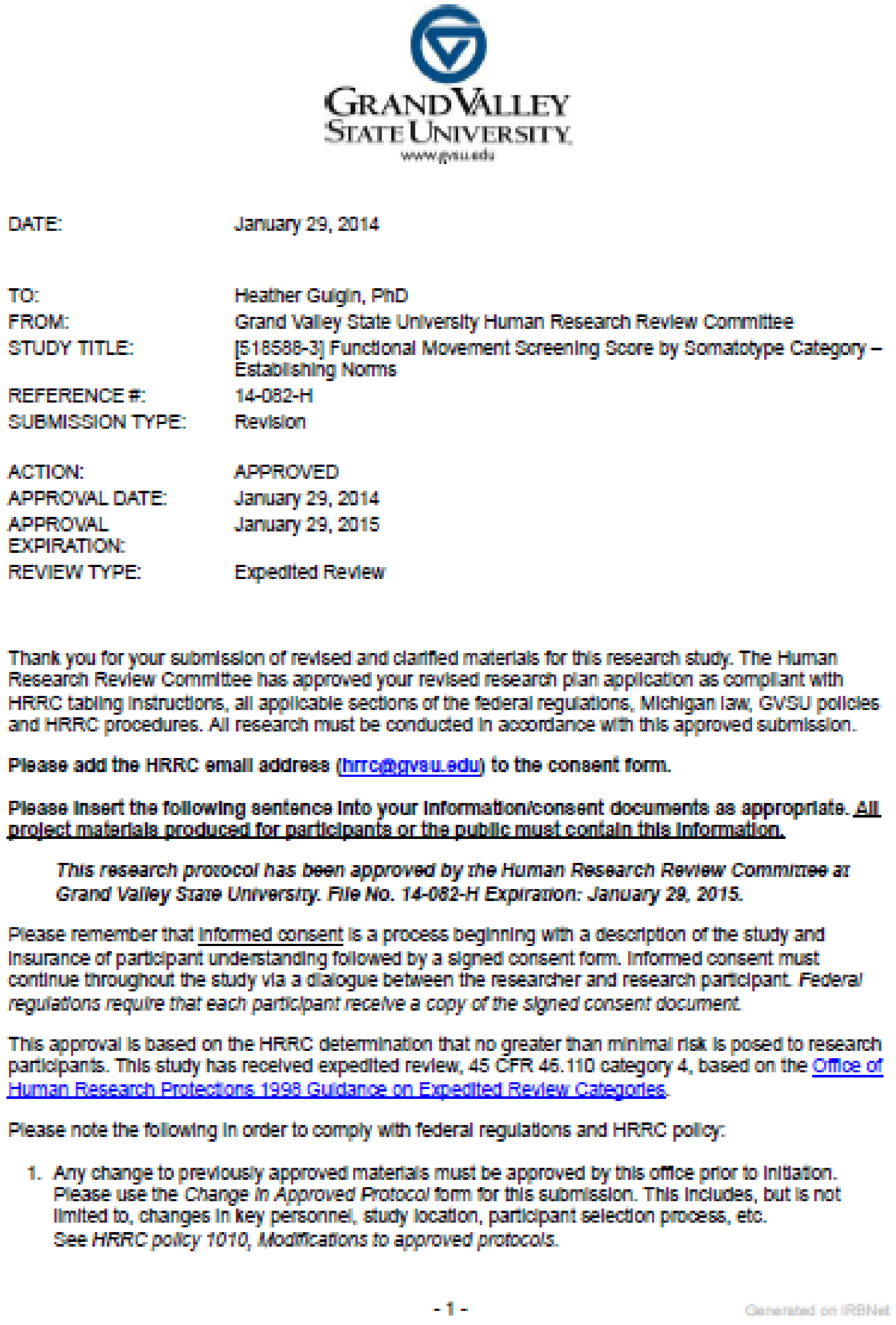
___ Yes
___ No
If you answered yes, please explain:
____
____
____

Have you had any surgeries in the past 6 months?

___ Yes
___ No
If you answered yes, please explain:
____
____
____

This research protocol has been approved by the Human Research Review Committee at Grand Valley State University. File No. 14-082-H Expiration: January 29, 2015.

Appendix D - HRRC Approval



GRAND VALLEY
STATE UNIVERSITY
www.gvsu.edu

DATE:	January 29, 2014
TO:	Heather Gulgin, PhD
FROM:	Grand Valley State University Human Research Review Committee
STUDY TITLE:	[518588-3] Functional Movement Screening Score by Somatotype Category – Establishing Norms
REFERENCE #:	14-082-H
SUBMISSION TYPE:	Revision
ACTION:	APPROVED
APPROVAL DATE:	January 29, 2014
APPROVAL EXPIRATION:	January 29, 2015
REVIEW TYPE:	Expedited Review

Thank you for your submission of revised and clarified materials for this research study. The Human Research Review Committee has approved your revised research plan application as compliant with HRRC tabling instructions, all applicable sections of the federal regulations, Michigan law, GVSU policies and HRRC procedures. All research must be conducted in accordance with this approved submission.

Please add the HRRC email address (hrrc@gvsu.edu) to the consent form.

Please insert the following sentence into your information/consent documents as appropriate. All project materials produced for participants or the public must contain this information.

> ***This research protocol has been approved by the Human Research Review Committee at Grand Valley State University. File No. 14-082-H Expiration: January 29, 2015.***

Please remember that informed consent is a process beginning with a description of the study and insurance of participant understanding followed by a signed consent form. Informed consent must continue throughout the study via a dialogue between the researcher and research participant. *Federal regulations require that each participant receive a copy of the signed consent document.*

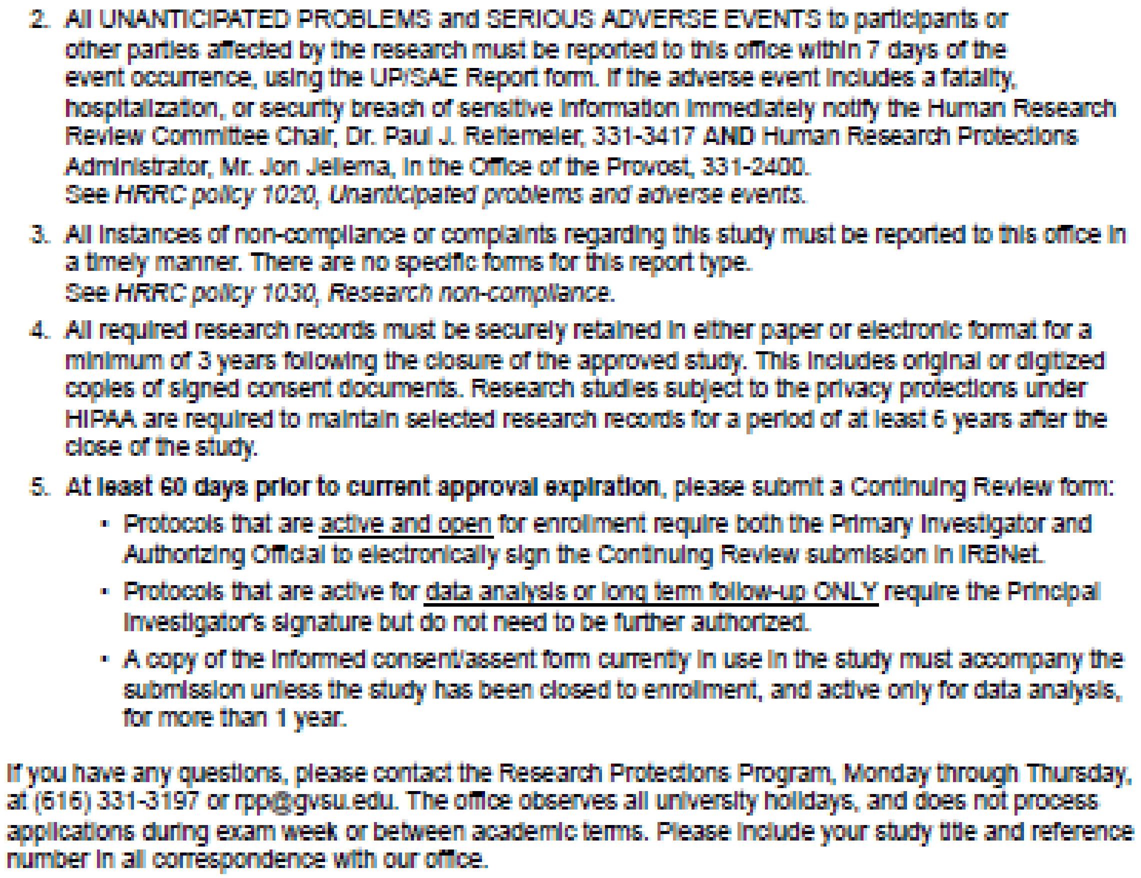
This approval is based on the HRRC determination that no greater than minimal risk is posed to research participants. This study has received expedited review, 45 CFR 46.110 category 4, based on the Office of Human Research Protections 1998 Guidance on Expedited Review Categories.

Please note the following in order to comply with federal regulations and HRRC policy:

1. Any change to previously approved materials must be approved by this office prior to initiation. Please use the *Change in Approved Protocol* form for this submission. This includes, but is not limited to, changes in key personnel, study location, participant selection process, etc. See *HRRC policy 1010, Modifications to approved protocols.*

- 1 -

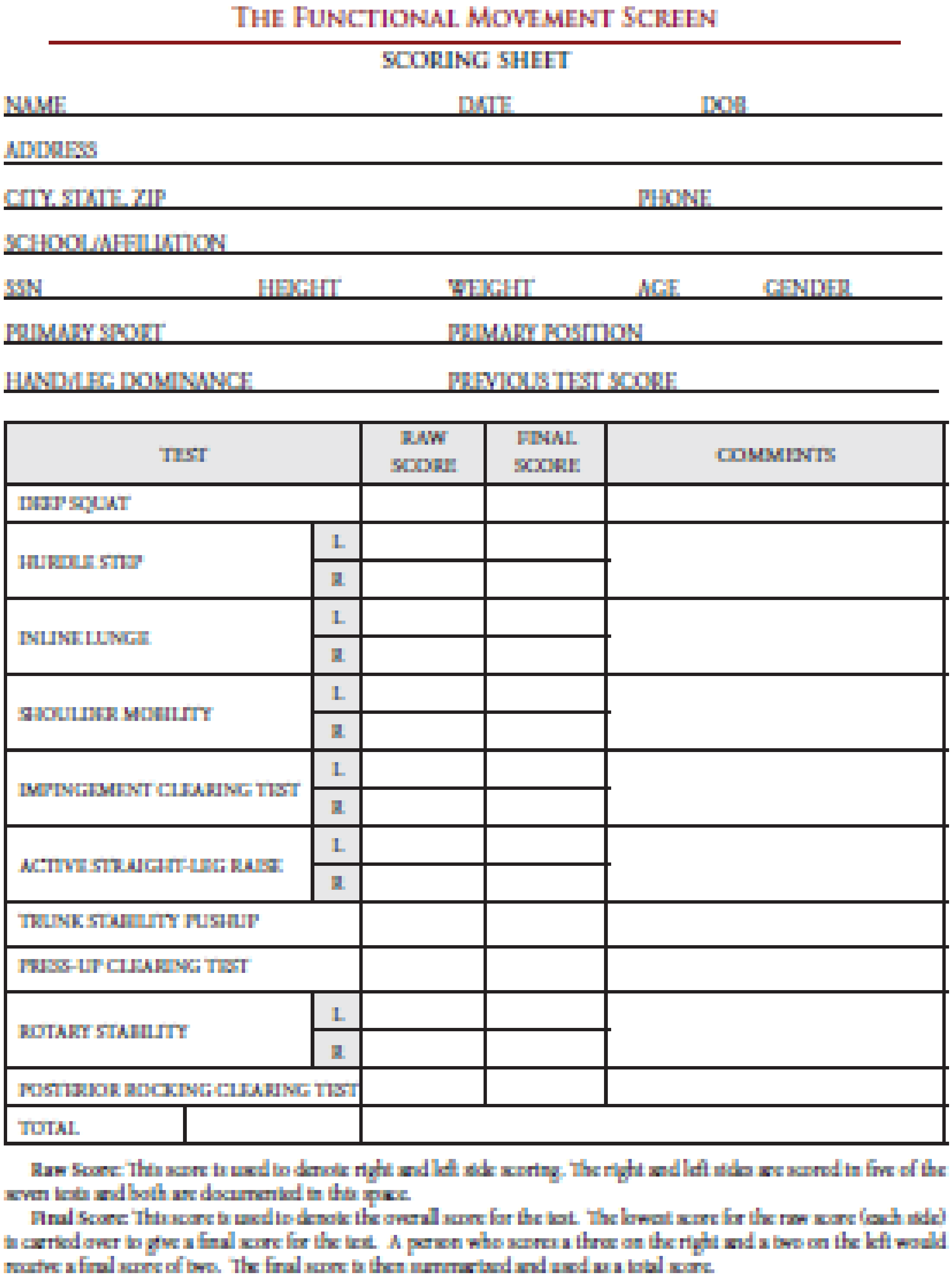
Generated on IRBNet



2. All UNANTICIPATED PROBLEMS and SERIOUS ADVERSE EVENTS to participants or other parties affected by the research must be reported to this office within 7 days of the event occurrence, using the UP/SAE Report form. If the adverse event includes a fatality, hospitalization, or security breach of sensitive information immediately notify the Human Research Review Committee Chair, Dr. Paul J. Reitemeier, 331-3417 AND Human Research Protections Administrator, Mr. Jon Jellema, in the Office of the Provost, 331-2400.
   See *HRRC policy 1020, Unanticipated problems and adverse events.*
3. All instances of non-compliance or complaints regarding this study must be reported to this office in a timely manner. There are no specific forms for this report type.
   See *HRRC policy 1030, Research non-compliance.*
4. All required research records must be securely retained in either paper or electronic format for a minimum of 3 years following the closure of the approved study. This includes original or digitized copies of signed consent documents. Research studies subject to the privacy protections under HIPAA are required to maintain selected research records for a period of at least 6 years after the close of the study.
5. **At least 60 days prior to current approval expiration**, please submit a Continuing Review form:
   - Protocols that are active and open for enrollment require both the Primary Investigator and Authorizing Official to electronically sign the Continuing Review submission in IRBNet.
   - Protocols that are active for data analysis or long term follow-up ONLY require the Principal Investigator's signature but do not need to be further authorized.
   - A copy of the informed consent/assent form currently in use in the study must accompany the submission unless the study has been closed to enrollment, and active only for data analysis, for more than 1 year.

If you have any questions, please contact the Research Protections Program, Monday through Thursday, at (616) 331-3197 or rpp@gvsu.edu. The office observes all university holidays, and does not process applications during exam week or between academic terms. Please include your study title and reference number in all correspondence with our office.

Appendix E - Functional Movement Screen Score Sheet



THE FUNCTIONAL MOVEMENT SCREEN

SCORING SHEET

NAME DATE DOB

ADDRESS

CITY, STATE, ZIP PHONE

SCHOOL/AFFILIATION

SSN HEIGHT WEIGHT AGE GENDER

PRIMARY SPORT PRIMARY POSITION

HAND/LEG DOMINANCE PREVIOUS TEST SCORE

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

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

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

Appendix F - Somatotype Equation Sheet

SOMATOTYPE EQUATION SHEET

Participant Identification Number: ____________________

Endomorphy

Tricep (mm) _________ Subscapular (mm) ___________ Suprailiac (mm)___________

Raw Skinfold Sum =

Height correction value = 170.18 / height in cm

Height Adjusted Skinfold Sum =

Mesomorphy

Upper Arm Girth (cm) =

Biceps (cm) = Upper Arm Girth (cm) – Tricep Skinfold (mm) ← convert to cm before subtracting

=

Calf Girth (cm) =

Calf Skinfold (mm) =

Calf (cm) = Calf Girth (cm) – Calf Skinfold (mm) ← convert to cm before subtracting

=

Ectomorphy

Weight (lb.) =

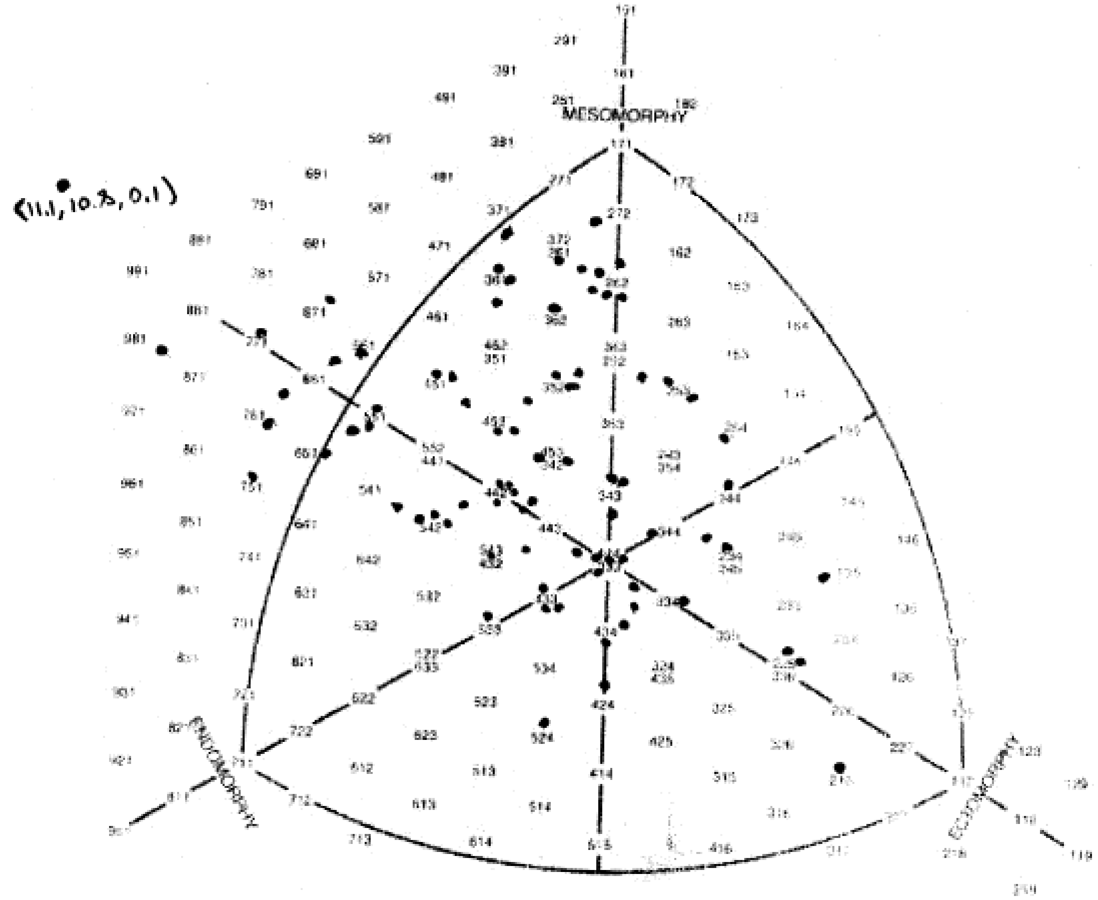
HWR = Height (in)/ $\sqrt[3]{Weight\ (lb)}$ ← Use for rating form

=

HWR = Height (cm) / $\sqrt[3]{Weight\ (kg)}$ ← Use for equations

=

Appendix G - Somatotype Chart of Sample Population



Bibliography

1. Carter JE, Heath BH. The heath-carter anthropometric somatotype. 2002.

2. Norton K, Olds T. *Anthropometrica: A Textbook of Body Composition Measurement for Sports and Health Courses*. Sydney, Australia: UNSW Press; 1996.

3. Ayan V, Bektas Y, Erol AE. Anthropometric and performance characteristics of Turkey National U-14 volleyball players. *Afr J Phys Health Educ Recreat Dance*. 2012;18(2):395-403.

4. Bale P. Relationships among physique, strength, and performance in women students. *J Sports Med Phys Fitness*. 1985;25(3):98; 98-103; 103.

5. Bale P, Colley E, Mayhew J. Size and somatotype correlates of strength and physiological performance in adult male students. *Aust J Sci Med Sport*. 1984;16(4):2-6.

6. Garganta J, Maia J, Pinto J. Somatotype, body composition and physical performance capacities of elite young soccer players. In: United Kingdom; 1993. http://articles.sirc.ca/search.cfm?id=318734; http://ezproxy.gvsu.edu/login?url=http://search.ebscohost.com/login.aspx?direct=true&db=s3h&AN=SPH318734&site=ehost-live&scope=site; http://articles.sirc.ca/search.cfm?id=318734.

7. GREENLEE G. The relationship of somatotype and isokinetic strength measures to lower extremity injuries in female athletes (Mise en relation du somatotype de la force isocinetique avec les blessures des extremites inferieures chez les femmes sportives). *Relatsh Somatotype Isokinetic Strength Meas Low Extrem Inj Female Athletes Mise En Relat Somatotype Force Isocinetique Avec Blessures Extrem Inferieures Chez Femmes Sport*. 01 1986.

8. Hopper DM. Somatotype in high performance female netball players may influence player position and the incidence of lower limb and back injuries. / Le somatotype des joueuses de netball de haut niveau peut influer sur la position occupee par les joueuses et l â⍰™ incidence des blessures des membres inferieures et de la region lombaire. *Br J Sports Med*. 1997;31(3):197-199.

9. Reilly T. Somatotype and injuries in adult student rugby football. *J Sports Med Phys Fitness*. 1981;21(2):186; 186-191; 191.

10. Carlson BR, Carter JEL, Patterson P, Petti K, Orfanos SM, Noffal GJ. Physique and motor performance characteristics of US national rugby players. *J Sports Sci*. 1994;12(4):403-412.

11. Salokun SO. Minimizing injury rates in soccer through preselection of players by somatotypes. / Minimiser l â⍰™ incidence des blessures en football par la preselection des joueurs d â⍰™ apres leur somatotype. *J Sports Med Phys Fitness*. 1994;34(1):64-69.

12. Wilsmore RG. The body type of female hockey players involved in different playing positions and levels of competition. *Aust J Sci Med Sport*. 1987;19(4):26-28.

13. Cook G. *Movement Functional Movement Systems: Screening, Assessment, and Corrective Strategies*. Aptos, CA: On Target Publications; 2010.

14. Gallahue DL. *In Adapted Physical Education and Sport. 3rd Ed, Champaign, Ill., Human Kinetics, c2000.*; 2000.

15. Haywood N Kathleen & Getchell. *Life Span Motor Development*. 5th ed. Champaign, IL: Human Kinetics; 2009.

16. Utley A, Astill S. *Motor Control, Learning and Development*. New York: Taylor & Francis; 2008.

17. Cook G, Burton L, Hoogenboom B. Pre-participation screening: the use of fundamental movements as an assessment of function - part 1. *North Am J Sports Phys Ther NAJSPT*. 2006;1(2):62-72.

18. Cook G, Burton L, Hoogenboom B. Pre-participation screening: the use of fundamental movements as an assessment of function - part 2. *North Am J Sports Phys Ther NAJSPT*. 2006;1(3):132-139.

19. Frost DM, Beach TA, Callaghan JP, McGill SM. Using the Functional Movement Screen to evaluate the effectiveness of training. *J Strength Cond Res Natl Strength Cond Assoc*. 2012;26(6):1620-1630.

20. Parchmann CJ, McBride JM. Relationship between functional movement screen and athletic performance. *J Strength Cond Res Natl Strength Cond Assoc*. 2011;25(12):3378-3384.

21. Lisman P, O'Connor FG, Deuster PA, Knapik JJ. Functional movement screen and aerobic fitness predict injuries in military training. *Med Sci Sports Exerc*. 2013;45(4):636-643.

22. Zou GY. Toward using confidence intervals to compare correlations. *Psychol Methods*. 2007;12(4):399-413. doi:10.1037/1082-989X.12.4.399.

23. Cook G, Burton L, Hoogenboom BJ, Voight M. Functional movement screening: the use of fundamental movements as an assessment of function - part 1. *Int J Sports Phys Ther*. 2014;9(3):396-409.

24. Cook G, Burton L, Hoogenboom BJ, Voight M. Functional movement screening: the use of fundamental movements as an assessment of function-part 2. *Int J Sports Phys Ther*. 2014;9(4):549-563.

25. Duncan MJ, Stanley M. Functional movement is negatively associated with weight status and positively associated with physical activity in british primary school children. *J Obes*. 2012;2012:697563.

26. Duncan MJ, Stanley M, Wright SL. The association between functional movement and overweight and obesity in British primary school children. *BMC Sports Sci Med Rehabil*. 2013;5(1):11.

27. Engquist KD, Smith CA, Chimera NJ, Warren M. Performance Comparison of Student-Athletes and General College Students on the Functional Movement Screen and the Y Balance Test. *J Strength Cond Res Natl Strength Cond Assoc*. 2015;29(8):2296-2303. doi:10.1519/JSC.0000000000000906.

28. Schneiders AG, Davidsson A, Horman E, Sullivan SJ. Functional movement screen normative values in a young, active population. *Int J Sports Phys Ther*. 2011;6(2):75-82.

29. Teyhen D. Normative data and the influence of age and gender on power, balance, flexibility, and functional movement in healthy service members. *Mil Med*. 2014;179(4):413-420.

30. Onate JA, Dewey T, Kollock RO, et al. Real-time intersession and interrater reliability of the functional movement screen. *J Strength Cond Res Natl Strength Cond Assoc*. 2012;26(2):408-415. doi:10.1519/JSC.0b013e318220e6fa.

31. Elias JE. The Inter-rater Reliability of the Functional Movement Screen within an athletic population using Untrained Raters. *J Strength Cond Res Natl Strength Cond Assoc*. July 2013.

32. Shultz R, Anderson SC, Matheson GO, Marcello B, Besier T. Test-retest and interrater reliability of the functional movement screen. *J Athl Train*. 2013;48(3):331-336.

33. Kiesel K, Plisky P, Butler R. Functional movement test scores improve following a standardized off-season intervention program in professional football players. *Scand J Med Sci Sports*. 2011;21(2):287-292.

34. Bodden JG, Needham RA, Chockalingam N. The Effect of an Intervention Program on Functional Movement Screen Test Scores in Mixed Martial Arts Athletes. *J Strength Cond Res Natl Strength Cond Assoc*. July 2013.

35. Clifton DR, Harrison BC, Hertel J, Hart JM. Relationship between functional assessments and exercise-related changes during static balance. *J Strength Cond Res Natl Strength Cond Assoc*. 2013;27(4):966-972.

36. Hartigan EH. Relationship of the Functional Movement Screen In-Line Lunge to Power, Speed, and Balance Measures. *Sports Health*. 2014;6(3):197-202.

37. Chapman RF, Laymon AS, Arnold T. Functional movement scores and longitudinal performance outcomes in elite track and field athletes. *Int J Sports Physiol Perform*. 2014;9(2):203-211.

38. Kiesel K, Plisky PJ, Voight ML. Can Serious Injury in Professional Football be Predicted by a Preseason Functional Movement Screen? *North Am J Sports Phys Ther NAJSPT*. 2007;2(3):147-158.

39. Letafatkar A, Hadadnezhad M, Shojaedin S, Mohamadi E. Relationship between functional movement screening score and history of injury. *Int J Sports Phys Ther*. 2014;9(1):21-27.

40. Butler RJ, Contreras M, Burton LC, Plisky PJ, Goode A, Kiesel K. Modifiable risk factors predict injuries in firefighters during training academies. *Work Read Mass*. 2013;46(1):11-17.

41. Kiesel KB, Butler RJ, Plisky PJ. Prediction of Injury by Limited and Asymmetrical Fundamental Movement Patterns in American Football Players. *J Sport Rehabil*. 2014;23(2):88-94.

42. Kazman JB, Galecki J, Lisman P, Deuster PA, O’connor FG. Factor Structure of the Functional Movement Screen in Marine Officer Candidates. *J Strength Cond Res Natl Strength Cond Assoc*. August 2013.

43. Li Y, Wang X, Chen X, Dai B. Exploratory factor analysis of the functional movement screen in elite athletes. *J Sports Sci*. December 2014:1-7. doi:10.1080/02640414.2014.986505.

44. Jill N. Hickey BAB. Reliability of the Functional Movement Screen Using a 100-point Grading Scale: 1765. *Med Sci Sports Exerc - MED SCI SPORT Exerc*. 2010;42. doi:10.1249/01.MSS.0000384722.43132.49.

45. Butler RJ. Interrater Reliability of Videotaped Performance on the Functional Movement Screen Using the 100-Point Scoring Scale. *Athl Train Sports Health Care*. 2012;4(3):103; 103-109; 109.

46. Mitchell UH, Johnson AW, Adamson B. Relationship between Functional Movement Screen Scores, Core Strength, Posture, and BMI in School Children in Moldova. *J Strength Cond Res Natl Strength Cond Assoc*. February 2015. doi:10.1519/JSC.0000000000000722.

47. Gribble PA, Brigle J, Pietrosimone BG, Pfile KR, Webster KA. Intrarater reliability of the functional movement screen. *J Strength Cond Res Natl Strength Cond Assoc*. 2013;27(4):978-981.

48. Minick KI, Kiesel KB, Burton L, Taylor A, Plisky P, Butler RJ. Interrater reliability of the functional movement screen. *J Strength Cond Res Natl Strength Cond Assoc*. 2010;24(2):479-486.

49. Gulgin H, Hoogenboom B. The functional movement screening (fms)^{TM}: an inter-rater reliability study between raters of varied experience. *Int J Sports Phys Ther*. 2014;9(1):14-20.

50. Smith CA, Chimera NJ, Wright NJ, Warren M. Interrater and Intrarater Reliability of the Functional Movement Screen: *J Strength Cond Res*. 2013;27(4):982-987. doi:10.1519/JSC.0b013e3182606df2.

51. Teyhen DS, Shaffer SW, Lorenson CL, et al. The Functional Movement Screen: a reliability study. *J Orthop Sports Phys Ther*. 2012;42(6):530-540.

52. Kraus K, Schütz E, Taylor WR, Doyscher R. Efficacy of the functional movement screen: a review. *J Strength Cond Res Natl Strength Cond Assoc*. 2014;28(12):3571-3584. doi:10.1519/JSC.0000000000000556.

53. Beardsley C, Contreras B. The Functional Movement Screen: A Review. *Strength Cond J Lippincott Williams Wilkins*. 2014;36(5):72-80.

54. Frost DM, Beach TA, Callaghan JP, McGill SM. FMS scores change with performers' knowledge of the grading criteria - Are general whole-body movement screens capturing "dysfunction"? *J Strength Cond Res Natl Strength Cond Assoc*. November 2013.

55. Frost DM, Beach TAC, Campbell TL, Callaghan JP, McGill SM. An appraisal of the Functional Movement Screen^{TM} grading criteria - Is the composite score sensitive to risky movement behavior? *Phys Ther Sport Off J Assoc Chart Physiother Sports Med*. February 2015. doi:10.1016/j.ptsp.2015.02.001.

56. Sprague PA, Monique Mokha G, Gatens DR, Rodriguez R. The relationship between glenohumeral joint total rotational range of motion and the functional movement screen^{TM} shoulder mobility test. *Int J Sports Phys Ther*. 2014;9(5):657-664.

57. Whiteside D, Deneweth JM, Pohorence MA, et al. Grading the Functional Movement Screen^{TM}: A Comparison of Manual (Real-Time) and Objective Methods. *J Strength Cond Res Natl Strength Cond Assoc*. August 2014. doi:10.1519/JSC.0000000000000654.

58. Chorba RS, Chorba DJ, Bouillon LE, Overmyer CA, Landis JA. Use of a functional movement screening tool to determine injury risk in female collegiate athletes. *North Am J Sports Phys Ther NAJSPT*. 2010;5(2):47-54.

59. O'Connor FG, Deuster PA, Davis J, Pappas CG, Knapik JJ. Functional movement screening: predicting injuries in officer candidates. *Med Sci Sports Exerc*. 2011;43(12):2224-2230.

60. Wiese BW, Boone JK, Mattacola CG, McKeon PO, Uhl TL. Determination of the Functional Movement Screen to Predict Musculoskeletal Injury in Intercollegiate Athletics. *Athl Train Sports Health Care J Pract Clin*. 2014;6(4):161-169.

61. Lockie RG, Schultz AB, Callaghan SJ, Jordan CA, Luczo TM, Jeffriess MD. A preliminary investigation into the relationship between functional movement screen scores and athletic physical performance in female team sport athletes. *Biol Sport*. 2015;32(1):41-51.

62. Lockie RG, Schultz AB, Jordan CA, Callaghan SJ, Jeffriess MD, Luczo TM. Can selected functional movement screen assessments be used to identify movement deficiencies that could affect multidirectional speed and jump performance? *J Strength Cond Res Natl Strength Cond Assoc*. 2015;29(1):195-205. doi:10.1519/JSC.0000000000000613.

63. Okada T, Huxel KC, Nesser TW. Relationship between core stability, functional movement, and performance. *J Strength Cond Res Natl Strength Cond Assoc*. 2011;25(1):252-261.

64. Chimera NJ, Smith CA, Warren M. Injury History, Sex, and Performance on the Functional Movement Screen and Y Balance Test. *J Athl Train Allen Press*. 2015;50(5):475-485.

65. Perry FT, Koehle MS. Normative data for the functional movement screen in middle-aged adults. *J Strength Cond Res Natl Strength Cond Assoc*. 2013;27(2):458-462.

66. Agresta C, Slobodinsky M, Tucker C. Functional Movement Screen $^{\text{TM}}$ - Normative Values in Healthy Distance Runners. *Int J Sports Med*. 2014;35(14):1203-1207.

67. Fox D, O'Malley E, Blake C. Normative data for the Functional Movement Screen in male Gaelic field sports. *Phys Ther Sport Off J Assoc Chart Physiother Sports Med*. November 2013.

68. Parenteau-G E, Gaudreault N, Chambers S, et al. Functional movement screen test: A reliable screening test for young elite ice hockey players. *Phys Ther Sport Off J Assoc Chart Physiother Sports Med*. October 2013.

69. Abraham A, Sannasi R, Nair R. Normative values for the functional movement screentm in adolescent school aged children. *Int J Sports Phys Ther*. 2015;10(1):29-36.

70. Anderson BE, Neumann ML, Huxel Bliven KC. Functional movement screen differences between male and female secondary school athletes. *J Strength Cond Res Natl Strength Cond Assoc*. 2015;29(4):1098-1106. doi:10.1519/JSC.0000000000000733.

71. Wright MD, Portas MD, Evans VJ, Weston M. The effectiveness of 4 weeks of fundamental movement training on functional movement screen and physiological performance in physically

active children. *J Strength Cond Res Natl Strength Cond Assoc*. 2015;29(1):254-261. doi:10.1519/JSC.0000000000000602.

72. Bardenett SM, Micca JJ, DeNoyelles JT, Miller SD, Jenk DT, Brooks GS. Functional movement screen normative values and validity in high school athletes: can the FMS^{TM} be used as a predictor of injury? *Int J Sports Phys Ther*. 2015;10(3):303-308.

73. Frohm A, Heijne A, Kowalski J, Svensson P, Myklebust G. A nine-test screening battery for athletes: a reliability study. *Scand J Med Sci Sports*. 2012;22(3):306-315. doi:10.1111/j.1600-0838.2010.01267.x.

74. Tarara DT, Hegedus EJ, Taylor JB. Real-time test-retest and interrater reliability of select physical performance measures in physically active college-aged students. *Int J Sports Phys Ther*. 2014;9(7):874-887.

75. Comerford MJ. Screening to identify injury and performance risk: movement control testing – the missing piece of the puzzle. *SportEX Med*. 2006;(29):21-26.

76. Mischiati CR, Comerford M, Gosford E, et al. Intra and inter-rater reliability of screening for movement impairments: movement control tests from the foundation matrix. *J Sports Sci Med*. 2015;14(2):427-440.

77. Olds T, Daniell N, Petkov J, David Stewart A. Somatotyping using 3D anthropometry: a cluster analysis. *J Sports Sci*. 2013;31(9):936-944.

78. Wilmore JH. Validation of the first and second components of the Heath-Carter modified somatotype method. *Am J Phys Anthropol*. 1970;32(3):369-372. doi:10.1002/ajpa.1330320306.

79. Carter JE. The somatotypes of athletes--a review. *Hum Biol*. 1970;42(4):535-569.

80. Martín-Matillas M, Valadés D, Hernández-Hernández E, et al. Anthropometric, body composition and somatotype characteristics of elite female volleyball players from the highest Spanish league. *J Sports Sci*. 2014;32(2):137-148.

81. Aerenhouts D, Delecluse C, Hagman F, et al. Comparison of anthropometric characteristics and sprint start performance between elite adolescent and adult sprint athletes. *Eur J Sport Sci*. 2012;12(1):9-15.

82. Barlow MJ, Findlay M, Gresty K, Cooke C. Anthropometric variables and their relationship to performance and ability in male surfers. *Eur J Sport Sci*. 2014;14:S171-S177.

83. Dewit O, Fuller NJ, Fewtrell MS, Elia M, Wells JC. Whole body air displacement plethysmography compared with hydrodensitometry for body composition analysis. *Arch Dis Child*. 2000;82(2):159-164.

84. Toombs RJ, Ducher G, Shepherd JA, De Souza MJ. The impact of recent technological advances on the trueness and precision of DXA to assess body composition. *Obes Silver Spring Md*. 2012;20(1):30-39. doi:10.1038/oby.2011.211.