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The Functional Movement Screen Is Not A Valid Measure of Movement Competency

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Graduate Program in Kinesiology
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Abstract

Movement assessments are used to determine injury risk, physical competency, and return-to-activity. The Functional Movement Screen (FMS) was developed to identify movement competency and susceptibility to injury. Although this tool is frequently used, its efficacy and validity have not been conclusively determined. The three studies presented in this thesis explored the validity of the FMS through comparison to existing validated tests and statistical measures of internal validity.

The purpose of Study 1 was to determine if performance in the FMS and the Y-Balance Test (YBT) were related. The YBT is a measure of dynamic postural control, a component of functional movement. This study showed partial correspondence between the tests, though the correlation was not strong enough to consider them interchangeable nor that dynamic postural control was a large component of the FMS score.

The purpose of Study 2 was to investigate the factorial validity of the FMS. This is particularly important as the aggregate score of the FMS test is used to determine injury risk. Exploratory factor analysis of a sample of healthy adults revealed that the FMS has a multidimensional factor structure, and therefore using the aggregate score of the FMS is not appropriate.

The purpose of Study 3 was to assess whether the factor structure of the FMS is consistent across different populations. We compared exploratory factor analyses and factor congruence of the FMS in a general population sample, varsity athletes, and firefighters. We observed a two-factor structure that varied in composition between groups, suggesting that the factor structure of the FMS may differ, according to population.

Overall, this thesis determined that the aggregate score of the FMS is not a valid tool for evaluating functional movement. Although the FMS does appear to partially quantify dynamic postural control, it is also characterized by a lack of consistency between populations, and a multidimensional factor structure. This suggests that the aggregate score should not be used to interpret an individual's movement proficiency or susceptibility to injury.

Keywords

Functional Movement Screen, Y Balance Test, Dynamic Postural Control, Factor Analysis, Firefighter Testing, Fitness Testing

Co-Authorship Statement

Chapters 2-4 are manuscripts that will be submitted for publication. The individual contributions of my collaborators are listed below.

Chapter 2:

Title: The Functional Movement Screen Does Not Accurately Quantify Dynamic Postural Control

Author List: Leila Kelleher, Tyson Beach, Shaylyn Kowalchuck, Jordin Higgs, Andrew Johnson, James Dickey

Leila Kelleher – wrote manuscript, study design, data collection and analysis; Tyson Beach – study design, edited manuscript; Shaylyn Kowalchuck – data collection; Jordin Higgs – data collection; Andrew Johnson – data analysis, edited manuscript; James Dickey – study design, edited manuscript

Chapter 3:

Title: Exploratory Factor Analysis of Conventional and Alternate Scoring Schemes for the Functional Movement Screen

Author List: Leila Kelleher, Paula van Wyk, Tyson Beach, Andrew Johnson, James Dickey

Leila Kelleher – wrote manuscript, study design, data collection and analysis; Paula van Wyk – data collection; Tyson Beach – edited manuscript; Andrew Johnson – study design, data analysis, edited manuscript; James Dickey – study design, edited manuscript

Chapter 4:

Title: Functional Movement Screen Factorial Validity and Congruence is Low in Three Populations

Author List: Leila Kelleher, Malinda Hapuarachchi, Tyson Beach, David Frost, Andrew Johnson, James Dickey

Leila Kelleher – wrote manuscript, study design, data collection and analysis; Malinda Hapuarachchi – data collection; Tyson Beach – edited manuscript; David Frost – data collection; Andrew Johnson – study design, data analysis, edited manuscript; James Dickey – study design, edited manuscript

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Tyson Beach has been a great source of knowledge about the FMS, strength and conditioning, and scientific method. I always enjoyed our meetings immensely, and they lasted for hours as we debated and brainstormed. His revisions and suggestions were always thoughtful and in sound judgment.

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List of Abbreviations

FMS	Functional Movement Screen
YBT	Y-Balance Test
SEBT	Star Excursion Balance Test
NHL	National Hockey League
NFL	National Football League
DS	Deep Squat
HS	Hurdle Step
ILL	Inline Lunge
SM	Shoulder Mobility
ASLR	Active Straight Leg Raise
TSPU	Trunk Stability Pushup
RS	Rotary Stability
TotalY	Summed Normalized Y-balance test reach distances

List of Definitions

Functional Movement

Typical biomechanical movement within the realm of normal human activity

Functional Movement Screen

A battery of tasks designed by Gray Cook to assess Functional Movement

Global Movement Competency

“Fundamental movement patterns of an individual” (Cook et al., 2014)

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

Chapter 1

1 General Introduction

Movement assessment tools are used to evaluate recreational, amateur, and professional athletes' movement competency and susceptibility to injury. Professional sports organizations have a financial interest in recruiting players who are the least likely to become injured during their careers. Traditionally, performance tests for professional athletes have been based upon sport-specific movements and skills as is seen in the National Football League (NFL) and National Hockey League (NHL) scouting combines. This testing battery also includes quantitative physiological measures of human performance such as Wingate and VO₂ max testing (Rowan et al., 2015). The Functional Movement Screen (FMS) was designed to assess movement quality ('functional movement'), and to identify susceptibility to injury, by assigning a score to describe global movement competency (Cook et al., 2006a; 2006b). It is widely used in the fitness industry to assess amateur and recreational athletes' risk of injury (Beckham and Harper, 2010). The FMS was integrated into the NFL combine in 2011 and into the NHL combine in 2013 (Rowan et al., 2015). This means that the results of the FMS could affect the career trajectory of a professional athlete. The validity of the FMS as an instrument for quantifying movement competency has not yet been conclusively determined. The global objective of this thesis was, therefore, to further investigate the validity of the FMS as a tool for evaluating human movement through comparison to existing tests of functional movement and statistical evaluation of test construction.

1.1 The Functional Movement Screen

The generic term 'functional movement' has been poorly defined in the literature, however it can be assumed that it denotes typical biomechanical movement within the realm of normal human activity. The FMS is purported to measure dynamic postural control, stability, mobility, movement patterns, and functional symmetry (Cook et al., 2006a; 2006b). It comprises seven functional movement tasks (Deep Squat (DS), Hurdle

Step (HS), Inline Lunge (ILL), Shoulder Mobility (SM), Active Straight Leg Raise (ASLR), Trunk Stability Pushup (TSPU), and Rotary Stability (RS)) and three associated clearing tests (Cook et al., 2006a; 2006b). The clearing tests are designed to detect pain in specific ranges of motion that are related to the associated movement task (Cook et al., 2006a; 2006b). All movement tasks, apart from the DS and TSPU, are performed bilaterally. The tasks are scored from zero to three. The FMS is performed using a testing kit, which may be purchased (Functional Movement Systems, Lynchburg, VA, USA) or manufactured. It is administered and graded using published, standardized verbal commands and procedures (Cook et al., 2006a; 2006b). Certification for administering and grading the FMS is attained by attending workshops or online study and by passing an exam. This certification is available at two levels. The first level is considered to be adequate for administering and grading the FMS; the higher level is focused on corrective exercise prescription informed by the FMS score (“FMS Get Certified,” n.d.).

1.1.1 Functional Movement Screen Tasks

The tasks described below are consistent with published FMS guidelines (Cook et al., 2006a; 2006b). The standardized verbal commands which should be used for testing are published elsewhere (Cook et al., 2010). Each of the tasks may be attempted three times during which coaching and/or corrections are not provided. Images of the FMS tasks and clearing tests described below are presented in Appendix 1.

The DS is performed while holding the FMS dowel with the hands pronated. The subject stands with their feet shoulder width apart with the dowel resting on their head. The subject is instructed to adjust the width of their grip until their elbows are flexed to 90°. The elbows are then extended and the subject performs an overhead squat with a one second pause at the bottom. If the subject is not able to squat until their femurs are at least parallel with the floor, or maintain an upright posture within three repetitions, they are asked to repeat the task with their heels elevated on the FMS board.

The HS is set up with an elastic hurdle string placed at the height of the subject's tibial tuberosity. The subject stands upright with their feet together and toes touching the FMS board. The dowel is held horizontally, resting behind their neck on the superior aspect of the trapezius muscles. The subject flexes their hip and knee to raise one leg over the hurdle, touches their heel down on the far side of the board, and then returns to the starting position.

The ILL is set up standing with a staggered stance along the FMS board. The distance between the toe of the back foot and the heel of the front foot is equal to the height of the subject's tibial tuberosity. The hand contralateral to the front foot holds the dowel behind the neck in line with the spine, and their other hand holds the dowel in the lumbar region of the spinous process. The dowel touches the back of the head, thoracic spine, and sacrum. While maintaining this upright posture, the subject flexes their knees and hips and lunges down, touching the back knee on the board behind the front heel. The subject then returns to the starting position.

SM is assessed by reaching behind their back with hands clasped in fists (thumbs inside the fists), their upper arm flexed at the elbow and reaching down, and their lower arm flexed at the elbow and reaching upwards such that their fists move towards each other. The subject is not permitted to move the fists once they make contact with the back. This task is assessed using the length of the hand (distal wrist crease to middle fingertip) for normalization.

The ASLR is performed with the subject lying supine with the FMS board under their knees. The assessor holds the FMS dowel vertically, halfway between the centre of the patella and the anterior superior iliac spine. The subject begins with feet together and ankles dorsiflexed. The subject then flexes at the hip, raising one leg as high as possible, without flexing their knee or rotating their supporting leg. The position of the medial malleolus of the moving leg with respect to the dowel is used for scoring this task.

The TSPU is performed with the subject prone, feet together and toes tucked under (ankles dorsiflexed). The palms of the hands are placed flat on the floor with the thumbs extended. The medial edges of the hands are placed trunk width apart with the thumbs in

line with the top of the forehead (for men) or with the chin (for women). The subject extends their elbows to perform a pushup, without allowing the trunk to deviate from its original alignment. If the subject is not able to perform a correct repetition of this movement within three trials, the task is repeated with the thumbs level with the chin (for men) or the clavicles (for women).

The RS task is performed with the subject in a quadruped position with the FMS board at the midline of the body (lengthwise between the hands and feet), ankles dorsiflexed and the thumbs and great toes touching the sides of the board. The subject is asked to extend an arm and leg unilaterally, raising the hand, knee, and foot simultaneously. They then flex their knee and elbow, to touch the elbow to the knee, re-extend the arm and leg, and then return to the start position. If the subject is not able to perform a correct repetition of this after three attempts, they perform a similar movement, but move contralateral limbs.

The scoring criteria for each movement task are specified individually, however the general scheme is: zero denotes pain during the movement; severe compensation or an inability to perform the movement is given a score of one; a score of two indicates some deviation from model form; and a score of three is awarded for perfect execution of the movement (Cook et al., 2006a; 2006b).

There are three clearing tests, each associated with a movement task: Shoulder Impingement with SM, Spinal Extension with TSPU, and Spinal Flexion with RS. The Shoulder Impingement test is performed bilaterally. The subject places the palm of their hand on the contralateral shoulder at the acromial process. The subject then flexes their shoulder to elevate their elbow, leaving the hand in contact with the shoulder. Spinal Extension is performed with the subject lying prone with the palms of the hands placed on the floor at shoulder level. The subject extends the elbows, leaving the hips in contact with the ground. The Spinal Flexion test is performed with the subject in a quadruped position with their ankles plantar flexed and the FMS board lengthwise between their hands and feet (similar to the RS task). The subject then flexes their knees and hips until their buttocks move towards their feet and their forehead descends towards the board. If the participant reports pain on a clearing test, then their score for the related functional

task becomes zero. For bilateral tasks, such as the ILL, the lower score of the right and left performances is recorded. The calculated scores on the seven tasks are then summed to create an aggregate score out of 21 (Cook et al., 2006a; 2006b).

1.1.2 Intra- and Inter-rater Reliability

A number of studies, with a variety of trained and untrained raters, have shown that the FMS has adequate intra-rater reliability (Gribble et al., 2013; Onate et al., 2012; Parenteau-G et al., 2014; Smith et al., 2013; Teyhen et al., 2012). Similarly, the inter-rater reliability of the FMS has been reported with ICC values > 0.76 (Butler et al., 2011; Chorba et al., 2010; Elias, 2013; Gulgin and Hoogenboom, 2014; Hotta et al., 2015; Letafatkar et al., 2014; Mostafavifar et al., 2015; Onate et al., 2012; Parenteau-G et al., 2014; Smith et al., 2013; Teyhen et al., 2012) and a weighted kappa value of .79-1.0 in one study (Minick et al., 2010). These studies demonstrate excellent correspondence between raters, however there is one study that compared live vs. video-based grading and reported poor reliability (Krippendorff's alpha values of 0.38 for inter-rater reliability and an ICC of 0.60 for live intra-rater reliability; Shultz et al., 2013). In that study, video-based rating demonstrated higher intra-rater correspondence (ICC=0.92; Shultz et al., 2013). Two reviews synthesized these data and concluded that the FMS has good intra- and inter-rater reliability (Bonazza et al., 2016; McCunn et al., 2016). One used the COSMIN checklist (Terwee et al., 2012) to rate the methodological quality of movement test intra- and inter-rater reliability (including the FMS; McCunn et al., 2016). They reported that none of the inter-rater reliability studies met the criteria for an 'excellent' rating, one was 'good' (Teyhen et al., 2012) and two were 'fair' (Minick et al., 2010; Shultz et al., 2013). A study that investigated an alternate, 100-point scoring method (Butler et al., 2011) also met the 'fair' criteria. The other 13 studies were of 'poor' quality, when using those criteria (McCunn et al., 2016). When methodological quality is accounted for, the amount of evidence for adequate inter-rater reliability is diminished, though the highest quality study (Teyhen et al., 2012) reported adequate ICC values that demonstrated 'excellent' reliability (Portney and Watkins, 2000). The other review article estimated that both intra- and inter-rater reliability is ICC=0.81 (Bonazza et al., 2016).

1.1.3 Injury Risk and the FMS

An early study examining the ability of the FMS to predict injury in professional football players (n=46) identified increased injury risk during a season if a player scored less than or equal to an FMS score of 14 (Kiesel et al., 2007). That study defined injury as a player being placed on the ‘injured reserve’ list for at least three weeks; however, it did not discriminate between the causes of injury. It is therefore not clear whether the injuries stemmed from “compensatory movement patterns” as suggested by the author of the test (Cook et al., 2006a), or whether the cause was likely unrelated to movement patterns, for example from traumatic, accidental injury such as concussion or shoulder dislocation. That kind of player-to-player contact injury accounted for 64% of injuries in a large sample of high school athletes (Badgeley et al., 2013). The professional players’ field positions were also not examined, which may have influenced their cause of injury. For example, offensive linemen are the most likely to become injured in football, especially from contact injuries (Badgeley et al., 2013). Another early study evaluating the association between FMS scores and injury was performed with a small (n=38) group of female NCAA division II athletes (Chorba et al., 2010). It dichotomized the players into a high-risk and low-risk group, using the FMS cut-off score of ≤ 14 as proposed above. They reported a correlation between sustaining a lower body injury during the season and an FMS score of ≤ 14 ($r=0.761$; Chorba et al., 2010). Based on these early studies, the ≤ 14 cutoff was supported as a potential threshold to predict elevated risk for injury. The authors of the original professional football study subsequently published a larger scale study of professional footballers (n=238) which further supported their assertion of the ≤ 14 threshold; asymmetry was also identified as a significant predictor of injury in this study; Kiesel et al., 2014). Confirmation of the ≤ 14 threshold was also found in a group of 160 collegiate athletes (Garrison et al., 2015) and in a meta-analysis (Bonazza et al., 2016).

In contrast, studies of high school athletes (Bardenett et al., 2015), college athletes (Warren et al., 2015), professional soccer players (Zalai et al., 2015), junior ice hockey players (Dossa et al., 2014), and competitive runners (Hotta et al., 2014) did not observe higher rates of injury in subjects with aggregate FMS scores ≤ 14 . Interestingly, the DS

and ASLR were more accurate predictors of running injuries in a group of 193 college track and field athletes than the total FMS score (Hotta et al., 2014). A study of older soccer players reported increased rates of injury with FMS scores <10 , but no significant increase in risk using the ≤ 14 threshold (Hammes et al., 2016). Therefore some studies support the ≤ 14 threshold while others do not, and some studies have identified different thresholds.

The predictive value of the FMS has also been examined in active military and service personnel. An FMS score of ≤ 14 predicted injury in firefighters (Butler et al., 2013) and active military servicemen (Bushman et al., 2015). Alternate schemes for identifying individuals at risk of injury have also been proposed. For example, a combination of the FMS and a complementary battery of exercises (three-mile run time, pull-ups, and abdominal crunches) has also been investigated (Lisman et al., 2013). That study reported greater correspondence between injury and the FMS score when combined with the three-mile run time; participants who scored poorly on both the FMS and run time were 4.2 times more likely to sustain injury, as opposed to twice as likely to become injured when evaluated with the FMS alone. Studies of U.S. Army Rangers (Teyhen et al., 2015) and task force police officers (McGill et al., 2015) did not show a significant association between the FMS score and injury over 12 month and 5 year periods, respectively. However, a study of coast guard cadets did show a weak association between the FMS and injury in males with scores ≤ 11 , and a stronger association between injury and FMS scores ≤ 14 for females (Knapik et al., 2015). A large scale study performed on U.S Marine officer candidates ($n=874$) also tested the ≤ 14 injury threshold (O'Connor et al., 2011). In that study, subjects with scores of ≤ 14 were at a significantly greater risk of injury than those who scored 15-17; however, they also observed that subjects with scores >18 were also at a significantly greater risk of injury. These bimodal results are contradictory to the conventional interpretation of the FMS whereby injury risk progressively decreases as FMS scores increase.

1.1.4 Validity of the FMS

1.1.4.1 Factor Analysis

Factor analysis is a classic test construction evaluation technique used to validate tests by analyzing observed variables to reveal underlying latent factors (Tabachnick and Fidell, 2001). It evaluates the correlations between variables to observe the underlying structure of a test. This approach can be used to determine whether the test is measuring the factors that it purports to quantify (its factorial validity).

The factorial validity of the FMS has been investigated using factor analysis in four studies (Gnacinski et al., 2016; Kazman et al., 2014; Koehle et al., 2016; Li et al., 2015). Because the aggregate (total) score of the FMS has been suggested as a tool for determining susceptibility to injury, it is imperative that the FMS has a single underlying factor. If the FMS has a single factor construction, then it can be considered a valid measure of one overall variable, presumably ‘functional movement’, which would validate the use of the aggregate score.

Exploratory factor analysis was first performed on a large group of U.S. Marine officer candidates (n=934; Kazman et al., 2014). That study investigated the validity of the FMS using two scoring systems – the published scoring criteria (Cook et al., 2006a; 2006b), and an alternate scoring criteria that did not take pain into account. Both analyses revealed two underlying factors in the FMS – factor one comprising the DS and ILL, with the second factor comprising the HS, SM, ASLR, and TSPU. RS was loaded onto both factors. That study used a population of marine officer candidates, which explains the mainly male (94%) and young (22.4 ± 2.7) cohort. This may have affected the results as age-grouped adults perform more poorly on the FMS as age increases (Mitchell et al., 2015).

The structure of the FMS was also examined using exploratory factor analysis with a large group (n=290) of Chinese elite athletes (Li et al., 2015). That study used the published scoring criteria (Cook et al., 2006a; 2006b) and reported that the FMS loaded onto two factors, however the distributions of the factor loadings were different from the previous study. RS was the only task that loaded heavily onto one factor; the DS, HS, and

ILL loaded onto the other factor. SM, ASLR, and the TSPU did not strongly load onto either factor. The main inclusion criterion in that study was having competed at an international level in the Chinese national team. The participants were from a variety of sporting disciplines including team, individual, and target sports, however, this mixed sample should not have affected the outcome as the FMS is designed for use on people with all athletic backgrounds (Cook et al., 2006a; 2006b).

A retrospective chart analysis was performed on a normal, albeit older (age=53.4 \pm 11.1), population in Canada (n=1113; Koehle et al., 2016). As with the previous two studies, that study showed that the FMS describes two underlying factors. The first factor comprised the DS, HS, and TSPU; SM and ASLR loaded onto the other. RS was split between the two factors. While the TSPU loaded more strongly toward the first factor, the relationship to this factor was not strong (Koehle et al., 2016). Unlike the previous exploratory factor analyses of the FMS, the authors of that paper performed a confirmatory factor analysis on their data, testing the fit of the extracted factor structure. They found that the two factor model had the best fit when the RS test was removed from the overall model, likely because it was split between both factors (Koehle et al., 2016).

Building upon this previous work, a confirmatory factor analysis was recently published (Gnacinski et al., 2016). That study tested the fit of both a single- and two-factor solution in a group of varsity athletes. Their two-factor model was similar to the model extracted in the general population sample (Koehle et al., 2016), however the general population loaded the RS on both factors and the varsity athlete study assigned the RS to the same factor as the DS, HS, ILL, and TSPU (Gnacinski et al., 2016). Although there was no statistically significant difference between the two solutions, there was a trend for the two-factor model to be superior ($p=0.054$). However, they concluded that the single factor solution was the best fit as it was the most parsimonious (Gnacinski et al., 2016). That interpretation supports the use of the aggregate score of the FMS; however, since their two-factor model approached statistical significance, their results were not definitive.

In a paper that clarifies the use of the FMS with respect to recent research, Cook et al. emphasized the use of the FMS as a screening tool, rather than a test, in part due to its apparent multidimensionality (Cook et al., 2014).

1.1.4.2 Other validity studies

Participants' knowledge of the scoring criteria affects their FMS score (Frost et al., 2015). In that study, subjects were told the grading criteria, but were not verbally coached to perform the movements. The participants' scores on the DS, HS, ILL, and SM tasks showed statistically significant improvements with this knowledge, which increased mean FMS scores from 14.1(1.8) without knowledge of the criteria, to 16.7(1.9) when the subjects were advised of the grading scheme. This casts doubt on the legitimacy of the use of FMS to measure movement competency since individuals appear to be capable of scoring better on the FMS test simply by being aware of the scoring criteria. In terms of the association between FMS scores and back loads, the peak low-back compression and anterior-posterior and medial-lateral reaction shear forces are not related to scoring above or below an FMS score of 14; this suggests that a low FMS score is not an accurate predictor of low-back injury or pain (Beach et al., 2014a).

The difference between real-time and objective rating methods has also been investigated (Whiteside et al., 2014). That study compared visually-based real-time assessment of the FMS, as proposed by the authors of the FMS (Cook et al., 2006a; 2006b), and an objective method using an inertial-based motion capture system. Overall, they found poor correspondence between the two methods, suggesting that inaccuracies due to manual grading may affect FMS scores (Whiteside et al., 2014).

Methodological item analysis is a statistical method used to compare the relative difficulty of different tasks (Lienert and Raatz, 1998). A recent study using this technique with the FMS reported four categories of item difficulty in a combined group of 455 elite, semi-professional, and recreational athletes (Kraus et al., 2015). The HS and RS were 'very difficult' tasks, DS and ILL were 'difficult', ASLR and TSPU were considered 'moderate', and the SM task was categorized as 'simple' (Kraus et al., 2015). That

variation suggests that the aggregate FMS score may not be an accurate measure of movement competency as similar FMS scores may not be comparable in difficulty.

1.2 Thesis Rationale

Thus far, evidence supporting the use of the FMS score as a measure of movement competency and injury risk is limited. Three of the four factor analysis studies identify that the FMS has a two-factor structure (Kazman et al., 2014; Koehle et al., 2016; Li et al., 2015), and the fourth presents equivocal single- and two-factor solutions (Gnacinski et al., 2016). The factor loadings in those studies also differ between populations, indicating instability in the structure of the test. A recent review indicated that studies that have evaluated the ≤ 14 threshold also had inconsistent findings (McCunn et al., 2016). The varied relationship between aggregate FMS scores and injury in these different groups does not support the accuracy or reliability of the FMS as a predictor of injury. This draws into question whether the aggregate FMS score is a valid measure of a single overall concept ('functional movement'). Further study of the validity of the FMS is therefore required in order to investigate the validity of FMS test and use of the aggregate score, especially for the purpose of predicting elevated risk of injury in athletes.

1.3 Thesis Organisation

Following this introductory chapter that outlines the structure of the FMS and literature regarding its reliability and validity, Chapter 2 presents Study 1, an investigation into the correspondence between the FMS and the Y-Balance Test (YBT). The aim of that study was to determine if dynamic postural control is a component of the FMS score by comparing it to a validated test. Our second study is reported in Chapter 3. That study performed an exploratory factor analysis on the FMS in a healthy, general population to determine if the aggregate FMS score is a measure of a single factor. Following on from that study, Study 3 (Chapter 4) compared the factor analysis and factor congruence from

the general population to those from two other populations – varsity athletes and firefighters. These three datasets are similar to the populations in previous exploratory factor analyses (Kazman et al., 2014; Koehle et al., 2016; Li et al., 2015). Through that study, we sought to replicate the previous work, determine the factor congruence of the FMS, and evaluate the factorial validity of the FMS (and thus, the validity of using the aggregate score in assessing functional movement). The final chapter synthesizes and summarises our findings with a general discussion, limitations, and summary of the thesis.

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Chapter 2

2 The Functional Movement Screen Does Not Accurately Quantify Dynamic Postural Control

2.1 Abstract

The Functional Movement Screen (FMS) is used to evaluate key movement patterns, functional symmetry, and identify individuals that are at elevated risk of injury. The purpose of this study was to assess whether dynamic postural control is a significant component of the FMS score by comparing it with Y-Balance Test (YBT) reach distances. Seventy-eight subjects (including 40 males) performed the standardized FMS protocol followed by the YBT. The YBT reach distances were normalized to leg length and averaged between sides and trials. The individual reach directions were evaluated, and were also summed to form an aggregate YBT score (TotalY). We observed weak correlations between FMS and normalized posterolateral reach, normalized posteromedial reach, and the TotalY ($r=0.36, 0.37, \text{ and } 0.36$, respectively; all $p < 0.05$). The correlation between FMS and normalized anterior reach was not statistically significant ($r=0.22$). Together these findings demonstrate partial correspondence between the two tests. However, the relationship is not strong enough to consider them interchangeable. This indicates that dynamic postural control is not a large component of the aggregate FMS score.

2.2 Introduction

Movement screening tools are widely used in fitness, professional sports, and as methods of assessing participants to determine underlying weaknesses or predisposition to injuries (McCunn et al., 2016). As one example, the Functional Movement Screen (FMS) is used as a pre-season screening tool in sports, and as a baseline measure to identify poor

“movement competency” and “faulty functional movement patterns” (inappropriate stability, mobility, compensatory movements, or proprioceptive/kinesthetic awareness; Cook et al., 2006a). Similarly, the Y-Balance Test (YBT), a modified version of the Star Excursion Balance Test (SEBT), is also used as a pre-participation screening tool and is designed to assess dynamic postural control and injury risk due to poor movement patterns (Plisky et al., 2009). Both the FMS and YBT are commonly used in the strength and conditioning industry (Beckham and Harper, 2010).

The FMS comprises seven functional movement tasks (Deep Squat (DS), Hurdle Step (HS), Inline Lunge (ILL), Shoulder Mobility (SM), Active Straight Leg Raise (ASLR), Trunk Stability Pushup (TSPU), and Rotary Stability (RS)) and three associated clearing tests (Cook et al., 2006a; 2006b). The clearing tests are designed to detect pain in specific ranges of motion that are related to the associated movement task (Cook et al., 2006a; 2006b). All movement tasks, apart from the DS and TSPU, are performed bilaterally. The seven movement tasks are scored from zero to three. The FMS is performed using a testing kit, which may be purchased (Functional Movement Systems, Lynchburg, VA, USA) or manufactured. The FMS is administered and graded using published, standardized verbal commands and procedures (Cook et al., 2006a; 2006b). Each of the tasks may be attempted three times. Coaching and/or corrections are not provided as knowledge of the grading criteria affects FMS results (Frost et al., 2015). The clearing tests are each associated with a functional test; Shoulder Impingement with SM, Spinal Extension with TSPU, and Spinal Flexion with RS. If the participant reports pain on a clearing test, then the score for the related functional task is changed to zero. For bilateral tasks, such as the ILL, the lower score from the right and left task performances is recorded. The scores on the seven tasks are summed to create an aggregate score out of 21 (Cook et al., 2006b; 2006a). Images of the FMS tasks are in Appendix 1.

Several studies have investigated the validity of the aggregate FMS score using factor analysis (Gnacinski et al., 2016; Kazman et al., 2014; Koehle et al., 2016; Li et al., 2015). Three of these studies (Kazman et al., 2014; Koehle et al., 2016; Li et al., 2015) concluded that the FMS was comprised of two factors. That means that the aggregate score is not unidimensional, and therefore that it is not a valid metric of a single

underlying concept, such as ‘functional movement’. In contrast, one study has reported that it was comprised of one factor, supporting the use of the aggregate score (Gnacinski et al., 2016).

The aggregate score of the FMS has been used to screen specific populations for individuals that may be at elevated risk of injury. Three review articles have provided commentary on the varied results of studies investigating the FMS’ accuracy in identifying individuals with an elevated risk of injury (Bonazza et al., 2016; Krumrei et al., 2014; McCunn et al., 2016). One review concluded that the FMS aggregate score could be used to predict injuries in specific populations (Krumrei et al., 2014); another concluded that injury risk increases with FMS scores ≤ 14 (Bonazza et al., 2016). The third reported that there is not enough research to support the FMS’ use as an injury prediction tool (McCunn et al., 2016). Clearly there is conflicting evidence about the relationship between FMS score and injuries, however its use as a screening tool may be more appropriate (Cook et al., 2014).

The SEBT is a clinical and research tool which assesses dynamic postural control (Gribble et al., 2012). In this test, subjects stand on a single leg and reach to eight directions with the other leg. The YBT is a reliable, instrumented variation of the SEBT (Plisky et al., 2009). It evaluates dynamic stability, coordination, and strength (Kang et al., 2015; Lee et al., 2014; Overmoyer and Reiser, 2015). In the YBT, the number of reach directions is reduced to anterior, posterolateral, and posteromedial, and the instrumented apparatus increases repeatability (Plisky et al., 2009). In order to account for different anthropometry, reach direction measurements can be normalized to leg length; this was the approach that was used for validation (Plisky et al., 2009). Images of the YBT reach directions are in Appendix 1.

Both the YBT and FMS are purported to assess dynamic postural control, stability, mobility, movement patterns, functional symmetry, and identify individuals that are at elevated risk of injury (Cook et al., 2006b; 2006a; Plisky et al., 2006). Accordingly, we would expect that individuals’ scores on the YBT and FMS should be correlated. This relationship has been investigated in several studies. For example, the FMS and YBT

scores have been compared between student-athletes and general college students (Engquist et al., 2015). There was no significant difference between these groups in the aggregate FMS score, however female athletes scored higher than general college students in all directions in the YBT (Engquist et al., 2015). Another study studied the FMS and the YBT in 200 NCAA Division I athletes and found that individuals with a self-reported history of injury or surgery had significantly lower aggregate FMS scores (Chimera et al., 2015). They also reported that female athletes had lower scores on some of the individual tests within the FMS (TSPU and RS) and higher scores on other tests (ILL, SM, and ASLR; (Chimera et al., 2015). However, they did not observe statistically significant differences in the YBT between individuals with and without a self-reported history of injury or surgery, nor between male and female participants (Chimera et al., 2015). The YBT and FMS scores have also been combined in the Move2Perform algorithm (Lehr et al., 2013). This proprietary algorithm uses demographic information, injury history, and the FMS and YBT scores to assess injury risk by placing subjects into four risk categories (normal, slight, moderate, and substantial). The efficacy of this tool was investigated in a group of NCAA athletes during one competitive season; they found a significant difference in lower extremity injury risk when the ‘moderate’ and ‘substantial’, and ‘slight’ and ‘normal’ were grouped together (reducing the number of risk categories to ‘high risk’ and ‘low risk’; Lehr et al., 2013). Normative FMS and YBT data in a population of military personnel has also been reported (Teyhen et al., 2014). That study found increased FMS, power, mobility, and balance scores in individuals younger than 30 years of age compared to those older than 30. They also reported that men had higher balance, power, and stability scores than women (Teyhen et al., 2014). None of those previous studies have explored the relationship between individuals’ scores on the FMS and YBT, nor have any studied a healthy, general population. Accordingly, the purpose of the current study was to directly assess the relationship between YBT reach distances and FMS scores in a healthy, general population, in order to determine whether dynamic postural control is a component of the aggregate FMS score.

2.3 Methods

2.3.1 Subjects

Seventy-eight subjects (40 males and 38 females; age= 28.1 \pm 9.1, age range 18-55, height 172.1 cm \pm 11.4, and body mass 71.0 kg \pm 13.7, BMI =23.9 \pm 3.1) gave written, informed consent to participate in the protocol approved by the Western University Research Ethics Board. None of the subjects had previously performed or administered the FMS and were therefore unaware of the scoring criteria. Subjects were eligible for inclusion if they were 18-69 years of age and did not have any current health and/or joint problems (they answered “no” to all of the questions in the Physical Activity Readiness Questionnaire; (Health Canada, 1992).

2.3.2 Procedures

The FMS was administered by a single certified FMS practitioner according to standardized procedures, equipment (Functional Movement Systems, Lynchburg, VA, USA) and verbal commands (Cook et al., 2006a; 2006b). The participants were video-recorded from the frontal and sagittal planes and the trials were graded at a later time. This is a commonly used (Beach et al., 2014b; Fox et al., 2014; Frost et al., 2015; 2011; 2012; Minick et al., 2010; Mitchell and Johnson, 2015), reliable (Shultz et al., 2013) method for scoring the FMS.

Subjects were familiarized with the YBT tool (Move2Perform, Evansville, IL, USA) and the movements that would void trials were explained (touching the floor, failing to return the moving foot to the centre of the apparatus, touching the top of the slider with any part of the foot, and using the slider poles for support). Subjects performed four practice trials on each side in each direction (anterior, posterolateral, posteromedial) during which they were given verbal feedback if they performed a trial that would be voided, however coaching was not provided (Robinson and Gribble, 2008). In order to allow the subjects to recover prior to performing the test trials, a rest period of approximately three minutes

was given, during which the length of their right leg was measured for normalization (right anterior superior iliac spine to medial malleolus; Plisky et al., 2009). The participants performed three test trials on each leg and in each reach direction. A trial was repeated if it was voided as described above.

2.3.3 Statistical Analyses

The mean of the six test trials in each reach direction of the YBT was calculated for each participant (i.e. three left and three right anterior reach distances were averaged). These mean reach distances were expressed as a proportion of leg length (Plisky et al., 2009). The individual directions were evaluated, and were also summed to form an aggregate YBT score (TotalY). This is similar to the approach used in previous research (Engquist et al., 2015). In this study, we chose to use the aggregate score of the FMS to ensure that we administered and graded the screen according to the intent of its developers (Cook et al., 2006a; 2006b). To determine the extent that the FMS aggregate score is related to the YBT, Pearson product-moment correlation coefficients were calculated between the FMS and YBT for each reach direction, and for the TotalY. These results are presented in the context of the power of the analysis, given the size of the sample. All statistical analyses were conducted in R (Champely, 2015).

2.4 Results

The mean \pm standard deviation aggregate FMS score for our participants was 16.3 ± 1.9 (range=11-20). Table 1 shows the mean normalized YBT reach distances for all directions. Anterior reach distance was frequently less than the leg length of the participants (average normalized anterior reach of 0.7). The normalized reach distances in the posterolateral and posteromedial directions were similar, with average normalized reach distances of 1.1. We observed statistically significant correlations between aggregate FMS scores and normalized posterolateral reach distances, normalized

posteromedial reach distances, and the TotalY ($r=0.36, 0.37, \text{ and } 0.36$, respectively; $p < 0.05$), reflecting that between 5 and 14% of the variance is common between the reach distances and the FMS score. These correlations are considered “fair” (Chan, 2003). The correlation between FMS scores and normalized anterior reach distances was not statistically significant ($r=0.22$). The relationships between these reach distances and FMS scores are presented in **Error! Reference source not found.-3Error! Reference source not found.**. The power for these calculations was high for the posterolateral, posteromedial, and TotalY variables (0.907, 0.923, and 0.907 respectively) but low for the anterior reach (0.495).

Table 1: Normalized reach distances (n=78) of the Y-balance test. The distances were normalized using the participants’ leg length

	Anterior	Posterolateral	Posteromedial	Total Y-balance
Mean	0.7	1.1	1.1	3.0
S.D.	0.1	0.1	0.1	0.2
Min.	0.6	0.9	0.8	2.3
Max	1.0	1.3	1.3	3.7

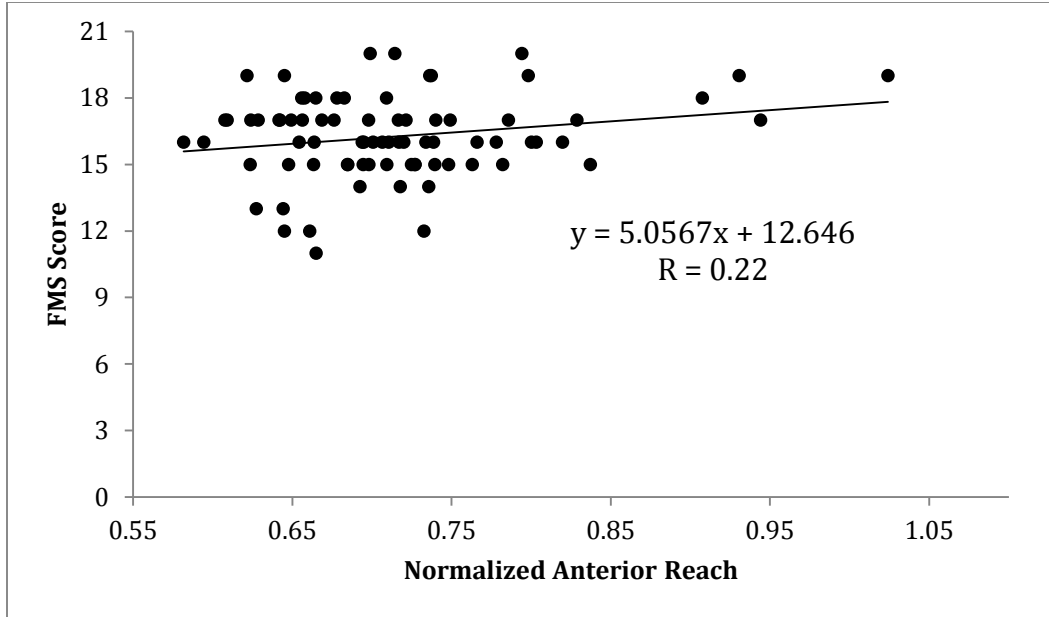


Figure 1: Relationship between the FMS score and the Y-balance test Anterior reach direction. All reach distances are normalized to the participants' leg length. The x scale in this graph is set to encompass the values observed in this study.

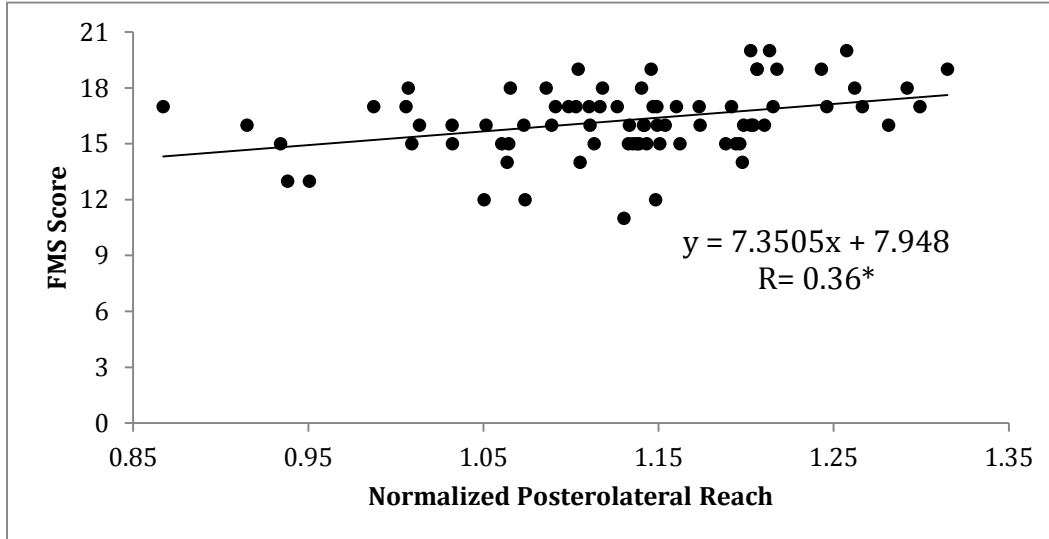


Figure 2: Relationship between the FMS score and the Y-balance test Posterolateral reach direction. All reach distances are normalized to the participants' leg length. The x scale in this graph is set to encompass the values observed in this study.

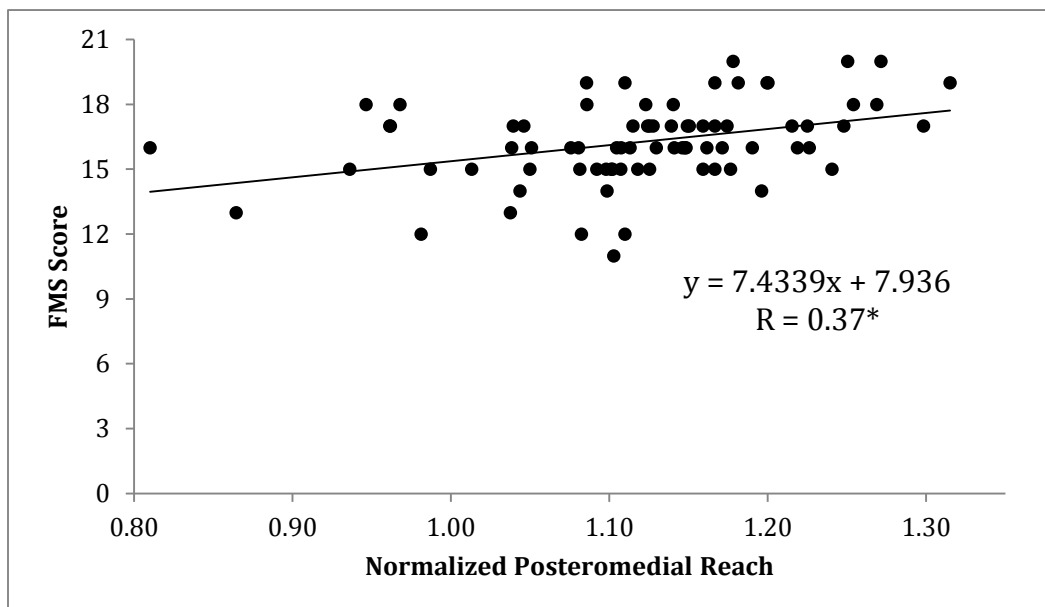


Figure 3: Relationship between the FMS score and the Y-balance test Posteromedial reach direction. All reach distances are normalized to the participants' leg length. The x scale in this graph is set to encompass the values observed in this study.

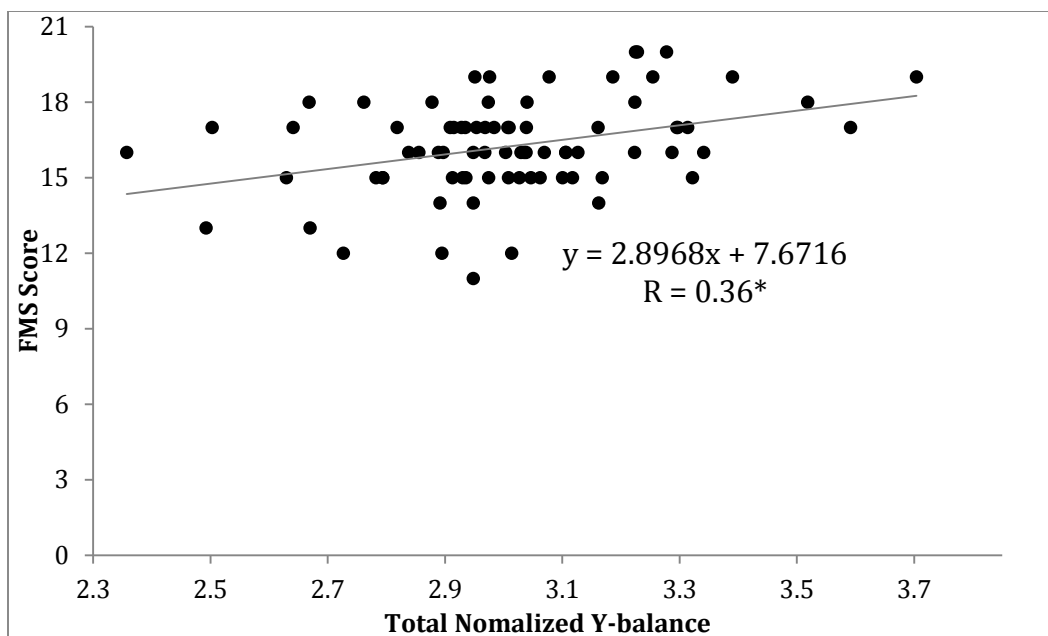


Figure 4: Relationship between the FMS score and the TotalY. All reach distances are normalized to the participants' leg length. The x scale in this graph is set to encompass the values observed in this study.

2.5 Discussion

The purpose of this study was to examine the relationship between aggregate FMS scores and YBT reach distances to determine the extent to which the FMS quantifies dynamic postural control. We observed a fair relationship, demonstrating that there is some degree of overlap between the two tests. However, the low level of explained variance suggests that the FMS is not a significant measure of dynamic postural control; there is between 5 and 14% common variance. These results are consistent with earlier work comparing individual FMS task scores with the SEBT (Lockie et al., 2015a). They found a statistically significant relationship between the TSPU and ILL with the posteromedial reach direction, and between the TSPU and the anteromedial reach direction (that reach direction is not tested in the YBT); however they did not compare the SEBT reach distances with the aggregate FMS score (Lockie et al., 2015b).

To date, much of the FMS literature has studied specific athletic and occupational populations. This study included a range of healthy subjects sampled from a general population. An earlier study examined normative data in a general, healthy sample ($n=209$) and reported similar mean FMS scores as our group (15.7 ± 1.9 ; Schneiders et al., 2011). The participants in that study were also similar to our cohort (age= 21.9 ± 3.7 , BMI= 24.4 ± 3.1), which indicates that our sample was representative of a larger, healthy population. A study examining normative data for middle aged adults (age 50.91 ± 10.80 , range 21-82; BMI= 26.02 ± 3.88) reported a mean aggregate FMS score of 14.14 ± 2.85 (Perry et al., 2013), which is lower than the current study. That study reported a negative association between age groups and BMI groups, and aggregate FMS scores. That negative association could explain the higher FMS scores in our study, as the mean age of our participants was lower and they had a lower BMI than the participants in the earlier work.

College-aged athletes and a general student population were compared previously using the FMS and YBT (Engquist et al., 2015). That study reported a mean FMS score of 14.2 ± 0.2 for student-athletes and 14.1 ± 0.2 for general college students. It is not clear why these FMS scores were so much lower than our sample, especially in the general college sample. Age does not seem to be responsible since the mean age was 20.3 ± 1.5 and 21.3 ± 1.6 for athletes and students respectively, which is younger than in our study, which suggests there should be higher FMS scores in that cohort than in our study. The YBT in that study was analysed using the best reach performance of the three attempts, compared to our approach averaging the YBT trials. We did not analyse our results using the best reach measure as the validation of the YBT was performed using a mean calculation across three trials (Plisky et al., 2009). Therefore, it is not possible to compare the YBT measurements in that study with our results.

We believe that the structure of FMS and the way that it is scored may shed light on why the correlations between aggregate FMS scores and YBT reach distances were low in our study. The FMS score is assumed to be a unidimensional construct since the individual task scores are combined into one aggregate score that is used as a measure of global 'functional movement' quality. This may not be the case since three out of four factor

analysis studies concluded that the FMS was comprised of two factors (Kazman et al., 2014; Koehle et al., 2016; Li et al., 2015). This may indicate that the FMS quantifies more than one factor, yet ‘functional movement’ was conceived as a single concept (Cook et al., 2006b; 2006a). If the FMS has a two-factor construction, then it is not appropriate to interpret the aggregate score as a metric of movement competency. In contrast, the standard FMS guidelines state that the FMS is a screening tool, that aggregate scores should be calculated, and that individual components of the FMS tests should not be interpreted (Cook et al., 2014; 2006b; 2006a). Alternative grading schemes have been evaluated (Butler et al., 2011; Frost et al., 2012), and some studies have evaluated specific task scores in isolation (Lockie et al., 2015). It may be that we have observed weak correlations between YBT and FMS scores because the FMS scores do not represent a single hypothetical construct. Since the correlation between FMS and YBT scores were low, we conclude that the FMS does not accurately quantify dynamic postural control.

2.6 Limitations

Correlations tend to be stronger if the ranges of variables are large (Bewick et al., 2003). Accordingly, the restricted range of FMS scores in our study may have attenuated our correlations, thereby limiting our ability to identify relationships that were statistically significant. For example, although we observed a mean FMS score similar to other studies (Betancourt et al., 2015; Frost et al., 2015), we did not have any scores lower than eleven or greater than 20. We found a similar range restriction problem within the TotalY reach distances, as none of our participants had a TotalY lower than 2.3.

FMS scores are related to BMI (Perry et al., 2013), but most of our participants had BMIs in the ‘normal’ range. This may be related to our recruiting strategy (university students, gymnasiums, and health clubs), as well as the difficulty of recruiting sedentary subjects to a fitness-related study, however our FMS results are similar to another study testing a healthy population (Schneiders et al., 2011).

2.7 Conclusions

Functional training has been identified as an important element of an exercise program and the FMS is frequently used by strength and conditioning coaches and personal trainers to identify weaknesses, imbalances, and compensatory movement patterns that can be 'corrected' through training (Beckham and Harper, 2010). We observed partial correspondence between the FMS and the YBT; however, the relationship was not strong enough to consider them interchangeable. This indicates that dynamic postural control is not a large component of the aggregate FMS score.

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Chapter 3

3 Exploratory Factor Analysis of Conventional and Alternate Scoring Schemes for the Functional Movement Screen

3.1 Abstract

The Functional Movement Screen (FMS) is a tool for evaluating injury risk based on qualitative appraisal of whole-body movement patterns. Its conventional scoring scheme assumes that the scores from the seven component tasks are independent, though testing complementary elements of one underlying factor. Accordingly, it is important to perform a factor analysis to determine the number of underlying factors in the test to assess its validity as a unitary construct. The FMS was administered to 100 healthy subjects from the general population. The FMS tasks were scored according to the published criteria, and also with an alternate grading scheme that did not account for pain. The factor structure was tested using a principal components analysis, and interpretation was facilitated using a varimax rotation. Examination of the eigenvalues suggested a two-factor solution that explained 45.2% of the variability in the FMS score when graded using the published scheme and 46.2% using the alternate scoring system without accounting for pain. In both analyses, three tasks (DS, HS, ILL) loaded on the first factor, three tasks (SM, ASLR, TSPU) loaded on the second factor, and the seventh task (RS) was split between the two factors. Our finding with a healthy, general population is consistent with previous exploratory factor analyses. Since the FMS does not test a single overall variable, the aggregate score of the FMS should not be considered as a measure of global movement competency. Nevertheless, it is possible that individual

FMS tasks scores may be used for this purpose, and to identify pain-provoking movement patterns.

3.2 Introduction

The Functional Movement Screen (FMS) was designed as a screening tool to evaluate movement competency in professional and recreational athletes (Cook et al., 2006a; 2006b). It comprises seven functional movement tasks (Deep Squat (DS), Hurdle Step (HS), Inline Lunge (ILL), Shoulder Mobility (SM), Active Straight-Leg Raise (ASLR), Trunk Stability Pushup (TSPU), Rotary Stability (RS)), and three clearing tests to detect whether pain is elicited during the movement tasks. Five of the functional movement tasks are performed bilaterally (HS, ILL, SM, ASLR, and RS), as is one of the clearing tests (Shoulder Impingement). The scoring of the FMS is standardized (Cook et al., 2006a; 2006b), and is briefly described for completeness. Each of the functional movement tasks is scored from zero to three. Zero denotes pain during the movement. Severe compensation or an inability to perform the movement is given a score of one, while a score of two indicates some compensation, and a score of three is awarded for perfect execution of the movement. The three clearing tests are each associated with a movement task; Shoulder Impingement with SM, Spinal Extension with TSPU, and Spinal Flexion with RS. If pain is reported while performing a clearing test, then the score for the related task is changed to zero. For bilateral tasks, the lower of the unilateral scores is used for the final calculation. These scores are added together to create an aggregate score out of 21.

The aggregate FMS score is also used to identify those at elevated risk of injury. Varying thresholds have been identified in different groups (Krumrei et al., 2014; McCunn et al., 2016). For example, a score of ≤ 14 was determined as a threshold for injury risk by using a cohort of professional American football players (Kiesel et al., 2007). This threshold is supported by some research (Bonazza et al., 2016; Chorba et al., 2010; Kiesel et al., 2014; O'Connor et al., 2011), but other studies have reported different scores that indicate an elevated risk of injury (Bardenett et al., 2015; Hotta et al., 2015; Knapik et al., 2015). The relationship between FMS and injury history has also been investigated. One study reported a significant correlation between the FMS scores and injury history in track and field athletes (Hotta et al., 2014). The aggregate FMS score has also predicted performance in occupational tasks in Police officers (Bock et al., 2014) and physical performance tests in basketball players (Klusemann et al., 2011). This use of the aggregate score of the FMS necessitates its validation.

Exploratory factor analysis is a statistical data-reduction method used to determine the number of underlying factors in a tool. The use of an aggregate (summed) score assumes that the tool has unidimensional construction – that it is measuring a single factor (Gorsuch, 1983). Unidimensionality in the FMS would indicate that it is appropriate to calculate an overall score by straight addition (unweighted), and that degraded performance on one task is equivalent to degraded performance on any other task.

Exploratory factor analysis has been performed on the FMS in several populations. One large study of US Marines (Kazman et al., 2014) analysed the FMS using the traditional scoring model (a score of zero for reporting of pain) and a 'no pain' model, where the FMS task scores were not reduced to zero when the participants experienced pain. This

group reported that the FMS was composed of two factors— one factor was loaded with the DS and ILL; the second factor with the HS, SM, ASLR, and TSPU tasks. The RS task was loaded onto both factors. They also showed that the FMS had low internal consistency (Cronbach's $\alpha=0.39$; Kazman et al., 2014). Another study used a cohort of 290 Chinese elite-level athletes (Li et al., 2015). They determined that the FMS was composed of two factors. One factor was heavily loaded with the RS task and the other factor was strongly loaded with the DS, HS, and ILL tasks, with low loadings of the other tasks. In contrast to the conventional approach for grading the FMS using the aggregate score (Cook et al., 2006a; 2006b), they concluded that the individual tasks of the FMS should be viewed independently.

A recent study used exploratory factor analysis to evaluate the FMS at a preventative health care centre (Koehle et al., 2016). There were no specific inclusion criteria for that study, so participants may have had physical injuries or health problems at the time the test was conducted. That study found that the FMS was composed of two factors; one factor comprising the DS, HS, ILL, and TSPU tasks, and the other describing the SM and ASLR tasks, with the RS task split between the two factors. As with the two earlier exploratory factor analyses, the results in that study do not support the use of the aggregate score of the FMS, as they observed a multidimensional construction.

One study performed a confirmatory factor analysis on the FMS. That study tested the fits of two- and single-factor models in a population of varsity athletes (Gnacinski et al., 2016). They did not find a statistically significant difference between the model fits, but there was a trend for the two-factor model to be superior ($p=0.054$). They concluded that a single-factor analysis was the most appropriate based on choosing the simplest model.

That interpretation supports the use of the aggregate score of the FMS; however, since their two-factor model approached statistical significance, their results were not definitive.

There are several trains of thought about the sample size that is required for factor analysis. One generally supported view is that at least 10 participants per variable should be collected, with an absolute minimum sample size of 100 (Gorsuch, 1983; Kline, 1979). Accordingly, a sample size of 100 is adequate for the number of variables in the FMS. Since previous factor analyses have not examined healthy adults from the general population, we proposed to use exploratory factor analysis to evaluate the factor structure of the FMS within a healthy population. This will determine whether the aggregate FMS score is a valid approach for assessing global movement competency.

3.3 Methods

One hundred subjects (male=50, female=50) were recruited and provided written, informed consent to participate in the protocol approved by the Western University Research Ethics Board. Participants were eligible for inclusion in the study if they were 18-69 years of age and answered “no” to each of the questions in the Physical Activity Readiness Questionnaire (Health Canada, 1992); subjects that had current physical injuries or chronic health concerns were ineligible to participate. Participants had a mean age of 27.3 ± 8.6 (range =18-55), height $172.1 \text{ cm} \pm 11.4$, and body mass $70.8 \text{ kg} \pm 15.9$.

The FMS was administered by a certified FMS practitioner using standardized procedures, equipment (Functional Movement Systems, Lynchburg, VA, USA) and

verbal commands (Cook et al., 2006a; 2006b). This approach to the FMS was chosen for repeatability and to ensure that the FMS was delivered consistently and without bias; knowledge of the FMS scoring criteria has been shown to affect subject performance (Frost et al., 2015). A maximum of three attempts for each FMS task was allowed and coaching was not provided. The protocol was video-recorded simultaneously from the frontal and sagittal planes for analysis by a single certified FMS rater at a later date. Previous research has shown that this is a reliable approach for grading the FMS (Shultz et al., 2013). The certified rater graded and scored the trials in accordance with FMS guidelines and training (Cook et al., 2006a; 2006b).

Separate analyses were conducted for FMS measurements that took pain into account and measurements that did not, as pain during movements could be a confounding factor, not related to poor movement patterns (for example, if the subject had previously sustained an acute injury). The FMS aggregate scores were therefore calculated according to the published grading criteria (Cook et al., 2006a; 2006b), and also with an alternate scoring scheme. The alternate scoring scheme removed the results of the clearing tests from the total score, and graded the other seven tasks on their execution, without regard to the subject reporting pain. This approach is similar to a previous study (Kazman et al., 2014).

The factor structure of the FMS was tested using a principal components analysis, and interpretation was facilitated by a varimax rotation. The number of extracted factors was determined through Horn's parallel analysis (Horn, 1965), which uses Monte Carlo simulation to identify the eigenvalues that would be expected due to chance, for a particular number of factor analytic items, and a given sample size. We used a Monte Carlo simulation based on 1000 simulated analyses. Factors with eigenvalues that were

greater than the average of the eigenvalues across the 1000 simulated datasets were considered candidates for extraction (Ledesma et al., 2007). The factorability of the data was estimated using the Kaiser-Meyer-Olkin (KMO) index. All statistical analyses were performed in R (Champely, 2015).

3.4 Results

The mean FMS scores for our participants were 16.1 ± 2.0 using the published criteria and 16.2 ± 1.9 using the alternate scoring criteria. Parallel analysis of both the conventionally- and alternately-scored datasets indicated a two-factor solution. These solutions were extracted and rotated (these analyses are presented in Figure 5 and Figure 6).

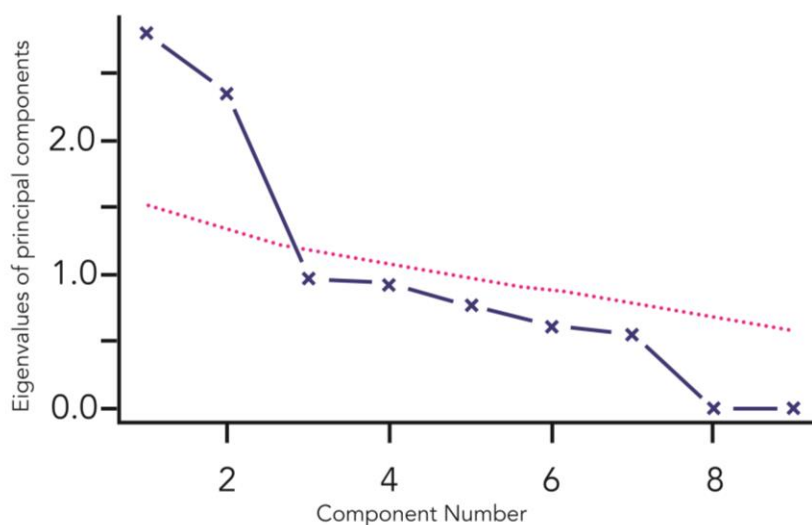


Figure 5: Parallel analysis of the FMS using the published scoring criteria. The dotted line represents the simulated data. The number of factors (indicated with crosses) above this line were extracted in our analysis.

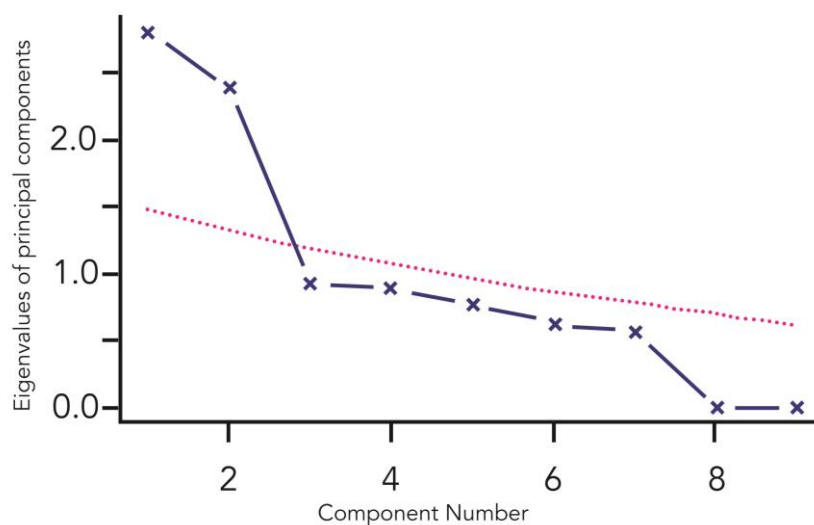


Figure 6: Parallel analysis of the FMS using the alternate scoring criteria (without pain affecting the score). The dotted line represents the simulated data. The number of factors (indicated with crosses) above this line were extracted.

The factor loadings of both analyses loaded the DS, HS, and ILL on the first factor, and the SM, ASLR, and TSPU on the second factor. The seventh task (RS) was split between the two factors. The two-factor principal components solutions are presented in Table 2 and Table 3. The overall factor solution for the conventionally scored analysis explained 45.2% of the variability in the original data; Factor 1 accounted for 24.9% of the variability and Factor 2 accounted for 20.3% of the variability. The overall factor solution for the alternate scoring system explained 46.2% of the variability in the original data. Factor 1 accounted for 24.7% of the variability and Factor 2 accounted for 21.5% of the variability. The KMO for both analyses was 0.5, which indicated that the factorability of the data was poor to borderline, suggesting that the tasks were not highly correlated.

Table 2: Factor loadings for the factor analysis of the FMS using the published scoring criteria

Item	I	II
Deep Squat	0.65	-0.16
Hurdle Step	0.70	0.09
Inline Lunge	0.76	0.11
Shoulder Mobility	0.09	0.57
Active Straight Leg Raise	0.03	0.75
Trunk Stability Pushup	0.19	-0.62
Rotary Stability	0.45	-0.35
Factor	Eigenvalue	
I	1.7	
II	1.4	

Table 3: Factor loadings for the factor analysis of the FMS using the alternate scoring criteria

Item	I	II
Deep Squat	0.66	-0.14
Hurdle Step	0.69	0.06
Inline Lunge	0.76	0.13
Shoulder Mobility (without shoulder clearing test)	0.07	0.57
Active Straight Leg Raise	0.05	0.74
Trunk Stability Pushup (without spinal extension clearing test)	0.22	-0.69
Rotary Stability (without spinal flexion clearing test)	0.43	-0.33
Factor	Eigenvalue	
I	1.7	
II	1.5	

3.5 Discussion

The purpose of this study was to determine if the aggregate score of the FMS is a valid measure of global movement competency. This is important since the published scoring criteria state that the FMS should be interpreted using the aggregate score (Cook et al., 2006a; 2006b). If the FMS test were measuring a unidimensional construct, then we would expect that the exploratory factor analysis would identify a single factor (unidimensional construction), representing movement competency. Our analyses showed that the FMS score is probably not unidimensional and therefore should not be used as a measure of movement competency or to predict susceptibility to injury. Our findings are generally consistent with those of previous studies, extending their findings on specialized populations, such as the military, to a wider variety of healthy subjects.

We also analysed our results using the alternate scoring criteria proposed by Kazman et al. (2014), because we hypothesized that the presence of pain may not indicate poor movement quality. For example, a subject may experience pain during a movement due to an underlying clinical condition that is not related to poor movement patterning. In this case, the score of zero on a task is not consistent with the assumption that the FMS scoring scheme is ordinal in nature. There were similar conclusions between the current and published study: both studies determined that the FMS has a two-factor structure even when the confound of pain is eliminated (Kazman et al., 2014).

However, there were also differences between the studies. For example, our data loaded onto factors slightly differently. The primary difference between the two populations was in the HS task. In the current study, this task loaded heavily into one factor, whereas the Marines' data were less clearly defined (Kazman et al., 2014). The differences between

these results may be due to the younger, mainly male population in the previous work. A two-factor loading solution was also reported in a group of 290 elite Chinese athletes (Li et al., 2015), however the distribution of the tasks was different to our group as the loadings were not clearly delineated apart from the RS test, which was the only task that loaded onto one factor. This was different to the current study and the other published factor analyses (Kazman et al., 2014; Koehle et al., 2016) which split the RS task between factors. That group also had a slightly lower average FMS score (15.2 ± 3.0) than in the current study (Li et al., 2015).

Two of the previous exploratory factor analyses examined the FMS in specific populations (Marines, Kazman et al., 2014; and elite athletes, Li et al., 2015). In contrast, a retrospective analysis of a general population reported that the FMS movements loaded onto two factors, similar to the current analysis and the Marines' study, however the TSPU task was grouped with the DS, HS, and ILL (Koehle et al., 2016). The data in the three previous exploratory factor analysis studies (Kazman et al., 2014; Koehle et al., 2016; Li et al., 2015), as well as the current study, indicate that the FMS is not a unitary construct and that therefore the aggregate score should not be used.

3.6 Limitations

A sample size of at least 100 has been suggested as a guideline for sample size and this is widely accepted in the literature (Gorsuch, 1983), however other factor analyses performed on the FMS have used larger datasets (Gnacinski et al., 2016; Kazman et al., 2014; Koehle et al., 2016; Li et al., 2015). The KMO in the current study was poor,

which indicates that these data are not highly factorable; KMO was not reported in previous factor analyses (Gnacinski et al., 2016; Kazman et al., 2014; Koehle et al., 2016; Li et al., 2015) so it is not clear whether this is a general property of the FMS.

3.7 Conclusion

The FMS score is purported to be a measure of “symmetry, mobility, and stability” (Cook et al., 2006a), however these are independent elements that do not naturally reflect a unidimensional construct. The use of an aggregate score assumes that a tool is a measure of a single underlying variable, in this case ‘functional movement’. We determined that the FMS does not have a single-factor structure using neither the published scoring criteria nor the alternate scoring criteria, and therefore the aggregate score cannot be recommended as a measure of movement competency or injury risk.

3.9 References

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Chapter 4

4 Functional Movement Screen Factorial Validity and Congruence are Low in Three Populations

4.1 Abstract

The scoring scheme for the FMS assumes that the scores from the tasks are independent, though all testing elements of ‘functional movement’. To determine if this is the case, we compared exploratory factor analyses of three populations using a principal components analysis in each, and evaluated the factor congruence between the samples. We studied three groups of participants that were similar to previously published FMS exploratory factor analyses: a healthy, general population (n=100), a group of varsity athletes (n=101), and a group of firefighters (n=397). Factor extraction was guided by parallel analyses, and interpretation was facilitated by varimax rotations. We observed a two-factor construction of the FMS in all of our sample groups. Additionally, we observed factor instability, low factor congruence, and inconsistent factor structure in our data and in previous studies. These analyses add to the evidence that the aggregate score of the FMS is not a valid measure of movement competency and should not be used to assess an individual’s susceptibility to injury.

4.2 Introduction

The Functional Movement Screen (FMS) is used to evaluate movement patterns and to identify those at higher risk of injury (Cook et al., 2006a; 2006b). The FMS comprises seven movement tasks (Deep Squat (DS), Hurdle Step (HS), Inline Lunge (ILL),

Shoulder Mobility (SM), Active Straight-Leg Raise (ASLR), Trunk Stability Pushup (TSPU), Rotary Stability (RS)) and three clearing tests (Shoulder Impingement, Spinal Extension, Spinal Flexion). The movement tasks assess movement competency, and the clearing tests detect pain in ranges of motion that may not be assessed in the movement tasks. The clearing tests are each associated with a functional test; Shoulder Impingement with SM, Spinal Extension with the TSPU, and Spinal Flexion with RS. The HS, ILL, SM, ASLR, and RS are performed on both sides, as is the Shoulder Impingement clearing test. The scoring and administration of the FMS is standardized (Cook et al., 2006a; 2006b). The seven movement tasks are scored from zero to three. Zero denotes pain during the task, a score of one indicates severe compensation or an inability to perform the task, a score of two indicates some restrictions, and a score of three is awarded for performing the task with no deviations from model form (Cook et al., 2006a; 2006b). The subject may perform each task up to three times to attempt to better their score. The best attempt is recorded as the score for that task. If pain is reported during a clearing test, then score for the related task is changed to zero. For bilateral tasks, such as the HS, the lower score of the sides is used for the final calculation. The final scores for each movement task are then summed to create an aggregate FMS score out of a possible 21 points.

The FMS has been proposed as a tool to identify those at elevated risk of injury. An FMS score of ≤ 14 was determined to indicate a greater risk of injury during a football season in a study using cohort of professional American football players (Kiesel et al., 2007). That threshold is supported by some research (Bock et al., 2014; Chorba et al., 2010; Klusemann et al., 2011; O'Connor et al., 2011), but not other studies (Bardenett et al.,

2015; Dossa et al., 2014; Garrison et al., 2015; Hotta et al., 2015; Knapik et al., 2015; Zalai et al., 2015). The predictive value of the FMS has also been evaluated in several review papers. One concluded that the FMS predicts elevated injury risk in certain populations including professional football players, college basketball, soccer, and volleyball players, and male marine officers (Krumrei et al., 2014). Similarly, another review paper determined that a score of ≤ 14 increased the likelihood of sustaining an injury (Bonazza et al., 2016). However, one review study does not support that conclusion (McCunn et al., 2015). The widespread use of the aggregate score of the FMS necessitates its validation to ensure consistency and efficacy.

One key component of test validation is the factor structure of the measure, which is particularly important given the typical interpretation of the FMS as a unidimensional (i.e., single-factor) measure. One method of evaluating the factor structure of a test is to employ exploratory factor analysis, where the correlations amongst items are evaluated to determine the number of factors that may be reliably identified within the data. In cases where a measure is interpreted using an overall score (as is recommended in the FMS; Cook et al., 2006a), one should observe a single factor within a factor analysis.

To date, three studies have performed exploratory factor analyses on the FMS. One large study of US Marines analysed the FMS using the conventional scoring system (a score of zero for reporting of pain) and a 'no pain' model. The alternate scoring scheme disregarded the presence of pain during the FMS tasks, as it was proposed that the presence of pain does not necessarily affect movement competency. Both analyses revealed two underlying factors – one factor was loaded with the DS and ILL, and the other factor was loaded with the HS, SM, ASLR, and TSPU. RS was loaded onto both

factors. Another study used a cohort of 290 elite-level athletes (Li et al., 2015). They also reported two factors; the first factor was heavily loaded with the RS task score with low loadings from other tasks. Their second factor was loaded with the DS, HS, and ILL, with some loading of the other tasks. Both of these studies concluded that the tasks of the FMS should be viewed independently and not as an aggregate (Kazman et al., 2014; Li et al., 2015). A third study performed an exploratory factor analysis on the FMS in a large group of adults at a preventative health care centre (Koehle et al., 2016). That study also reported two factors in the FMS; one factor loaded with the DS, HS, ILL, and TSPU and the other factor was loaded with SM and ASLR. RS loaded onto both factors. A recent study performed a confirmatory factor analysis on a group of varsity athletes (Gnacinski et al., 2016). They compared the fit of the two-factor model proposed above (Koehle et al., 2016), to a single-factor model. Their results did not find a statistically significant difference between fits, however a single-factor analysis was determined to be the best, as it was the more parsimonious. However, the two-factor model they tested approached a statistically significant value ($p=0.054$).

The factor loading of the FMS appears to vary in different populations (Kazman et al., 2014; Koehle et al., 2016; Li et al., 2015). Therefore, the factor congruence of the FMS is likely inconsistent, which indicates that separate scoring models should be developed for each group (Ferguson and Cox, 1993). This lack of factor congruence may explain the variability in the determined thresholds for elevated risk of injury in different groups (Krumrei et al., 2014). Furthermore, when there are fewer than three tasks loading onto a single factor, as in all of the earlier exploratory factor analyses (Kazman et al., 2014;

Koehle et al., 2016; Li et al., 2015), the factor solution may be unstable (Costello and Osborne, 2005).

The purpose of this study was to compare exploratory factor analyses in three populations: firefighters, varsity athletes, and a healthy, general population, to determine if the FMS is unidimensional. As these datasets roughly correspond with previous validity studies (service members, athletes, and general population), we were also interested to see if the factor structure of the FMS was consistent between similar populations to determine if there is a similar factor structure within comparable groups.

4.3 Methods

A retrospective chart review was performed on three previously collected datasets. These samples were a healthy, general population ($n=100$; 50 females, 50 males; age= 27.3 ± 8.6 , range=18-55), a group of varsity athletes from a variety of team-sport disciplines ($n=101$; 53 females, 48 males; age= 20.35 ± 1.94 , range=17-25), and a group of active-duty firefighters ($n=397$, no other data available). We received approval from the universities and appropriate institutions to review their data. The FMS in all datasets was administered and graded using standardized procedures, equipment (Functional Movement Systems, Lynchburg, Virginia, USA) and verbal commands (Cook et al., 2006b; 2006a) by certified (general population sample) and trained (athlete and firefighter samples) practitioners.

In our exploratory factor analyses, the factor structure for the FMS in each group was tested using principal components analysis, and interpretation was facilitated by varimax

rotation. The number of extracted factors was determined using Horn's parallel analysis (Horn, 1965) which uses Monte Carlo simulation to identify the eigenvalues that would be expected due to chance, for a particular number of factor analytic items, and a given sample size. Our Monte Carlo simulation was based on 1000 simulated analyses. We visually inspected each parallel analysis, and factors with eigenvalues that were greater than the average of the eigenvalues across the simulated datasets were considered to be candidates for extraction (Ledesma et al., 2007). The factorability of the data was estimated using the Kaiser-Meyer-Olkin (KMO) index and Bartlett's test of sphericity. Factor identification was conducted separately in each sample. Factor congruence was evaluated using a combination of qualitative appraisal of the factor solutions and Tucker's index of congruence. The factor loading matrices were compared amongst the three samples and to published exploratory factor analyses (Kazman et al., 2014; Koehle et al., 2016; Li et al., 2015).

4.4 Results

The mean aggregate FMS scores were 16.1 ± 2.0 for the general population, 13.1 ± 2.0 for the varsity athletes, and 13.0 ± 2.5 for the firefighters. The parallel analysis conducted on the general population data indicated a two-factor principal components solution (see Figure 7); we extracted and rotated two factors in our factor analysis. This two-factor principal components solution for the general population is presented in Table 4. In our general population sample, the DS, HS, and ILL loaded on the first factor, SM, ASLR, and TSPU loaded on the second factor, and RS was split between the two factors.

Bartlett's test of sphericity was statistically significant, suggesting that the variables were sufficiently correlated and therefore acceptable for factor analysis. The KMO

factorability of the general population data was 0.5, which is considered poor to borderline. The overall factor solution explained 45.2% of the variability in the original data; Factor I accounted for 24.9% and Factor II accounted for 20.3% of the variability.

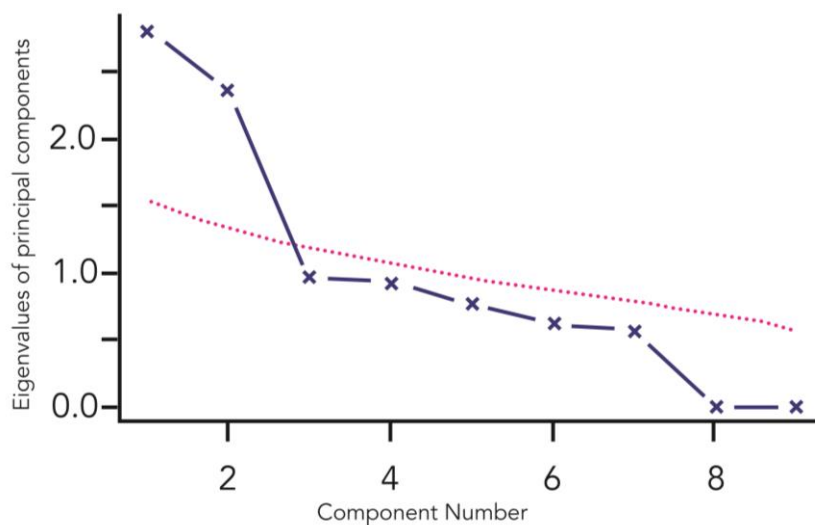


Figure 7: Parallel analysis of the FMS in a healthy, general population. The dotted line represents the simulated data. The two factors (indicated with crosses) above this line were extracted in our analysis

Table 4: FMS factor loadings in a healthy, general population

Item	I	II
Squat	0.65	-0.16
Hurdle	0.70	0.09
Lunge	0.76	0.11
Shoulder	0.09	0.57
Straight Leg Raise	0.03	0.75
Trunk Stability Pushup	0.19	-0.62
Rotary Stability	0.45	-0.35
Factor	Eigenvalue	
I	1.7	
II	1.4	

The parallel analysis conducted on the varsity athlete data indicated a two-factor principal components solution (see Figure 8); we extracted and rotated two factors in our factor analysis. These factor loadings are presented in Table 5. In the varsity athlete sample, the DS and ILL loaded on the first factor, while HS and TSPU loaded on the second factor. SM was split between the two factors, and neither ASLR nor RS loaded strongly on either factor. Bartlett's test of sphericity was statistically significant, suggesting that the variables are sufficiently correlated and therefore acceptable for factor analysis. The KMO was 0.51, which is considered borderline (but still acceptable), signifying that the data was acceptable for factor analysis. The overall factor solution explained 39.5% of the variability in the original data. Factor I accounted for 21.0% and Factor II accounted for 18.5% of the variability.

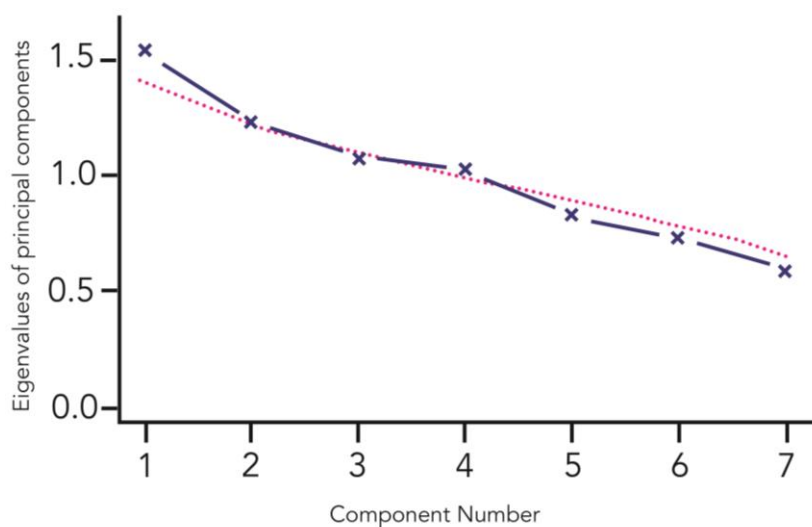


Figure 8: Parallel analysis of the FMS in varsity athletes. The dotted line represents the simulated data. Two factors were extracted in our analysis.

Table 5: FMS factor loadings in varsity athletes

Item	I	II
Squat	0.67	0.08
Hurdle	0.36	0.65
Lunge	0.75	0.04
Shoulder	0.52	-0.51
Straight Leg Raise	0.03	-0.29
Trunk Stability Pushup	0.02	0.67
Rotary Stability	0.24	0.27
Factor	Eigenvalue	
I	1.5	
II	1.3	

The parallel analysis conducted on the firefighter data indicated a two-factor principal components solution (see Figure 9); we extracted and rotated two factors in our factor analysis. The factor loadings are presented in Table 6. In the firefighter sample, the HS, ILL, SM, TSPU, and RS loaded on the first factor, while DS and ASLR loaded on the second factor. Bartlett's test of sphericity was statistically significant, suggesting that the variables were sufficiently correlated to be acceptable for factor analysis. The KMO was 0.66, signifying that the data is acceptable for the performance of a factor analysis. The overall factor solution explained 46.8% of the variability in the original data. Factor I accounted for 28.2% and Factor II accounted for 18.7% of the variability.

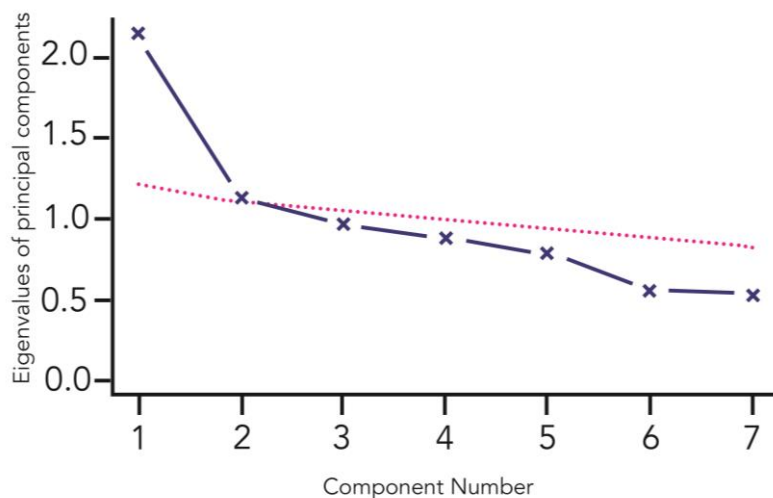


Figure 9: Parallel analysis of the FMS in firefighters. The dotted line represents the simulated data. The two factors (indicated with crosses) above this line were extracted in our analysis

Table 6: FMS factor loadings in a group of active-duty firefighters

Item	I	II
Squat	0.18	0.72
Hurdle	0.66	-0.30
Lunge	0.69	0.06
Shoulder	0.59	0.14
Straight Leg Raise	0.01	0.72
Trunk Stability	0.52	0.15
Pushup		
Rotary Stability	0.64	0.37
Factor	Eigenvalue	
I	2.0	
II	1.3	

The factor congruences for the first factor were fairly consistent between the general population and athletes, general population and firefighters, and athletes and firefighters (0.89, 0.83, and 0.79, respectively). However the congruences for the second factor were not at all consistent (-0.71, 0.19, and -0.16, respectively).

The factor structure was not consistent between general samples (our general sample and Koehle et al., 2016), athletes (our varsity sample and Li et al., 2015), and service members (our firefighter sample and Kazman et al., 2014). Those comparisons are presented in Figure 10.

4.5 Discussion

The purpose of this study was to determine if the aggregate score of the FMS is a valid measure of functional movement. This is important since the published scoring criteria recommend that the FMS is scored using the aggregate value (Cook et al., 2006a; 2006b). If the FMS test is a valid construct that can be interpreted with an aggregate score, then we would expect that the factor analysis would identify a single factor (unidimensional construction), presumably representing 'functional movement', and that there would be strong factor congruence between different populations. All three of our analyses showed that the FMS score has two underlying factors, and the second factor showed low congruence between our groups. The aggregate score of the FMS is therefore not an accurate measure of movement competency and should only be used as a screening tool. This is consistent with elements of a recently published paper by the authors of the FMS (Cook et al., 2014).

The three published exploratory factor analyses all determined that the FMS tasks load onto two factors, similar to our results (Kazman et al., 2014; Koehle et al., 2016; Li et al., 2015). However, an earlier confirmatory factor analysis supported a single-factor solution (Gnacinski et al., 2016). We used visual appraisal of our parallel analyses (Figures 7-9) to determine the number of factors we extracted. Our general population had two factors clearly above the simulated eigenvalues, however the number of factors to extract in our varsity athletes and firefighters were less evident. Although we extracted two factors in all our analyses, the varsity athlete plot approached a three-factor model, though two of the factors were very close to the eigenvalue line. In order to select the most parsimonious factor model, we extracted two factors (Kline, 1979). The firefighter analysis approached a single-factor solution, however we decided to extract two factors as the second factor's eigenvalue was 1.3. An eigenvalue of >1 is sometimes used as an alternate criterion for factor extraction (Kaiser, 1960).

The factor congruences in our study were consistent in one factor, however low in the other factor. That suggests that the aggregate score of the FMS does not appraise different populations with reliability and that separate scoring models for each group should be developed (Ferguson and Cox, 1993). Factor stability is enhanced when there are at least three variables per factor (Costello and Osborne, 2005). We observed fewer than three tasks in one factor in our varsity athletes and firefighters, as well as in earlier exploratory factor analyses (Kazman et al., 2014; Koehle et al., 2016; Li et al., 2015). This instability may explain the low second-factor congruences in our study.

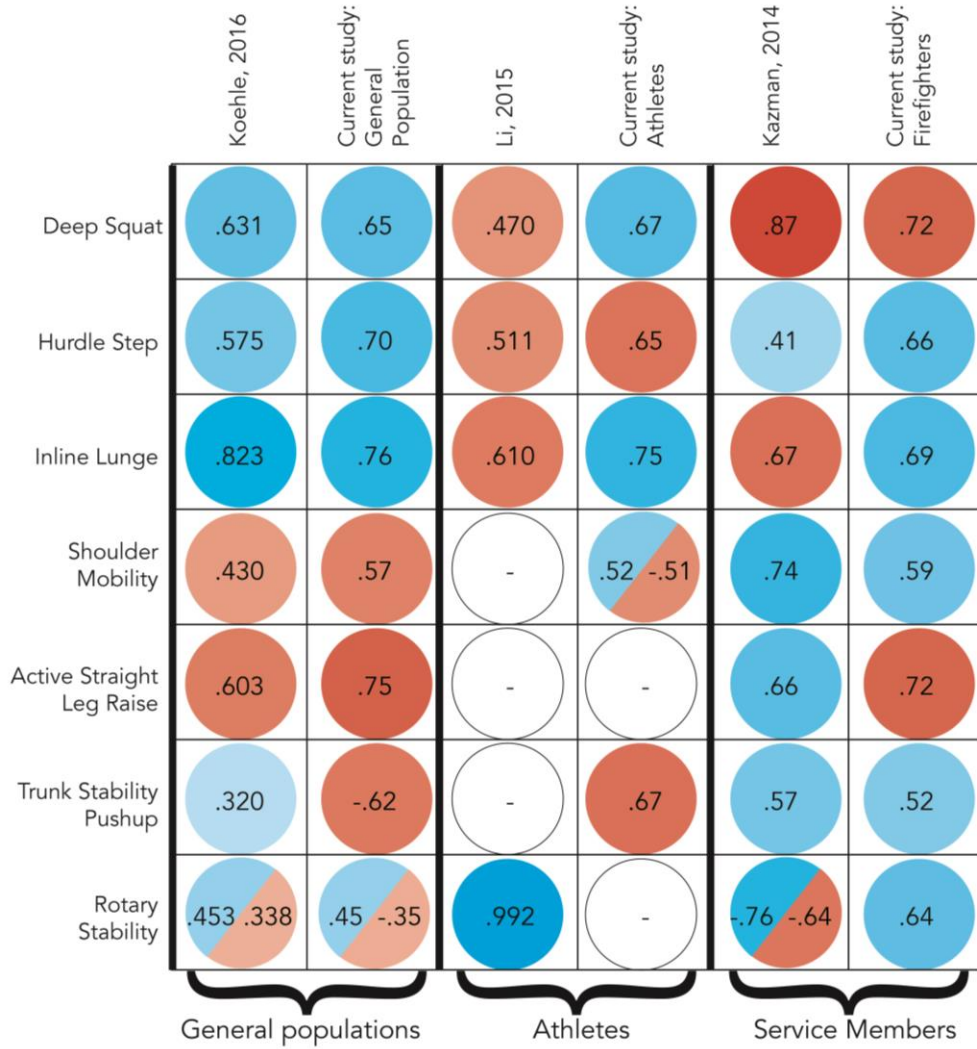


Figure 10: Comparison of factor structure between published studies and our data, arranged by population type (Kazman et al., 2014; Koehle et al., 2016; Li et al., 2015). Factor I is shaded with blue and Factor II is filled in red. The strength of the loading is indicated with colour saturation. Tasks that are split between factors are indicated as such, and the empty cells indicate that the task did not load onto either factor

We also wanted to determine if the factor structure was consistent between similar sample groups (Figure 10). There were differences, however, between the factor structures in all of the studies. The factor structure of the general population samples were most similar, however the TSPU loaded onto the same factor as the DS, HS, and ILL in the earlier analysis (Koehle et al., 2016). Our general population data placed the TSPU into the same factor as the SM and ASLR. The Chinese athletes (Li et al., 2015) and our varsity athletes showed very different factor loadings. This may be due to the level of athletic achievement (the Chinese group were international-level competitors; Li et al., 2015), or the composition of the groups. The athletes in our study were all team-sport players, while the Chinese athletes came from team, individual, and target sports; only 44 of the 290 participants in that study were team-sport competitors (Li et al., 2015). There was also a large difference in factor loading between the Marines study (Kazman et al., 2014) and our group of firefighters. This difference may be due to the age of the participants as FMS scores decline with increasing age-groups (Perry et al., 2013). Although we do not have demographic data for the firefighters in the current study, the age of the firefighters is likely older than that of the Marines (22.4 ± 2.7), as they were active-duty, and not trainees as in the previous work. Other research on active-duty firefighter fitness (a separate, though perhaps similar sample) has reported a mean age of 33.4 ± 7.0 (Frost et al., 2012).

4.6 Limitations

Suggested sample size for factor analysis varies within the literature, however a sample size of 10 participants per variable has been suggested to be reasonable, with an absolute

minimum sample size of 100 (Gorsuch, 1983; Kline, 1979). Each of our three datasets had 100 cases or more, but other sources suggest a minimum of 300 cases for factor analysis (Tabachnick and Fidell, 2001). If judged on this basis, our general and athlete samples would be considered inadequate, however our firefighter sample size would be adequate. Other exploratory factor analyses performed on the FMS have used larger datasets with similar results as our analyses (Kazman et al., 2014; Koehle et al., 2016; Li et al., 2015).

4.7 Conclusion

We observed a two-factor construction of the FMS in firefighters, varsity athletes, and a healthy, general population. Additionally, we observed factor instability, low factor congruence, and inconsistent factor structure in our data and in previous studies. These analyses add to the evidence that the aggregate score of the FMS is not a measure of movement competency and should not be used to assess an individual's susceptibility to injury.

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5 General Discussion and Summary

5.1 General Discussion

The overall purpose of this thesis was to investigate the validity of the aggregate FMS score. Our data demonstrate that the aggregate FMS score is not a valid measure of dynamic postural control or global movement competency. The first study (Chapter 2), investigated whether the FMS is a gauge of dynamic postural control by comparing it with a validated test, the YBT. Although there was some degree of correspondence between the two tests, we concluded that the FMS is not an accurate representation of this measure. Chapters 3 and 4 presented exploratory factor analyses of the FMS to determine whether it quantifies a single factor ('functional movement'). Chapter 3 presented an exploratory factor analysis of the FMS in a healthy, general population. The data was best described with a two-factor model, which does not support the use of the aggregate FMS score. In Chapter 4, we compared this analysis to exploratory factor analyses of two other populations, a group of varsity athletes and a group of active-duty firefighters. The factor analyses in Chapters 3 and 4, as well as previously published studies (Kazman et al., 2014; Koehle et al., 2016; Li et al., 2015), determined that the FMS has a multifactorial structure, and therefore the aggregate score should not be used. Furthermore, we observed that the factor congruence of the FMS is both low and unstable which indicates that the test is not a reliable measure in different populations.

The FMS score is frequently used to assess movement competency and susceptibility to injury. Because individual task scores in the FMS are added together to form an aggregate score, it is important that the tool is validated to ensure it is an accurate and reliable measure of a single, global concept. This has previously been undertaken by determining if the aggregate score predicts injury risk (Bonazza et al., 2016; Krumrei et al., 2014; McCunn et al., 2016), and also through investigation into the structural validity of the FMS using psychometric analyses (Gnacinski et al., 2016; Kazman et al., 2014; Koehle et al., 2016; Kraus et al., 2015; Li et al., 2015). This thesis continued examination into the validity of the aggregate FMS score. Chapter 2 builds on previous work on the FMS and the YBT (Chimera et al., 2015). That study investigated whether injury history and sex affect the relationship between the FMS and YBT. They found that

injury history does not affect summed YBT scores and that there are differences between sexes in aggregate FMS scores (Chimera et al., 2015). Our study used a similar approach to appraise the relationship between the FMS and the YBT to determine if the FMS is a measure of dynamic postural control. ‘Functional movement’ is poorly described in the literature, however since dynamic postural control is an important element of many sports and normal daily activities, we thought it would likely be a significant component of the FMS. However, though the slope of the regression line was statistically significant in some reach directions, we concluded that dynamic postural control was not a large component of the FMS as it only represented a small amount of the variance. Core stability is not a component of the FMS (Okada et al., 2011) and glenohumeral range of motion does not influence scoring in the SM task (Sprague et al., 2014). As ‘functional training’ is designed to improve dynamic and static balance and range of motion (Beckham and Harper, 2010), one would expect a functional movement assessment tool to reflect these measures. However, our results and previous work determines that the definition of ‘functional movement’ in the context of the FMS is still poorly understood, and consequently the underlying element/s that comprise the FMS are not known.

In order to further explore the construct of the FMS, this thesis continued the investigation into the structural validity of the aggregate FMS score. Previous studies have performed factor analyses in populations of Marines (Kazman et al., 2014), elite athletes (Li et al., 2015), a general population at a health centre (Koehle et al., 2016), and varsity athletes (Gnacinski et al., 2016). The first three studies revealed a two-factor structure of the FMS that does not support the use of the aggregate FMS score; the fourth study supported its use in varsity athletes. These earlier works examined specific population groups; we performed an exploratory factor analysis on a group of healthy adults to examine the factor structure of the FMS in a general population (Chapter 3). Our analysis revealed two underlying factors in the FMS. Our factor structure was similar to Koehle et al. (2016), with differences potentially due to the age of the participants; the subjects were older in the earlier study (age=51.7 \pm 11.8) compared to our group (age=27.3 \pm 8.6). Participants in our study were excluded if they had health and/or joint problems in contrast to the other study (Koehle et al., 2016), which was conducted in a

health care facility, so their participants could have had physical conditions that may have affected their FMS results. We concluded that the FMS demonstrates a multidimensional factor structure in healthy adults. This structure does not support the use of the aggregate score in this population, as the FMS does not measure a single, overall concept.

A multidimensional factor structure has also been reported in three of the four published factor analyses (Kazman et al., 2014; Koehle et al., 2016; Li et al., 2015). The two-factor model observed in these populations, however, varied. We were interested to compare the factor structure of different populations to determine if the FMS is a valid and/or consistent measure of movement competency. Chapter 4 described the factor structure of the FMS in different populations. We compared exploratory factor analyses of the FMS in three groups: the same general population that we analysed in Chapter 3, a varsity athlete sample, and a group of active-duty firefighters. We observed two-factor construction of the FMS in all three groups. In addition to comparison between our groups, we also compared our results to previous exploratory factor analyses of the FMS (Kazman et al., 2014; Koehle et al., 2016; Li et al., 2015). The varsity athlete cohort in our exploratory factor analysis revealed two underlying factors in the FMS, however a published confirmatory factor analysis of varsity athletes found no statistically significant difference between single- and two-factor models, though their two-factor model approached significance (Gnacinski et al., 2016). We observed differences in factor structure between our groups and earlier exploratory factor analyses on similar populations. Although all groups demonstrated a two-factor structure, the distribution of tasks in each factor was not consistent. When the factor structure of a test is not consistent between populations, a separate scoring model should be developed for each group (Ferguson and Cox, 1993). The inconsistency we observed suggests that the FMS is sensitive to different tasks, depending on the population. If a different scoring model should be developed for each group, then the practical utility of the FMS is questionable.

Furthermore, an item analysis study determined varying levels of difficulty within the tasks in the FMS (Kraus et al., 2015). Since the scoring scale for the FMS is not intervallic, simple addition of the tasks scores can mean that similar aggregate FMS scores can be unequal in overall difficulty. The strength of the FMS, therefore, may lie in

individual task analysis (although this was not the intent of the FMS' developers; Cook et al., 2006a) as it presents a battery of tasks of varied difficulty. Recent recommendations identify that use as a general screening tool for pain or underlying injury may be the most appropriate application of the FMS (Cook et al., 2014).

The cumulative evidence presented in this thesis has determined that the FMS is not a reliable or valid tool for quantifying global movement competency or for determining risk of injury.

5.2 Limitations

The analyses contained in this thesis are based on datasets that were collected by the authors (Chapters 2, 3, and 4) and also by third parties (Chapter 4). The general population dataset was collected and graded by a certified FMS practitioner, however the varsity athletes and firefighters were collected by trained, but not certified raters. This constitutes potential differences in administration and rating techniques; however, previous research has determined that the experience of the rater does not affect the results of the FMS (Gulgin and Hoogenboom, 2014). To evaluate the effect of this in our data, we performed an inter-rater reliability study on the varsity athlete dataset, which showed excellent agreement between raters (details of this study are in Appendix 2).

Demographic data for the firefighters were not available so we were not able to determine if age or sex were contributing factors in the results for that dataset. This may have affected the results as age groups and FMS scores are negatively correlated (Mitchell et al., 2015). Our general population sample also had a BMI within the normal range (BMI = 23.9 ± 3.1), which may mean we did not test a representative general population sample as >41% of Canadian adults aged 18-59 have a BMI of >25 (overweight or obese; (Statistics Canada, 2012). This is may be due to our recruiting strategy which was based primarily at health clubs, preventative health care facilities, and physical recreation centres.

The recommended sample size for factor analysis varies within the literature; Tabachnick (Tabachnick and Fidell, 2001) recommends at least 300 cases. If adjudicated on this basis, the sample sizes for our general population and varsity athletes were too low to perform accurate factor analyses. Other sources, however, recommend ten cases per variable with a minimum of 100 cases (Gorsuch, 1983; Kline, 1979). As there are seven variables in the FMS, our general and varsity athlete datasets (n=100 and 101, respectively), were adequate according to those guidelines and our firefighter sample size (n=397) was sufficient by all of those measures.

5.3 Future Directions

This thesis investigated the validity of the FMS and has provided evidence that it is not an accurate or reliable measure of dynamic postural control, global movement competency, or susceptibility to injury. Continuation of this work is important since the aggregate score of the FMS continues to be widely used to assess an individual's movement competency and injury risk (Krumrei et al., 2014; McCunn et al., 2016). To date, there has not been a large-scale factor analysis performed on a heterogeneous population by a certified FMS practitioner. Using a certified FMS practitioner/s would ensure consistency in delivery and rating, true to the intent of the tool, thereby providing irrefutable evidence regarding its validity.

Alternate scoring criteria (Butler et al., 2011) and modifications to the FMS (Frohm et al., 2012) have been proposed. Although the 100-point scoring system (Butler et al., 2011) did not result in a meaningful improvement in scoring (Frost et al., 2012; 2011), there is potential for the development of other scoring schemes. The validity and efficacy of these should be investigated further as they may represent the development of a more reliable and accurate tool for quantifying movement competency than the FMS appears to be. While there has been some research into the kinematics of the DS task (Butler et al., 2010), greater insight into the causes and implications of low scoring in other FMS tasks could inform the development of a more refined tool for quantifying movement competency.

5.4 Summary

The FMS is a tool that purports to measure movement competency and to identify those at risk for sustaining an injury (Cook et al., 2006a; 2006b). This approach assumes that the FMS tasks are each describing elements of a single factor ('functional movement'), such that it is appropriate to interpret the test using an aggregate score. This thesis presents evidence that the aggregate FMS score is not a consistent nor accurate tool for quantifying global movement competency. This was determined through comparison of the FMS to a validated measure of dynamic postural control (Chapter 2), exploratory factor analysis in a healthy, general population (Chapter 3), and by comparing exploratory factor analyses and factor congruence in diverse populations (Chapter 4). Overall, the implications of this thesis impact the use of the FMS in professional sports scouting combines, recreational and amateur athletes, as well as in clinical settings, as the aggregate score of the FMS is not a valid measure of movement competency or susceptibility to injury.

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Appendix 1

Demonstration of Functional Movement Screen tasks



Plate 1: Deep Squat (DS)

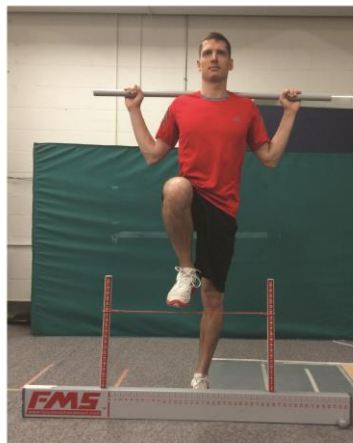


Plate 2: Hurdle Step (HS)

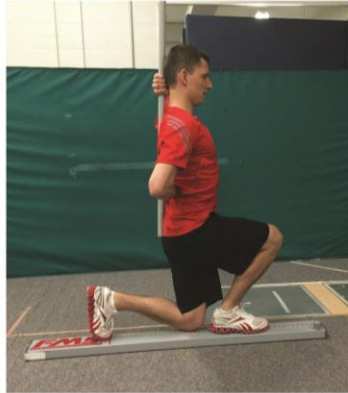


Plate 3: Inline Lunge (ILL)



Plate 4: Shoulder Mobility (SM)



Plate 5: Shoulder Impingement Clearing Test



Plate 6: Active Straight Leg Raise (ASLR)



Plate 7: Trunk Stability Pushup (TSPU)



Plate 8: Spinal Extension Clearing Test



Plate 9: Rotary Stability (RS)



Plate 10: Spine Flexion Clearing Test

Demonstration of the Y-balance Test Reach Directions



Plate 11: Anterior reach direction



Plate 12: Posterolateral reach direction



Plate 13: Posteromedial reach direction

Appendix 2

The varsity athlete group analysed in Chapter 4 was administered and graded by a third party. In order to ensure that the rating system was consistent between the FMS certified rater and the varsity athlete rater (trained, but not certified), we performed an interrater reliability test using the video-recorded FMS tasks. The certified rater graded 14 of the 101 varsity athletes for comparative purposes and did not have knowledge of the trained rater's results.

We computed an ICC3k intraclass correlation coefficient on the two sets of ratings, wherein the raters were assumed to be fixed (i.e., not a random sample of possible raters), and the dependent variable was an average of multiple ratings. Using this method, we found an intraclass correlation coefficient of 0.95 (95% confidence interval, 0.84 to 0.98). This demonstrated excellent correspondence between the two raters.

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Education

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Publications

Development And Verification Of A Kinematic Protocol To Quantify Hip Joint Kinematics: An Evaluation Of Ice Hockey Goaltender Pads On Hip Motion
Ryan Frayne, Leila Kelleher, Peter Wegscheider, James Dickey
American Journal of Sports Medicine September 2015 (vol. 43 no.9: 2157-63)

Biomechanical Research on Bowed String Musicians: a Scoping Study
Leila K. Kelleher, Kody R, Campbell, James P. Dickey
Medical Problems of Performing Artists, December 2013 (vol. 27, no. 4: 212-218)

Conferences

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Core Stability Measures Predict Functional Movement Screen Scores
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Podium presentation – National Strength and Conditioning Association
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Individual Y-Balance Test Reach Length and Functional Movement Screen Scores Are Related

Leila K. Kelleher, Tyson A.C. Beach, Andrew M. Johnson, James P. Dickey
Poster presentation – National Strength and Conditioning Association
July 8-11, 2015 – Orlando, Florida, USA

Functional Movement Screen (FMS) scores are related to the Anterior and Posteromedial reach distances in the Y-Balance Test, but not the Total Y-Balance Reach

Leila K. Kelleher, Tyson A.C. Beach, Andrew M. Johnson, James P. Dickey
Podium presentation – Pan American Sport and Exercise Research Summit
April 16-18, 2015 – Toronto, Ontario, Canada

Quantifying Hip Kinematics in Ice Hockey Goaltenders

Ryan Frayne, Leila Kelleher, Peter Wegscheider, James Dickey
Poster Presentation – World Congress of Biomechanics
July 5-11, 2014 – Boston, MA, USA

Prevalence of PRMPs in Professional and Pre-Professional Classical Musicians: A Scoping Review

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Fine-Wire EMG Analysis of Muscle Activity During Orchestral Viola Performance

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- 2012-2014** **Injury Prevention for Musicians**
National Youth Orchestra of Canada
2012 – London, ON, Canada
2013, 2014 – Waterloo, ON, Canada
- 2013** **Musicians' Biomechanics**
Seminar for all faculty and students
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- 2013** **Career Paths After Music**
Cleveland Institute of Music (Cleveland, OH, U.S.A.)

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Canadian Society of Biomechanics