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The Relationship Between the Functional Movement Screen™ and Countermovement Jump Height

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THE RELATIONSHIP BETWEEN THE FUNCTIONAL MOVEMENT SCREEN[TM]

AND COUNTERMOVEMENT JUMP HEIGHT

by

Joshua K. Conlon

A Thesis Submitted in

Partial Fulfillment of the

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ABSTRACT

THE RELATIONSHIP BETWEEN THE FUNCTIONAL MOVEMENT SCREEN^{TM}
AND COUNTERMOVEMENT JUMP HEIGHT

by

Joshua K. Conlon

The University of Wisconsin-Milwaukee, 2013
Under the Supervision of Professor Kyle T. Ebersole, Ph.D., ATC

Introduction: Pre-participation measures of functional movement and functional performance are commonly used to gauge injury risk and performance baselines before engaging in activity. Functional movement can be evaluated using the Functional Movement Screen™ (FMS™). Performance on the FMS™ has been shown to be related to injury risk by previous researchers. Functional performance can be evaluated with countermovement jump (CMJ) testing; performance on a CMJ demonstrates transferable power to athletic tasks. Performance literature has shown that there are movement factors that influence CMJ height. However, to date a significant relationship between performance on functional movement and functional performance tests has not been found. Therefore, the primary purpose of this study was to examine the relationship between the FMS™ total score, scored on a 100-point and 21-point scale, and CMJ height. The secondary purpose of the study was to perform an exploratory analysis examining the relationship of the 21-point live scoring method as well as a 21-point video scoring method of the FMS™. **Methods:** This study examined the relationship between functional movement and functional performance of 36 participants. Functional

movement was evaluated with the FMS™. The FMS™ was scored on three scoring scales: 21-point live, 21-point video and 100-point. Functional performance was quantified with CMJ height. Performance height of the CMJ was examined through the use of a Myotest Sport unit. Bivariate Pearson correlations were used to examine the relationships among all tested variables. **Results:** All FMS™ scoring methods were significantly related to CMJ height. Each of the FMS™ scoring scales were also significantly related to one another. **Conclusions:** Functional movement appears to be related to functional performance regardless of the scale used to score the FMS™. Additionally, the strong relationship shown between the scoring scales suggests that the scales evaluate movement patterns similarly. However, more research is needed to better understand the relationship between these two variables. Further research is also needed to determine the validity of the FMS™ scoring scales and identify if the component tests are scored differently on each scale.

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CHAPTER I: INTRODUCTION

Background

It is widely accepted that sport participation and exercise are methods by which individuals stay active and physically fit. It is recommended that prior to participation in physical activity, active persons utilize pre-participation measures to gauge injury risk and performance baselines before engaging in activity (Cook, Burton, & Hoogenboom, 2006a). The use of injury risk and athletic performance field tests have become integral elements in the pre-participation evaluation process for exercisers and athletes (Kiesel, Plisky & Voight, 2007; Minick et al., 2010). These field testing methods are commonly used to assess the risk of injury for an individual as well as track training adaptations. Both injury risk and athletic performance tests can be used as a guideline for inclusion and exclusion in sport participation. Despite the possible benefits of each method of evaluation, a single method of evaluating both injury risk and athletic performance has not been developed to be used in field testing. This provides an opportunity to research how current tools for injury assessment could be used to evaluate athletic performance.

Pre-participation screening assessments are used by researchers, clinicians and coaches to establish baseline performance values. An injury risk field testing method that has grown in popularity is the Functional Movement Screen™ (FMS™). It was developed as a method to evaluate the balance of mobility and stability within an individual's movements, which may lead to injury (Cook et al., 2006a; Cook, Burton, & Hoogenboom, 2006b). The FMS™ is a series of seven tests that purposefully place participants in positions representing fundamental movement patterns, in an attempt to isolate a segment, or segments, that are deficient in, or have asymmetric (O'Connor,

Deuster, Davis, Pappas & Knapik, 2011) amounts of strength, stability, and balance

(Kiesel et al., 2007). The seven tests of the FMS™ include a Deep Squat, Hurdle Step,

In-line Lunge, Shoulder Mobility, Active Straight Leg Raise, Trunk Stability Push Up,

and Rotary Stability. These tests were designed to identify areas of limitation,

asymmetry and imbalance within movement patterns (Cook et al., 2006a; Cook et al.,

2006b). Although pre-participation screening may improve identification of injury risk

(cite), a relationship between performance on pre-participation screening and athletic

performance has yet to be established.

The Functional Movement Screen™ is a reliable tool (Chorba, Chorba, Bouillon,

Overmyer & Landis, 2010; Kiesel et al., 2007; Peate, Bates, Lunda, Francis & Bellamy,

2007) for the identification of injury risk and has been used on a variety of active

populations (i.e., firefighters, collegiate athletes, military officer candidates). It provides

observable data of an individual's movement patterns where compensatory motions exist

to mask current limitations. Previous literature has attempted to find a relationship

between FMS™ and athletic performance; however, these papers were unsuccessful

(Okada, Huxel & Nesser, 2011; Parchmann & McBride, 2011). In the studies that

attempted to show a relationship between functional movement and athletic performance,

the 21-point scale was used to score all seven tests. Despite the varying movement

complexities, each of the movement tests was scored out of the same total number of

points. By treating each test similarly, the 21-point scale may limit the precision of the

FMS™ as it serves to identify large movement limitations. Improved specificity of the

scoring system used with the FMS™ may provide a more precise relationship between

movement and athletic performance.

One way that the scoring of the FMS™ has become more precise is through the use of a 100-point scale. The 100-point scoring method, originally described by Butler et al. (2012), was developed to add precision to the scoring method of the movements and sensitivity to the measurement scale by allotting a greater total point value to more complex movements. As a result, the total aggregate score increased from 21-points to 100-points (Butler et al., 2012). In Butler et al. (2012), the reliability of the 100-point scale was shown to be strong between raters (ICC = 0.99). Therefore, both the 21-point and the 100-point scales of measurement for the FMS™ each have high interrater reliability (Butler et al., 2012). Butler et al. (2012) also suggested that through further research using a more precise method of scoring the FMS™ that a relationship between one's functional movement and athletic performance could be established.

A variety of athletic performance measures have been compared to the FMS™ without successful findings of a positive relationship (Okada et al., 2011; Parchmann & McBride, 2011). These performance measures were brought out through a series of tests assessing flexibility, power, strength and speed. Power, strength and speed have been shown to be variables of interest as each element translates well into many sport-specific tasks (Lees, Vanrenterghem, & De Clercq, 2004; Luebbers et al., 2003; Moran and Wallace, 2007; Salles et al., 2011; Vanrenterghem et al., 2008). Field tests, such as a vertical jump, can be used to assess athletic performance by quantifying many variables that translate well to sport (Aragón-Vargas, 2000; Cronin & Hansen, 2005; Luebbers et al., 2003). More specifically, countermovement jump (CMJ) testing, a method of vertical jumping, demonstrates the explosive power that can be generated by the lower extremity muscles during sport tasks that also requires rapid development of strength and power

(Domire & Challis, 2007; Hartmann et al., 2012; Vanezis & Lees, 2005). Methods of jump height measurement exist as ways to quantify the power generated by the lower extremity. Of the methods available, the MyoTest Sport Unit will be used for this study as it is both a valid and reliable method of measuring jump height (Bubanj, Stankovic, Bubanj, Bojic, Dindic, & Dimic, 2010; Casartelli, Mueller, & Maffiuletti, 2010; Nuzzo et al., 2011).

The use of the FMS™ is well-documented as a pre-participation risk assessment tool; yet, previous findings have been unable to find a relationship between functional movement ability and athletic performance tasks (Okada et al., 2011; Parchmann & McBride, 2011). This review suggests that the FMS™ may be related to countermovement jump performance when scored on a scale that provides a greater amount of detail from the tests. The ensuing results may provide evidence toward a relationship between functional movement capacity and functional performance.

Purpose

The primary purpose of this study was to examine the relationship between the FMS™ total score, scored on a 100-point and 21-point scale, and CMJ height. The secondary purpose of the study was to perform an exploratory analysis examining the relationship of the 21-point live scoring method and the 21-point video scoring method of the FMS™.

Hypotheses

A 21-point scale does not provide enough detail on various physiological and biomechanical measures that would contribute to underlying performance; however, the 100-point scoring scale for the FMS™ has a higher degree of precision to evaluate a

participant's movement patterns in more detail. It was hypothesized that those who perform better on the FMS™, when scored on a 100-point scale, will demonstrate a positive relationship with countermovement jump height. It was also hypothesized that a relationship exists between the scoring scales of the FMS™ (i.e., 21-point live, 21-point video, 100-point).

Significance

Scientific significance. This study offers scientific significance as it was the first study to test the possible relationship between functional movement, measured by the FMS™ on a 100-point scale, and functional performance (i.e., CMJ peak height). The MyoTest SPORT unit was used to determine CMJ performance so that the influence that functional movement has on peak height could be evaluated. Additional significance can be taken from this study as it offered a comparison of two methods of scoring the FMS™ 21-point scales. If the two methods are significantly correlated to one another, FMS™ scoring on a 21-point scale could be compared despite different methods of tests evaluation.

Practical significance. This study was the first to delve into the relationship between functional movement, which is defined as the total FMS™ score, and functional performance, defined as CMJ height. This study provides a contribution to a current gap in the literature, by attempting to understand how performance markers could be influenced by one's ability to move. The results of this study may shed light on how athletes who have greater amounts of mobility and dynamic stability, as well as fewer compensatory movement patterns, may be better performers in a jumping task. A relationship already exists between functional movement and injury risk assists. If a

relationship is found between the FMS™ and a functional performance task (i.e., CMJ height), a case could be made that a relationship may exist between injury risk and athletic performance. This potential relationship would suggest that someone that has greater movement ability will not only perform better in an explosive movement task, but will also be less likely to sustain an injury during their performance. Significance may also be found by comparing two methods of scoring the 21-point scale. A comparison of the two scoring methods, live and video assessment, was examined to determine the reliability of the compared methods. If a relationship is found between each of the methods of scoring, practitioners and clinicians using the FMS™ will be able to use live and post hoc video analysis interchangeably.

Delimitations

The delimitations of this study were put in place to reduce the influence of factors (i.e., injury history, gender, age, physical activity level, body mass index, FMS™ experience) that may influence an individual's performance in both FMS™ and CMJ testing. In an attempt to reduce injury risk during data collection, all participants that had recently had an injury, surgery, or bone abnormalities (i.e., of the shoulder, hip, knee, and/ or the ankle), were currently taking medication for illness, had a heart condition and/ or chest pain, suffered from dizziness, and/ or had a hearing impairment (due to the need to hear the auditory stimulus from the MyoTest), were not be allowed to participate in this study. Another variable that was being controlled was gender. Only male participants were evaluated in this study in an attempt to build on the previous primary research that has used the FMS™ (Frost, Beach, Callaghan, & McGill, 2012; Goss, Christopher, Faulk, & Moore, 2009; Kiesel et al., 2007; Kiesel, Plisky, & Butler, 2011;

O'Connor et al., 2011). In addition, while evidence demonstrates a lack of significant

difference between males and females in total aggregate FMS™ score on a 21-point

scale, differences existed within the individual component test scores that make up the

total FMS™ score (Schneiders, Davidsson, Hörman, & Sullivan, 2011). Since the

FMS™ scored on a 100-point scale does not have identical total scores for each of the

tests and allows for a wider range of achievable points, it is possible that the individual

test score differences may become more prominent through the use of a more precise

scoring method; therefore, only males were be recruited for this study. Age was also a

potential influencing factor to an individual's FMS™ and CMJ performance. To remain

consistent with the age range of populations used in the current literature, all participants

were between the ages of 18-30 years old (Butler et al., 2010; Chorba et al., 2010; Frost

et al., 2012; Goss et al., 2009; Onate et al., 2012). Age can have additional effects on

performance. Evidence exists to support age-related tendon degeneration as early as 30

years of age (Bosco & Komi, 1980). Furthermore, to reduce the influence that training

had on jump height, only participants that self-identified as exercising at least to the

American College of Sports Medicine (ACSM) guidelines were included in this study.

Athletes and those currently participating in organized training to actively improve their

vertical jump performance were excluded. Lastly, those who have had previous

experience with the FMS™ were excluded from this study in an attempt to control for the

learning effect that one may have from previous experience with the component tests. By

following this set of inclusion criteria, the results of this study are not generalizable

beyond those who do not fit the populous examined; therefore, further research in this

area is needed in order to make more global conclusions.

Assumptions

This study made the following assumptions: (a) participants answered the Inclusion Criteria and the Exercise History Questionnaire honestly; (b) participants met the minimum weekly requirement of physical activity, as set by the ACSM guidelines, (c) participants refrained from smoking (or the use of any tobacco products) and the intake of caffeine within the four hours prior to testing, and heavy resistance exercise in the 24-48 hours that separate the two days of testing; (d) participants performed a maximum effort jump for each of the CMJ trials; and (e) perform the FMS™ to their best ability.

Limitations

Major limitations of this study included possible experimenter and equipment error. Experimenter error may have resulted from the subjective interpretation that is involved with scoring the FMS™ as well as errors in the measurement of the anthropometric data. Anthropometric errors may influence the equipment used to determine jump height. The MyoTest accelerometer measured jump height through a programmed equation that takes the participant's weight into account when determining flight time.

CHAPTER II: LITERATURE REVIEW

Introduction

Active populations such as athletes, both professional and tactical, make use of injury risk and athletic performance field tests (Cook et al., 2006a; Cook et al., 2006b). Performance testing and injury risk assessment testing are used to establish baseline performance levels and measure the effectiveness of training (Kiesel et al., 2007; Minick et al., 2010). Such information may be useful in research and clinical settings to improve the performance of participants, clients, and patients during exercise. Despite the prevalence of each of these tests, a gap exists in the current literature as to how with the FMS™ total score relates with athletic performance.

One test that is used to assess an individual's injury risk is the Functional Movement Screen™ (FMS™). The FMS™ is a reliable tool used for identifying injury risk and has been used in a variety of active populations (i.e., firefighters, collegiate athletes, military officer candidates) (Chorba et al., 2010; Kiesel et al., 2007; Peate et al., 2007). This pre-participation screen grades individual's on their movement patterns and compensatory motions that exist due to functional limitations (Cook et al., 2006a). Previous literature has attempted to find a relationship between the FMS™ and athletic performance (Okada et al., 2011; Parchmann & McBride, 2011). These papers used the 21-point scale to score each of the functional movement tests. Despite a variety of athletic performance tasks, there were no significant relationships made between the total FMS™ score and any athletic performance measures. It is possible that the 21-point scale lacks the precision to distinguish a relationship between FMS™ score and athletic performance as all seven tests are scored equally despite representing varying levels of

complexity across the tests (Butler et al., 2012; Frost et al., 2012). This review will describe a FMS™ scale that has a greater amount of precision with an attempt to 100-point scale of measurement.

One commonly used measure of athletic performance that demonstrates a representation of power, strength and speed is vertical jump testing (Aragon-Vargas, 2000; Luebbers et al., 2003). For this review, sport performance is defined as mean jump height and will be further elaborated upon in this study. Specifically, this review will focus on a countermovement jump (CMJ) as a sport performance. The use of a CMJ test during pre-participation screening provides insight to performance variables that are transferrable to sport such as power, strength and speed (Cronin & Hansen, 2005; Vanezis & Lees, 2005). Performance on CMJ is indicative of the explosive power that can be generated during a rapid full body movement (Domire & Challis, 2007; Hartmann et al., 2012; Vanezis & Lees, 2005). It is proposed in this study that an individual's ability to jump is influenced by their ability to move. The current literature has not successfully shown a relationship between functional movement (i.e., FMS™) and functional performance (i.e., CMJ). It is possible that this lack of a relationship is due the over-simplified 21-point scale of measurement for the movement tests and that a more precise method of measurement is needed to identify movement deficiencies that influence athletic performance. This review will provide evidence toward the possible relationship between the FMS™, assessed on a 100-point scale, and CMJ height.

The Functional Movement Screen™

Traditionally, prior to the participation in athletics, athletes and exercisers have undergone pre-training physicals and performance assessments (Cook et al., 2006a).

While some of these tests are able to provide information as to where performance strengths and weaknesses exist, others lack the ability to gauge the individual's movement patterns and movement deficiencies that may lead to injury over time (Cook et al., 2006a; Cook et al., 2006b). The Functional Movement Screen™ (FMS™), a series of seven movement tests, was developed by Gray Cook and colleagues as a tool to address this gap in pre-participation screening. The FMS™ is used to identify functional movement pattern limitations and muscle asymmetries within an individual during motion (Cook et al., 2006a; Cook et al., 2006b; O'Connor et al., 2011). The seven that comprise the FMS™ are: the Deep Squat, Hurdle Step, In-line Lunge, Shoulder Mobility, Straight Leg Raise, Pushup, and Rotary Stability (Cook et al., 2006a; Cook et al., 2006b).

The FMS™ rates the balance, range of motion, muscle compensation and quality of movement through each of the seven movement tests (Kiesel et al., 2007). In reference to the functional pyramid (Appendix J), the quality of a movement pattern is influenced by a combination of the mobility and stability, and is considered functional movement. These factors of movement may be overlooked by more traditional methods of physical assessment (Cook et al., 2006a; Cook et al., 2006b). Through the use of the FMS™, this series of movement tests highlight one's movement pattern compensations and asymmetries that may lead to an increased risk of injury (Cook et al., 2006a; Cook et al., 2006b).

Description of the FMS™ scoring and tests. The scoring protocol and descriptions of each of the movement tests is adapted from the founders of the FMS™ (Cook et al., 2006a; Cook et al., 2006b).

Scoring. The scoring method that was originally developed for the FMS™ was a live, in real time scoring of the seven tests, 21-point scale. Each of the seven tests is scored on a subset of a zero to three points, where a score of three is deemed a maximum score. A score of three is given to an individual that performs the correct movement pattern without asymmetries or compensations. A score of two is given when an individual performs the correct movement pattern(s) with the recruitment of at least one compensation or asymmetry. A score of one is given when the individual cannot achieve the proper movement pattern despite the recruitment of compensatory movements, but doesn't experience any pain through the range of motion. If during any of the movements pain is experienced by the participant, the resulting score is a zero (Cook et al., 2006a; Cook et al., 2006b). The seven tests that comprise the FMS™ are the Deep Squat, Hurdle Step, In-line Lunge, Shoulder Mobility, Active Straight Leg Raise, Trunk Stability Push Up, and Rotary Stability (Cook et al., 2006a; Cook et al., 2006b).

Deep squat. The Deep Squat test is performed to lowest depth without pain with a dowel overhead. To begin the test, the individual stands straight with their feet shoulder width apart, toes facing forward. From this position, the dowel is extended overhead so that the arms and back are straight. Next, the individual squats to their lowest depth without pain, while attempting to maintain their arms overhead, a straight back that is parallel to the tibia, and the knees behind the toes. Throughout the test, the individual should remain with their feet fully on the ground. The test consists of five slow and controlled squats with the rater assessing their movements from their front, side, and back before proceeding to the next motion.

Impairments that can be identified from the Deep Squat include limited hip, trunk, and shoulder mobility, poor hip, knee, and ankle flexion, and low stability. In the event that an individual is not able to elicit the targeted motion during the Deep Squat, the FMS™ board is placed under the heels, with the toes on the ground, to adjust the initial position of the Deep Squat. By doing so, less ankle dorsiflexion is required to squat to a greater depth. The individual would repeat the movement up to five times before moving to the next motion.

Hurdle step. The Hurdle Step is performed with a dowel across the shoulders, parallel to the ground, as the individual steps over hurdle. To start the test, the height of the individual's tibial tuberosity is taken to set the height of a rubber strap; this strap is used as the crossbar of the hurdle and is adjusted to standardize for the height of the individual. The test begins with the dowel laid across the shoulders behind the head and the individual's feet together, behind the hurdle with the toes in contact with the base. The individual is then instructed to raise a foot off the ground and reach it over the hurdle so that they can lightly tap their heel to the ground on the opposite side of the hurdle. They are not allowed to look down at the rubber strap nor may they shift their weight forward onto the lead heel. They are then instructed to bring their foot back over the hurdle to the initial position.

Impairments from the Hurdle Step that may be found may result from poor movement patterns opposed to a single limb's movements. Poor bilateral, asymmetric hip stability and dynamic stability as well as poor single-limb stance are major contributing factors to decreased performance on the Hurdle Step test. The Hurdle Step

also assesses both the left and the right side separately, providing a left-right comparison that identifies asymmetrical movement patterns within the movement pattern.

  In-line Lunge. The In-line Lunge is a controlled lowering task that requires spinal and pelvic stability while the upper body maintains a neutral position, with respect to the lower body. To begin this test, the height of the tibial tuberosity is measured. The individual begins in the stride position with one foot behind the start line on the FMS™ board, and the other foot is standing firmly on the FMS™ board. The distance between the start line and the heel of the lead foot should be equal to the length of the tibial tuberosity. The arm positioning is in a reciprocal pattern to the leg position. With a dowel positioned in parallel with the individual's spine, one arm is raised overhead to grasp the dowel near the neck while the other arm reaches behind the back near the lumbar spine to hold the dowel near the small of the back. The individual is then instructed to lunge forward so that the rear knee makes contact with the lead heel and board, while maintaining a straight back and with the dowel in contact with the lumbar spine, between the shoulder blades, and the back of the head. These three points help the observer gauge how well the participant is able to limit the lunging movement to the sagittal plane.

  Impairments that are observed during the In-line Lunge may relate to ankle, knee, or hip mobility, trunk flexibility, and dynamic stability on a small base of support. Deficiencies may result in a forward lean of the torso, a rise in the heels off the board, or a compensatory twist in the trunk to assist the contact of the rear knee and lead heel. The In-line Lunge is another test where both the left and right side are assessed independently for asymmetrical movement patterns.

Shoulder Mobility. The Shoulder Mobility test is used to assess the relationship between the spine and shoulders during a reciprocal arm motion. Prior to the start of the Shoulder Mobility test, a clearance test is performed to identify pain in the joint that is otherwise missed during the screen movement. For this test, the hand is raised to the opposite shoulder so that the palm comes in contact with the shoulder near the clavicle. The elbow is then raised so that it points forward while keeping the palm in contact with the shoulder. If no pain is felt, a (-) is marked and the participant is allowed to perform the Shoulder Mobility test. If pain is felt, however, a (+) is marked next to Shoulder Mobility, and the individual receives a zero. The participant skips the Shoulder Mobility test and proceeds to the next test.

To begin the Shoulder Mobility test, the individual's hand must be measured as the length of the hand is used as the landmark for flexibility. The measurement is taken from the most distal crease of the wrist to the tip of the middle finger. With the feet positioned together and an erect posture, the individual makes fists by wrapping their fingers around their thumbs. In one smooth motion, the arms move in unison. The participant will reach each hand, as a fist, toward the center of the back, one over the top and one underneath, to bring them as close together as possible in one fluid motion. The goal of this test is to have the measured distance less than or equal to the length of the hand. This test is repeated up to five times for each side.

Factors that may affect an individual's performance on the Shoulder Mobility test include shoulder and trunk mobility as well as postural and core stability. A lack in any of these areas will increase the distance measured between the two fists. Additionally,

overdevelopment of the abdominals and chest muscles may exhibit as a rounding of the shoulders that decreases the mobility of the glenohumeral joint.

Active Straight Leg Raise. The Active Straight Leg Raise is a movement that assesses the amount of flexibility the individual has in their legs when the legs are separated in an unloaded position. To begin the test, the individual will lay supine with the palms up and the FMS™ placed underneath the knees. The dowel is positioned vertically between the anterior superior iliac spine and the joint line of the knee. While keeping the feet at a 90° angle, one leg is raised off the ground while the other leg remains flat on the floor. At the leg's peak position, the malleolus position with respect to the dowel is assessed and scored appropriately. The goal of this test is to have the malleolus at least reach the position of the dowel. This test is repeated a maximum of five times before assessing the opposite side. This test assesses each side of the body independently to provide a left-right comparison of the scores.

Limitations that are found during the Active Straight Leg Raise result from poor flexibility of the gluteal muscles, hamstrings, and iliotibial band, poor core stability, and limited extension of the opposite hip. In the event that the individual has movement limitations that do not allow for the malleolus to surpass the dowel, the dowel is placed on the superior side of the board, just above the knee, and the Active Straight Leg Raise is repeated. If the malleolus still cannot pass the dowel, the dowel is repositioned to the inferior portion of the board. The test is then repeated.

Trunk Stability Push Up. This test assesses core stability more than upper body strength. This test begins with a clearance test to protect the participant from painful motions. This clearance test is similar to the *cobra stretch*. Prone on the ground with

their legs together and palms flat on the mat, the individual then pushes the upper body up into a spinal extension bringing the head toward the ceiling. If pain is recorded, a (+) is marked for the Trunk Stability Push Up and the test is scored as a zero. The Trunk Stability Push Up is then skipped and the participant proceeds to the next test.

The Trunk Stability Push Up test is similar to a standard push up except for a modification to the placement of the hands. The participant will begin this test prone on the ground with the legs and feet extended together and the hands on the ground with fanned fingers. Men will begin with their thumbs in line with their forehead and women will begin with their thumbs in line with their chin. Next, the individual will position the toes into the ground, raising the legs and hips off the ground. When instructed, the individual will push into the ground and raise the shoulders and back in one motion. This test is done to a maximum of three times.

Poor performance on the Trunk Stability Push Up may result from poor stabilization of the core muscles, insufficient upper body strength and/ or scapular stability, and reduced hip and thoracic spine stability. As a result of such insufficiencies, the shoulders and back will not rise in unison. If the individual is not able to lift their body as a single entity, the hand placement can be adjusted lower, closer to standard push up position. For men, the hand placement would be lowered to the chin, and women's hands would be lowered to the clavicle.

Rotary Stability. The Rotary Stability test is a coordination test that assesses the individual's ability to maintain core stability in the quadruped position. A clearance test is performed prior to the beginning of this test to identify pain that the participant may have. From the quadruped position, the individual would flex the neck bringing the head

to the chest while simultaneously arching the back. If pain is observed, a (+) is marked for the Rotary Stability test and a zero is recorded for the score. If no pain is observed, a (-) is marked and the participant proceeds with the Rotary Stability test.

To begin the test, the FMS™ board is positioned underneath and in parallel with the individual's spine so the hands and knees are on the ground on either side and in contact with the board, while in the quadruped position. The test requires the individual to raise their ipsilateral hand and knee so that the raised elbow and knee can make contact, above the ground, before the hand and knee return back to the initial position.

Factors that may limit one's performance on the Rotary Stability test include reduced shoulder, spine, hip, and knee mobility, poor scapular and hip stability, and reflexive stability of the trunk and core muscles. These deficiencies result in a rounding of the hips and shoulders as the individual attempts to touch elbow to knee without falling. If compensations are observed due to the above deficiencies, the test can be modified to a diagonal motion of opposite shoulder and hip motion, which result in contact between the knee and the elbow over the board.

FMS™ populations. While the use of the FMS™ is still in its relative infancy, it has thus far been used on a variety of populations. In particular, the 21-point FMS™ has been used to assess risk of injury (Chorba et al., 2010; Goss et al., 2009; Kiesel et al., 2007; Kiesel et al., 2011; O'Connor et al., 2011; Peate et al., 2007) as well as the effectiveness of training interventions (Frost et al., 2012). Populations of interest included female volleyball, basketball, and soccer players (Chorba et al., 2010), male and female firefighters (Frost et al., 2012; Peate et al., 2007), male and female Special Operations Soldiers (Goss et al., 2009), male American football players (Kiesel et al.,

2007; Kiesel et al., 2011), male Marine officer candidates (O'Connor et al., 2011), and collegiate male and female golfers (Parchmann & McBride, 2011).

Gender. The FMS™ has been used on many different active populations; the populations, while predominantly male, have included both genders. In an effort to determine gender differences in FMS™ testing, a study was designed to establish normative values for both males and females in the FMS™ using the 21-point scale (Schneiders et al., 2011). No significant differences were observed between genders and FMS™ total score (males $\bar{x} = 15.8 \pm 1.8$; females $\bar{x} = 15.6 \pm 2.0$) leading the researchers to the conclusion that the FMS™ can be used on mixed-gender populations effectively (Schneiders et al., 2011). Despite the lack of significant differences between the genders in the total score, significant differences were observed within the FMS™ comparing the individual component test scores between genders (Schneiders et al., 2011). In particular, females performed significantly better than males on the shoulder mobility test ($\chi^2 = 17.238$, $p = 0.001$) and the Active Straight Leg Raise ($\chi^2 = 42.097$, $p < 0.001$). Subsequently, males significantly outperformed females on the Trunk Stability Push Up ($\chi^2 = 64.475$, $p < 0.001$) and the Rotary Stability test ($\chi^2 = 7.230$, $p = 0.027$) (Schneiders et al., 2011). This may have occurred as some of the tests rely more heavily on either strength or flexibility; both strength and flexibility are variables that are not congruent for males and females (Kibler, Chandler & Maddux, 1989). Males scored better on the Trunk Stability Push Up and the Rotary Stability tests; females in the study scored better on the Active Straight Leg Raise and Shoulder Mobility tests (Schneiders et al., 2011).

The Trunk Stability Push Up and the Rotary Stability test are representational of gender differences in muscular strength (Schneiders et al., 2011). Each of these tests

require adequate stabilizing strength of the trunk with concomitant motion in either the upper and/or lower extremity (Cook et al., 2006b). Kibler and colleagues supported this idea by examining the gender differences for flexibility and strength tests. Females demonstrated greater flexibility than males while males exhibited greater muscular strength than females (Kibler et al., 1989). These muscular strength differences may provide further evidence to the scoring differences observed by Schneiders and colleagues (2011) on the FMS™ trunk and Rotary Stability tests between males and females.

The Active Straight Leg Raise and Shoulder Mobility tests differences may also result from innate gender differences in flexibility. In Kibler et al. (1989), of the participants examined (n=2107), females were significantly more flexible than males. These observed differences in flexibility may have influenced the results observed by Schneiders and others (2011). Females were observed to have higher scores on the Active Straight Leg Raise and Shoulder Mobility tests than males. Both of these tests are designed to test the active functional range of motion that an individual has in their hamstrings and shoulder complex, respectively. With a greater amount of flexibility the resulting component score for the FMS™ was better (Cook et al., 2006b). Gender differences may support the findings that females scored better on flexibility FMS™ tests than males (Schneiders et al., 2011).

Aggregate FMS™ scores on a 21-point scale can be compared with mixed gender populations. However, due to gender differences in muscular strength and flexibility, the ability to compare individual component scores of the FMS™ is limited. As a result, researchers and clinicians whom utilize the FMS™ for assessing injury risk are restricted

to comparing homogeneous gender groups. In order to prevent gender differences from influencing the relationship between functional movement and functional performance, only males will be allowed to participate in this study.

Injury identification. The FMS™ was originally developed as a tool to screen active populations and assess risk for injury by evaluating a series of functional movement patterns prior to participation in sport (Cook et al., 2006a). At the time of its inception, a standardized test to evaluate injury risk in active populations had not been developed. The FMS™ was designed to challenge the functional movement of the kinetic chain as well as proprioceptive function and assess the interaction between the mobility and stability of the individual (Chorba et al., 2011; Cook et al., 2006a; Cook et al., 2006b). The 21-point FMS™ scoring method has shown that a significant correlation exists between 21-point total score and injury risk in active populations ($r = -.7676$) (Chorba et al., 2010). Therefore, those that have a lower FMS™ score are at a higher risk of injury due to the limitations observed within the functional movement patterns. Further research took a more in-depth look at the relationship between the FMS™ score and injury risk which resulted in the development of an athletic *cut-off score* (Kiesel et al., 2007).

Cut-off score. In an effort to find the relationship between FMS™ and injury, Kiesel et al. (2007) used the FMS™ as a preseason screening tool with a professional American football team. Although a cause-effect relationship wasn't established, a *cut-off score* for athletic clearance for sport participation was identified. Based on the FMS™ total score, professional football athletes who scored less than or equal to 14 on the FMS™ were 11 times more likely to suffer a serious injury during the season

opposed to players that scored greater than a 14 (Kiesel et al., 2007). Serious injury was

defined as an injury that relegated the athlete to the injured-reserve for a minimum three

weeks. Of the professional athletes used, the odds ratio formulated from the results

presented a 15% probability of an injury with an FMS™ score above 14. However,

football players that scored a 14 or below had an elevated probability (51%) of suffering

a time-loss injury. The idea of a *cut-off score* was further corroborated in additional

research (Chorba et al., 2010; O'Connor et al., 2011).

In order to determine if the presence of compensatory movements within a given

movement pattern was related to injury risk, the FMS™ was used in a population of

female Division One athletes (n=38) (Chorba et al., 2011). The FMS™ was used as a

tool to identify movement compensations. Of the athletes that scored a total of 14 or less

on the 21-point scale, 69% suffered an injury and had a 4-fold increase in injury risk

(Chorba et al., 2011). These findings supported the *cut-off score* originally discovered by

Kiesel et al. (2007), despite the differences in the activity and gender of the population

recruited.

The existence of a *cut-off* score was further supported in O'Connor et al. (2011).

A population of male Marine officer candidates (n = 874) were pre-screened with the

FMS™ prior to inclusion in either a short cycle (six week) or long cycle (ten week)

training interventions.   Those that scored 14 or less on the FMS™ 21-point scale had a

1.91 times (95% confidence interval (CI) = 1.21–3.01, P < 0.01) higher any injury

incidence rate compared with a score > 14. When both the short and long cycles of

training were combined, the relative risk of injury in an officer candidate was 150%

greater in those with an FMS™ ≤ 14 compared to those with a total score > 14 (O'Connor et al., 2011).

The FMS™ *cut-off score* provides a relative baseline for inclusion in an athletic activity for both competitive and tactical athletes. However, the FMS™ is a tool that is subjectively scored following a previously established set of criteria formatted by the founders of the FMS™. The reliability of the testers to properly evaluate each movement may limit the utility of the FMS™ if the reliability between raters or subsequent tests is poor.

Reliability of the Functional Movement Screen™. The FMS™ can be used to risk stratify athletes based on the aggregate score that is scored based on their functional movement patterns (Chorba et al., 2011; Kiesel et al., 2007; O'Connor et al., 2011). The scoring system for the FMS™, while directed by guidelines of the testing protocol, may be subject to the training level and interpretation of the rater (Minick et al., 2010; Onate et al., 2012; Teyhen et al., 2012). Although the movement tests follow preset guidelines, raters subjectively score the movement patterns (Teyhen et al., 2012). Due to the subjective nature of the scoring system, confirmation of the reliability of the FMS™ was needed for the findings to hold value to further populations. Previous reliability studies have supported the levels of reliability that exist within raters and between sessions for the FMS™ (Gribble, Brigle, Pietrosimone, Pfile, & Webster, 2013; Minick et al., 2010; Onate et al., 2012; Smith, Chimera, Wright, & Warren, 2013; Teyhen et al., 2012).

Interrater reliability is a method of determining the consistency of scoring between different raters. Onate et al. (2012) examined the interrater reliability of raters using a population (n = 19) of physically active men and women that were scored by two

raters; one was a FMS™-certified rater while the other was not. Onate et al. (2012) confirmed that the FMS™ was highly reliable test (ICC of 0.98 ($\kappa = 0.25$)) when scored by raters with differing levels of experience (Onate et al., 2012). While Onate and colleagues used a small population of raters to compare (n = 2), strong reliability was shown between raters for six of the seven tests. The results were surprising as one of the raters had no experience using the FMS™. It may be concluded from these results that those familiar with varying exercise movement patterns will be able to score a FMS™ similar to a scorer that is certified.

In addition to the reliability between those with and without FMS™ certifications, interrater reliability has also been examined comparing novice and expert level raters. Minick et al. (2010) described novice raters as FMS™-certified raters with less than one year of testing experience. Expert raters were defined as having more than 10 years of testing experience. In order to examine the reliability of the FMS™, both novice and expert level raters viewed video footage of 40 healthy males performing the seven tests of the FMS™ (Minick et al., 2010). The seven tests were divided into 17 components; both the right and the left side of the test were treated as an independent component. Substantial to excellent agreement ($\kappa = 0.69\text{-}1.00$) was found between the novice raters on 14 of the 17 tests. Additionally, substantial to excellent agreement ($\kappa = 0.60\text{-}0.95$) was recorded on 13 of the 17 components between the expert raters. Further analysis was done to measure the amount of agreement in scoring between the novice and the expert raters. Substantial to excellent agreement was seen for all 17 components tested ($\kappa = 0.74\text{-}1.00$). When the standard FMS™ testing procedure is used, the reliability of the scoring mechanism is strong (Minick et al., 2010).

The interrater and intrarater reliability of the FMS™ were further examined in

Teyhen et al. (2012). Using a population (n = 64) of armed service workers, the seven

FMS™ tests were scored by eight novice raters. Testing sessions were separated by 48-

72 hours. Interrater reliability was examined by comparing the scores that any two

testers had for a particular participant. The interrater reliability was identified as

moderate to excellent by weighted Kappa values ($\kappa_w \geq 60\%$) on six of the seven tests

(Teyhen et al., 2012). The In-line Lunge (ILL) test was not included among the tests that

had moderate to excellent Kappa values suggesting that there is enough variability within

the ILL to raise concerns about the reliability of this component (Teyhen et al., 2012).

Intrarater reliability was established through the comparison of the scores of the raters

between the first and the second test day. The standard error of the measurement for both

the interrater and intrarater reliability was less than one point for a 21-point scale, while

the minimal detectable change ranged between 2.1-2.5 points on the 21-point scale

(Teyhen et al., 2012).

The FMS™ can be a reliable method of assessing injury risk in participants, both

within and between raters. Despite the precision that raters have while reviewing each of

the movements, the FMS™ on a 21-point scale is limited to observing to detecting large

movement limitations (Butler et al., 2012). In response to the lack of specificity, a more

precise method of measurement was developed; this method was the 100-point scale.

The 100-point scale. As an injury risk assessment tool, the FMS™ was designed

to examine how an individual moves through large gross movement task as a means of

identifying dysfunctional movement patterns (Butler et al., 2012). While the live 21-

point scoring method is both a valid and reliable method of scoring the FMS™ (Minick

et al., 2010; Onate et al., 2012; Teyhen et al., 2012), it is a basic method that lacks the precision to identify risk beyond large movement dysfunction (Butler et al., 2012). To improve on the precision that is provided from the 21-point scale, the 100-point scale was developed as an alternative form of scoring that provides more precision by itemizing each movement and scoring bilateral movements separately by side.

Movement test itemization. The 100-point scale has improved precision over the 21-point by itemizing each test into varying point values (Butler et al., 2012). The scoring rubric for the 100-point scale itemizes the individual components of each movement test (i.e., upper torso is parallel with tibia or toward vertical; knees aligned over feet; dowel aligned overhead) and provides a point value to each component. Component itemization allows for a broader continuum of scores for each of the movement tests and may provide a more in-depth interpretation of the total score beyond a 0-3 ranking (Butler et al., 2012). Itemization may improve the sensitivity of the scoring scale and may become a better reflection of the individual.

Unlike the 21-point scale, not all seven tests are worth an equal number of points on the 100-point scale. The total score of each of the tests is based around the overall complexity of the movements (Butler et al., 2012). The movement tests with a lower complexity (i.e. Shoulder Mobility) are worth less total points than more complicated movements (i.e., Deep Squat) on the 100-point scale (Butler et al., 2012).

Movement test tiers: Tier I. The lowest tier of test complexity consists of the joint mobility tests (Butler et al., 2012). These tests, when compared to others, have least amount of simultaneous stabilization. The Shoulder Mobility has a maximum score of 8

points, 4 for each side, and the Active Straight Leg Raise has a maximum of 10 points, 5 for each side (Butler et al., 2012).

Movement test tiers: Tier II. The mid-level of the FMS™ tests consists of the core stability tests. These movement tests require stabilization of the trunk in succession with an upper and/ or lower extremity movement(s). This tier includes both the Trunk Stability Push Up and Rotary Stability; the maximum score for each of these tests is 12. While the Trunk Stability Push Up is a whole body movement, the Rotary Stability is bilateral which scores each side separately at 6 points per side (Butler et al., 2012).

Movement test tiers: Tier III. The highest tier of tests includes the Deep Squat, the Hurdle Step and the In-line Lunge. Each of these tests requires multi-joint motion as well as trunk stability over the course of the movement. The Deep Squat and the Hurdle Step each have a maximum score of 18; the Hurdle Step is a bilateral test, where each side has a maximum score of 9 points. The In-line Lunge is worth 20 points that are divided into a score for each bilateral movement. This movement test is scored as the most valuable because of the amount of eccentric control used during the flexion of the lunge on a narrow base of support (Butler et al., 2012).

Bilateral test assessment. The 100-point scale adds further specificity to the FMS™ by independently rating bilateral movements into separate scores (Butler et al., 2012). In each of the five bilateral tests, both the right and the left side are given separate scores. Once each side is rated, these scores are summed together to provide a total component score for the given movement. The 100-point scale provides greater detail assessing bilateral tasks as it highlights existing asymmetries that a participant has between each side of a given movement (Butler et al., 2012).

Video analysis. In order to score the FMS™ with a more precise scale, video analysis is recommended. Scoring of the FMS™ on the 100-point scale is done post hoc by recording video footage of all seven tests and rating the movement tests (Butler et al., 2012; Frost et al., 2012). Video camera position has been standardized in the perpendicular and sagittal planes of the participant (Butler et al., 2012; Frost et al., 2012). Scoring in such a way allows the rater to view each of the seven tests with a greater amount of detail than the 21-point scale. While this is an advantage of the use of the 100-point scale, it is also time intensive as it involves the FMS™ tests as well as the post hoc scoring. For this reason, the use of the 100-point scale has been shown to be disadvantageous in its use because of the time needed to be performed and scored (Butler et al., 2012).

100-point reliability. Like the 21-point scale, the 100-point scale is scored subjectively by the rater administering the FMS™. The 21-point scale has been shown to have high validity and reliability between raters (Minick et al., 2010; Onate et al., 2012; Teyhen et al., 2012). To determine the repeatability of the 100-point scale, the interrater reliability of the 100-point scale was examined (Butler et al., 2012). Of the seven movement tests, six of the movements had high interrater reliability (ICC = 0.98). The In-line Lunge had an ICC of 0.98 or higher. The In-line Lunge on the left side was slightly lower, however still highly reliable across the raters, with an ICC of 0.91 (Butler et al., 2012). These ICC values showed high reliability for the 100-point scale as ICC values greater than 0.8 are seen as near perfect agreements.

The 100-point scale was developed to further build upon the precision of the FMS™. Movement itemization and independent bilateral scoring or movement test may

improve the interpretations for injury risk that are made from the total score by identifying the limiting component of the most limited movement pattern (Butler et al., 2012). These scoring modifications increase the precision of evaluating the FMS™ and may assist in the development of a link between functional movement and functional performance.

Functional Performance

The Functional Movement Screen™ provides clinicians and sports medicine professionals some insight into the quality of the movement used by an individual. In reference to the functional pyramid (Appendix J), functional movement is the base of an individual's movement and a combination of both mobility and stability. The conversion of this functional motion into goal-orientated movement is considered functional performance (Cook, 2010). An individual's functional movement directly affects their risk of injury as has been shown with the FMS™ (Chorba et al., 2011; Cook et al., 2006a; Cook et al., 2006b). Functional movement may also affect an individual's ability to convert their available movement into a performance task.

Previous research has attempted to find a relationship between functional movement and functional performance using the FMS™ and the 21-point scoring method. In Parchmann and McBride (2011), 25 mixed-gender NCAA Division I golfers were examined in both general athletic and specific performance measures (i.e., sprint time, vertical jump height, T-test agility, and club head swing velocity) as well as functional movement. Results indicated that there were no significant findings between any of the general or sport-specific performance measures and the FMS™ ($p > 0.05$) (Parchmann & McBride, 2011). This may be a result of the lack of precision from the

21-point FMS™ scoring method as it pertains to functional limitations that exist within an individual.

Functional movement and functional performance were also compared in a review by Okada and colleagues (2011). Participating individuals were measured on a 21-point FMS™ scale and a variety of physical performance measures (i.e., backwards overhead medicine ball throw (BOMB throw), single-leg squat and T-run agility test). While a few individual tests of the FMS™ (Shoulder Mobility, Hurdle Step, and In-line Lunge) had significant positive correlations with the BOMB throw, it was suggested that the total score of the FMS™ was not effective in predicting athletic performance (Okada et al., 2011). These results may also be due to the nature of the FMS™ 21-point scale as an identifier of large movements. With the use of the 100-point scoring method, the precision of the FMS™ may improve to identify a link between an individual's movement capacity and conversion of functional movement into functional performance.

Vertical jump performance. Functional performance may be limited by the mobility and stability of an individual. Vertical jumping is an example of converting the available functional movement that an individual has into a powerful functional task (Cook, 2010). This athletic task provides measureable, transferrable elements of many sports such as strength, speed, and power (Lees et al., 2004; Luebbers, Potteiger, Hulver, Thyfault, Carper, & Lockwood, 2003; Moran & Wallace, 2007; Salles, Baltzopoulos, & Rittweger, 2011; Vanrenterghem, Lees, & De Clercq, 2008). In particular, one method of vertical jump that is used to measure the amount of power that can be produced by the lower extremities, and mimics actions relevant to sport, is the counter movement jump (CMJ) (Markovic, Dizdar, Jukic, & Cardinale, 2004; Vanezis & Lees, 2005). A CMJ is a

vertical jump that begins in the standing then lowered eccentrically into a squatted position and followed by a concentric rising phase into take-off. The sport-specific expression of power, strength and speed make CMJ testing a worthwhile approach for measuring functional performance.

The use of a CMJ is not only useful as an expression of lower extremity power, strength and speed, but it is also a reliable test to use across participants (Markovic et al., 2004). In Markovic (2004), seven different explosive tests including five vertical jumping tests and two horizontal jumping tests. Both the squat jump and the CMJ were the most reliable ($\alpha = 0.97$ and 0.98, respectively) of the power tests. Furthermore, the CMJ had the greatest average intertrial correlation (AVR) and ICC among all jump tests (0.94 and 0.98, respectively) (Markovic et al., 2004).

The motions used to execute a CMJ are similar to those in a variety of sports that require power, strength and speed (Lees et al., 2004; Luebbers et al., 2003; Moran and Wallace, 2007; Salles et al., 2011; Vanrenterghem et al., 2008) as well as reproducible across participants (Markovic et al., 2004). In order to appropriately quantify CMJ trials across participants, reliable methods of measurement are needed to ensure the reliability of data for comparison.

Measurement. The peak heights of the CMJ tests can be measured in a variety of methods. The use of these techniques are often dependent on the amount of available space, finances, accuracy of measurements and the ease of transport of the testing device. Often, the need for transport and cost limit the equipment that is used to measure the height of a CMJ. The reliability of each testing method is compared to motion capture

analysis, the gold standard for measuring the height of a CMJ (Leard et al., 2007; Nuzzo, Anning, & Scharfenberg, 2011).

The most accurate and valid way of measuring vertical jump height is with a video motion capture system. It has been deemed the *gold standard* of vertical jump measurement (Aragon-Vargas, 2000; Casartelli et al., 2010; Leard et al., 2007; Nuzzo et al., 2011). Through the use of reflective markers, a motion capture system determines the height of a jump by tracking the displacement of one's center of gravity through the phases of a vertical jump (Leard et al., 2007). While the motion capture system is effective, it is costly, immovable and requires extensive calibration and training to accurately measure jump heights (Casartelli et al., 2010; Leard et al., 2007; Nuzzo et al., 2011).

Less costly methods of vertical jump measurement have been produced that have improved the utility of the vertical jump test without sacrificing validity of the jump height. Two of the more prevalent methods of vertical jump measurement are the Vertec (Vertec, Sports Imports, Hillard, OH) and the MyoTest (Myotest Inc., Durango, CO) systems. With the addition of being easily transported and relatively simple to use (Bubanj et al., 2010; Casartelli et al., 2010; Leard et al., 2007; Nuzzo et al., 2011) both the Vertec and MyoTest accurately measure jump height.

Vertec. The Vertec is one method of vertical jump measurement that is available to be used in field testing. This system consists of an adjustable metal pole with plastic swiveling panes, each representing a height increase of 0.0127 meters. Jump height is determined through the subtraction of a standing, two-handed maximal vertical reach height from the height of highest displaced pane's height on the Vertec pole (Klavora,

2000 from Leard et al., 2007). Each of these heights is measured by counting the number of displaced panes and adding it to the starting height of the Vertec pole. In a comparative study, Leard and colleagues examined the accuracy of the Vertec test for peak height as it related to the height recorded from a motion-capture system. The peak height validity of the Vertec test was shown to have a strong correlation to the height recorded by the motion-capture system ($r = 0.906$) (Leard et al., 2007) illustrating the validity of jump height when measured by the Vertec measuring system.

Despite the measured jump height validity, the Vertec has less accuracy when predicting jump height. One flaw of the Vertec measurement method that has been noted was the significant difference in the measured height of jumps that were found in a comparison of the Vertec and the motion capture system (Leard et al., 2007). The Vertec method is also sensitive to the accuracies of the tester's measurements (Leard et al., 2007; Nuzzo et al., 2011). Both the standing, two-handed reaching height and the jumping height are measured manually by the tester and are subject to errors in counting. Lastly, the Vertec test is limited by the innate movement coordination pattern of the jump test. In order for the Vertec to be an accurately measure jump height, the participant must strike the panes of the Vertec pole at the peak of the jump. That is, after the complex multi-joint movement of the vertical jump, the participant must swing their arms vertically, while in flight, to the highest point and strike the panes to signify the apex of the jump. The added arm swing may reduce the level of accuracy for measuring jump height by increasing the level of difficulty of the technique needed. An added arm swing may also decrease the accuracy of measurement as it requires adequate shoulder mobility to swing, reach, and strike the panes of the (Leard et al., 2007; Nuzzo et al., 2011).

The use of the Vertec system for measuring jump height is a low cost method of measuring the peak height of a vertical jump that is portable and gauges jump height similarly to a 3-camera motion-capture system (Leard et al., 2007). While the validity of this equipment is high when compared to a motion-capture system, there are other devices that record jump heights more reliably between participants.

Myotest. In addition to the Vertec, the MyoTest is another cost-effective, portable method of measuring jump height (Casartelli et al., 2010; Leard et al., 2007; Nuzzo et al., 2011). The MyoTest SPORT unit (Myotest Inc., Durango, CO) is an accelerometer that collects flight time and acceleration data used to calculate jump height. Peak heights are measured through the recorded displacement height of the device during a jump. The recorded accelerations are integrated to find vertical velocity by which the overall jump height is estimated. Jump height is calculated through two methods (Casartelli et al., 2010). The first method estimates peak height by interpreting flight time through the use of the equation (Height = [g x flight time^2]/8). The second method of calculating peak height uses takeoff velocity through the use of the equation (Height = max vertical velocity^2/ [2 x g]) (Casartelli et al., 2010).

Evidence exists in the literature to support the test-retest reliability of the MyoTest's ability to estimate peak height (ICC = 0.92-0.96) (Bubanj et al., 2010; Casartelli et al., 2010; Nuzzo et al., 2011). Nuzzo and colleagues (2011) examined three methods of measurement for peak vertical jump height. Of the three methods, the MyoTest was the most reliable with the lowest percent variation of the examined methods (3.3%-3.9% opposed to 4.2%-5.5% for other methods) (Nuzzo et al., 2011).

The MyoTest is not without limitations that may restrict the measurement of a true peak vertical jump height. The MyoTest equipment uses the acceleration of the jump and the mass of the individual to determine jump height; therefore, the accuracy of the mass entered into the MyoTest may compromise the reliability of the equipment (Nuzzo et al., 2011). The mass values that are entered into the MyoTest increase in increments of 0.2kg which may result in an over or underestimation of the individuals mass. Furthermore, while the MyoTest is a highly valid and reliable method of determining peak jump height, it has low validity in determining the velocity of a vertical jump (Casartelli et al., 2010). It is possible that the MyoTest-measured velocity may be invalid due to the timing of the measured maximal velocity. To calculate the overall jump height, the MyoTest, while capable of identifying instants of takeoff and landing, incorrectly uses the positive peak of the vertical velocity of the jump instead of the velocity at takeoff (Casartelli et al., 2010).

Equipment summary. In order to compare jump heights within a sample, it is necessary that the reliability of the measurement tool is high. The MyoTest Sport Unit is a tool that is not only valid and reliable between trials for jump height, but is also an accurate tool that compares well to the motion capture system. The jump measurement equipment of choice for this study was the MyoTest Sport Unit.

Factors for successful vertical jumping. Successful performance of a vertical jump requires the hips, knees, and ankles to generate a powerful movement in order to reach a maximum height (Lees et al., 2004; Parchmann & McBride, 2011). The powerful movement that is generated from the legs and hips may be dependent on multiple factors that may affect the overall height of a vertical jump. The factors that will be discussed in

the following section that affect vertical jump performance, defined as jump height, in this study will be squat depth, muscular stiffness, the stretch-shortening cycle, and jump practice (Domire & Challis, 2007; Fukashiro, Hay and Nagano, 2006; Kubo et al., 1999; Moran & Wallace, 2007).

   Squat depth.   The depth to which someone can squat depth may be a limiting factor in one's ability to achieve maximum jump performance (Domire & Challis, 2007; Hartmann et al., 2012; Kubo et al., 1999; Moran & Wallace, 2007; Salles et al., 2011; Vanrenterghem et al., 2008). Evidence is available in the literature to support the notion that muscle length and flexibility of the muscles involved in squatting will affect the depth of a squat and influence jump height. More specifically, the amount that a muscle can lengthen during the eccentric phase of a CMJ influences the joint angle that is created at the hip and knee (Domire & Challis, 2007; Salles et al., 2011). In a study that focused on the influence of squat depth and its relationship to vertical jump height, it was stated that the deeper a participant was able to squat in a CMJ, the higher the participants were able to jump (Domire & Challis, 2007). By increasing the depth of the squat, the time that the contributing muscles could generate force increased (Domire & Challis, 2007) which may ultimately increase the peak height that is achieved in a vertical jump.

   These findings were further corroborated in an intervention study using both deep and quarter squats (Hartman et al., 2012). In Hartman and colleagues, after 10 weeks of resistance training, 1-repetition maximum (1RM) improved angle specific strength for the ¼ squat group; however, no significant peak jump height changes or dynamic strength changes were established (Hartman et al., 2012). Those that trained through a greater range of motion were able to produce greater amounts of strength that could be converted

into a greater peak height during a CMJ (Hartmann et al., 2012). It can be demonstrated that increases in the length of the muscle will allow a deeper squat in the eccentric lowering portion of the vertical jump (Kubo et al., 1999; Moran & Wallace, 2007; Salles et al., 2011; Vanrenterghem et al., 2008). Ultimately, a deeper squat may result in a greater peak vertical jump.

Squat depth during a CMJ may also be affected by the flexibility of the muscles involved with the extension of the hips, knees, and ankles (Domire & Challis, 2007; Kritz et al., 2009; Moran & Wallace, 2007; Salles et al., 2011). A deeper squat requires a greater angle of hip flexion and knee flexion (Domire & Challis, 2007; Kritz et al., 2009; Moran & Wallace, 2007; Salles et al., 2011). Salles et al. (2011) examined squat depths of $25°$, $50°$, $70°$, and $90°$ of knee flexion and the effect that the squat depth had on countermovement jumps height. Angles of knee flexion were used with respect to $0°$ where $0°$ was defined as standing knee extension. The deeper countermovement jumps resulted in higher recorded jumps (Salles et al., 2011). It was noted in this study that increases in knee flexion increased the angle of hip flexion, the primary power source of a vertical jump, and resulted in an increase in peak jump height. These findings were further supported by Moran and Wallace (2007) whom examined three types of jump (i.e., drop, countermovement, and squat) at both $70°$ and $90°$ of knee flexion. For each type of jump used, greater heights were recorded when a greater amount of knee flexion was utilized (Moran & Wallace, 2007).

Squat depth has been shown the influence the peak height achieved during jump performance (cite). More specifically, the use of a deeper squat in the eccentric phase of a CMJ has been shown to have a positive impact on peak jump height when compared to

shallow squats. Greater flexibility in the lower extremity may allow an individual to lower to a greater extent in the eccentric phase of a squat and increase jump performance (Domire & Challis, 2007; Moran & Wallace, 2007; Salles et al., 2011). The stiffness of the connective tissue surrounding the muscles during the eccentric phase may be an influencing factor on jump performance.

Stiffness. Another factor that may limit an individual's ability to reach maximal vertical jump height is the stiffness of the elastic components of the muscle. The greater the stretch of the elastic components of the muscle, the greater the maximal vertical jump height (Domire & Challis, 2007; Fukashiro et al., 2006; Kubo et al., 1999; Nagano et al., 2004). The stiffness, or tension, is produced from two sources: the parallel elastic component (PEC) and the series elastic component (SEC). The PEC structure is aligned in parallel with the SEC. Both the PEC and SEC are described with reference to the contractile component (CC), the thin actin and thick myosin filaments that are responsible for muscular contraction.

The PEC, SEC, and CC are all components of the Hill three-component model of the muscle. The PEC refers to the interstitial connective tissue (i.e., epimysium, perimysium, endomysium) which surrounds and runs parallel to the contracting muscle fibers and associated sarcolemma membrane (Dean, 1988; MacIntosh & MacNaughton, 2005). The SEC refers to the tendon and aponeurosis of the muscle (Fukashiro et al., 2006; Kubo et al., 1999; MacIntosh & MacNaughton, 2005; Nagano et al., 2004a) and is positioned in series to the CC. The SEC is responsible for returning the muscle to its original resting length after contraction. The combination of these two elastic components with the active muscle creates the muscle-tendon complex (MTC).

Compliance of the entire MTC has been shown to increase the benefits of a

countermovement motion in an explosive task (Nagano et al., 2004a). These results

regarding jump height and the compliance of the elastic components of muscle were

corroborated in other literature as well (Bobbert, 2001; Fukashiro et al., 2006; Kubo et

al., 1999; Lichtwark & Wilson, 2005).

The PEC is responsible for some of the passive tension that is present in the

muscle at rest. When the active muscle fiber lengthens, the PEC is stretched, increasing

the amount of tension within the PEC (MacIntosh & MacNaughton, 2005). Despite the

amount of tension that resides in the PEC in resting muscle, the influence that it has on

the height of a vertical jump is questionable (Kurokawa, Fukunaga & Fukashiro, 2001).

As such, this review will not emphasize the PEC.

While the MTC as a whole is able to store elastic energy, the majority of this

energy is stored specifically in the tendon, or the SEC. The elasticity, or compliance, of

this structure directly affects the height of a participant's jump (Domire & Challis, 2007;

Fukashiro et al., 2006; Kubo et al., 1999; Nagano et al., 2004). In Nagano and colleagues

(2004), a computer model was used to simulate the CC, SEC, and the PEC to determine

how to raise an inertial body to its highest point. It was found that more elasticity in the

SEC resulted in the highest jump height of the body.

Through the use of a computer simulation investigating the compliance of the

triceps surae, jump height was shown to be at its highest when the corresponding SEC

compliance was also at its highest (Bobbert, 2001). In this study, compliance was

determined by the percent of SEC strain at a maximum isometric force. At the highest

strain, 10%, jump height improved the most, 9cm (Bobbert, 2001). Additionally, Bobbert

and colleagues reported an increase in the efficiency ratio, the ratio of energy transferred into the jump to the total amount of work done, with an increase in SEC compliance. This may relate back to the MTC. It has been shown that a more compliant MTC will increase the use of elastic energy as well as increase the performance of a vertical jump (Kubo et al., 1999). Therefore, an increase in SEC compliance may improve the height of a vertical jump through an increase in the capacity and efficiency of use of the stored strain energy (Bobbert, 2001; Fukashiro et al., 2006; Kubo et al., 1999).

Along with tendon compliance, the length of a tendon also contributes to vertical jump performance (Fukashiro et al., 2006). The length that a tendon can achieve is important because vertical jump height will increase as the tendon stretch increases (Domire & Challis, 2007). A tendon with a greater amount of compliance and an increased length will also have more elastic behavior leading to a greater peak jump height (Fukashiro et al., 2006). As the elastic behavior increases in the MTC, a relatively longer SEC has more elastic behavior than a MTC with a relatively shorter SEC (Fukashiro et al., 2006). Elastic, or spring-like, behavior during a stretch-shortening cycle was defined by the length and compliance of the tendon of the MTC. A larger amount of tendon compliance and a longer length of tendon result in more spring-like tendinous behavior (Nagano et al., 2004b).

The amount of stiffness within the tendon and aponeurosis of the muscles of the lower extremity may influence CMJ performance. The amount to which the SEC can stretch in particular may influence an individual's performance. More specifically, the elastic energy that is stored in the SEC is greater when the tendon and aponeurosis can

store energy through a larger phase of movement. The conversion of the elastic energy

into CMJ performance is accomplished through the stretch-shortening cycle.

  Stretch-shortening cycle. Seldom does functional performance result purely from

concentric contraction. Movement often requires a countermovement where the active

muscle is stretched immediately prior to contraction. This countermovement is an

example of how the stretch-shortening is used in performance tasks. The stretch-

shortening cycle (SSC) may be a factor that influences CMJ performance (Hartmann et

al., 2012; Luebbers et al., 2003; Luhtanen & Komi, 1980; Moran & Wallace, 2007;

Yamauchi & Ishi, 2007).

  The presence of a countermovement may improve vertical jump performance

through the storage of elastic energy during the SSC (Cavanga & Citterio, 1974; Moran

& Wallace, 2007; Nagano et al., 2004a). Elastic energy is stored within the SEC of the

active muscle and immediately released during the concentric muscle contraction to

produce more power during the CMJ (Cavanga & Citterio, 1974). This expression of

power has been shown to increase jump performance over jump trials where no

countermovement was used (Moran & Wallace, 2007).

  Peak jump performance improves with an initial countermovement as elastic

energy is stored during the eccentric loading phase (Asmussen & Bonde-Petersen, 1974;

Moran & Wallace, 2007; Nagano et al., 2004a). Nagano et al. (2004a) suggested that an

increase in the SEC compliance may illicit a larger countermovement. This in turn may

influence the possible jump height that is achieved.

  Using a countermovement prior to a vertical jump has been shown to improve

performance when compared to vertical jumps with an isometric initial position (Bosco,

Viitasalo, Komi, & Luhtanen, 1982; Kubo et al., 1999; Moran & Wallace, 2007; Luebbers et al., 2003; Luhtanen & Komi, 1980; Yamauchi & Ishi, 2007). Moran and Wallace (2007) examined the influence that the SSC had on jump performance. Participants jumped from a variety of squat depths in order to achieve differing ranges through which the SSC was active for each CMJ. As the range of motion increased during the eccentric phase of the SSC, a greater peak jump height was recorded for the tested CMJ. The eccentric load was controlled through the use of 70° and 90° of knee flexion. Jump height increased by 17.4% in the countermovement jump with greater eccentric loading (Moran & Wallace, 2007).

The ability to store elastic energy during the SSC is partially dependent on the elastic behavior of the tendon (Kubo et al., 1999). In particular, an increase in the elasticity of the SEC will increase the power output and efficiency of the concentric motion of the SSC (Lichtwark & Wilson, 2005). Increases in SEC elastic compliance were found to relate to earlier muscle activation in the SSC with an increase in SEC compliance (Lichtwark & Wilson, 2005). With an increase in the elasticity of the SEC, the magnitude of optimal countermovement phase motion increases resulting in a greater storage of elastic energy that is transferred into the CMJ (Nagano et al., 2004a).

The height that can be achieved during a CMJ may be improved by utilizing a countermovement and activating the SSC. If the MTC has a greater amount of compliance, the capacity for utilization of the elastic energy during the SSC will increase (Kubo et al., 1999). In particular, the creation, storage and conversion of elastic energy during the SSC into power output influences CMJ performance. The larger the SSC, the greater the ensuing power output generated for a CMJ.

__Arm swing.__ Use of an arm swing may also influence the height of a CMJ Arm

swing use in a CMJ was assessed in one study that divided players (Vanezis & Lees,

2005), in a homogeneous soccer team population, into high and low jump height groups.

When allowed to use an arm swing, jump height increased similarly across the groups.

The improvement benefits of an arm swing were further supported in a jump study by

Gerodimos et al. (2008). In an effort to examine the effects of arm swing on CMJ

performance, four groups male basketball players, divided by age, were studied. The

addition of an arm swing to a CMJ increased the height significantly ($p < 0.05$) within

each of the four age ranges (Gerodimos et al., 2008).   Height increases were 4-7cm or a

16-20% increase in all age groups. The use of an arm swing during a CMJ will improve

the height achieved during a CMJ (Gerodimos et al., 2008; Vanezis & Lees, 2005).   It is

possible that lack of shoulder movement ability will negatively impact the influence of

the arm swing on a CMJ.

__Jump practice.__ Jump performance may be influenced by neuromuscular factors

as well as the biomechanical and physiological factors of the muscle. Specifically, the

quantity of practice jumps provided prior to data collection trials may influence peak

jump performance. In literature that has used practice trials to reduce the learning effect

of a CMJ task in inexperienced jumpers, no more than five practice jumps were used

prior to data collection (Aragon-Vargas, 2000; Gerodimos et al., 2008; Harman,

Rosenstein, Frykman & Rosenstein, 1990; Luhtanen & Komi, 1980). These trials are

often used by the researcher to provide feedback on the quality of the movement (i.e.,

proper hip, knee, and ankle flexion; trunk flexion; arm and hand position). Research

providing specific evidence to support the amount of practice trials needed for an

individual to learn a CMJ task is limited; however, the rationale for the use of practice jumps can be substantiated.

The use of explosive warm-up may prepare the neuromuscular innervations of the lower extremity. Practice jumps as a warm-up for explosive jump performance were shown to have a positive influence on jump performance (Young & Behm, 2003). The optimal number of jumps that is necessary to maximize performance may be task dependent, but the rehearsal of the task during a warm-up may facilitate motor unit activation. Increased facilitation of the motor unit was described as an opening of the site-specific neural pathway. These findings were further evidenced by Trimble and Harp (1998). It was shown that the performance of maximal voluntary contractions may create a post-activation potentiation of the motor unit that may result in a decreased recruitment threshold (Trimble & Harp, 1998). Task-specific, explosive warm-ups increase the ensuing performance on a jump test by facilitating motor unit activation of the lower extremity.

Complex explosive tasks are multifactorial in the influences that can affect performance. Biomechanical, physiological and neuromuscular factors all contribute to the performance of a CMJ. Similarly, the FMS™ has been used in athletic populations to gauge the overall quality of an individual's movement patterns by examining full body mobility and stability. Poor movement patterns may be a result of inefficient biomechanical, physiological and neuromuscular factors that also affect jump performance. It is possible that the same underlying factors that inhibit quality movement patterns that leave individuals at a higher risk of injury may also inhibit CMJ performance.

FMS™ and CMJ

The factors that may affect the achievable height from a vertical jump are the squat depth, tension of the elastic components of muscle, the SSC, and CMJ practice (Domire & Challis, 2007; Fukashiro et al., 2006; Kubo et al., 1999; Moran & Wallace, 2007; Young & Behm, 2003). When limitations exist in the above factors, vertical jump performance suffers. The FMS™ is a tool that may provide detail as to some current limitations that a participant may have that would inhibit jump performance.

Deep Squat. The first test of the FMS™ is the Deep Squat. A crucial element of the Deep Squat is whether or not the participant is able to squat low enough so that their knees are bent to at least 90°. Limitations in flexibility may be related to tightness in key hip flexors such as the iliopsoas, sartorius, and rectus femoris as these muscles may limit one's ability to lower into a deep squat. When one cannot squat to or below this cut off of 90°, a limitation is present that may affect the performance on a vertical jump through a deficient amount of eccentric loading during the SSC. A 90° knee angle has been shown to be the optimal angle for maximal jump height (Moran & Wallace, 2007; Salles et al., 2011). Additionally, optimal performance on the Deep Squat requires that both the trunk and tibia are parallel to one another at the bottom of the squat. Failure to maintain this posture becomes evident with an excessive amount of forward flexion beyond parallel with the tibia. This is not to say that an erect spine is needed throughout the Deep Squat. Research has shown that an optimal squatting position has some trunk flexion in order to maximize the hip extension muscles (Kritz et al., 2009; Vanrenterghem et al., 2008). Furthermore, the SEC of the quadriceps muscles and the calf muscles must be complaint enough for the individual to complete the test. For

example, without adequate Achilles SEC compliance, the participant will not be able to keep their heels on the ground during the Deep Squat. In such testing cases, the FMS™ reflects the elastic insufficiency in the scoring. It is possible that someone may perform poorly on the vertical jump if they have a low score on the FMS™ Deep Squat.

Hurdle Step. The Hurdle Step test from the FMS™ is another test that provides relevant information for a vertical jump. In order to perform the Hurdle Step test appropriately, the participant needs hip flexion, single-leg stability, and spinal stability to complete the test. Comparable to the Deep Squat, the iliopsoas and rectus femoris require sufficient flexibility and contralateral stability to properly perform this movement test. Insufficient amounts of hip flexion would be evident in the Hurdle Step test as the participant would struggle to flex their thigh to their torso as they raise the leg up and over the rubber band. Inferences could be made through this test that inadequate hip flexion to raise the leg over the rubber band may lead to a reduction in squat depth and lower amounts of eccentric loading for a vertical jump. In such cases, observable compensatory movement patterns, such as hip eversion, are utilized to lift the thigh up to the set height for foot clearance. A participant that lacks sufficient hip flexion to perform the Hurdle Step test may struggle to generate enough hip flexion in the eccentric phase of their vertical jump to reach a maximum height.

In-line Lunge. The In-line Lunge may show limitations that would affect a participant's ability to perform a vertical jump. Like both the Deep Squat and the Hurdle Step, the In-line Lunge requires hip flexion to complete the task; however, the stabilizing muscles of the task must be active simultaneously during spinal extension. Poor performance in the In-line Lunge test may result from inadequate hip flexion, low rectus

femoris flexibility, and an imbalance in the hip abductor's and adductor's flexibility and

strength. Insufficiencies may exist either in the lead or rear leg that can affect an

individual's performance on the in-line lunge test. Low mobility of the hips that would

be evidenced by the In-line Lunge may reflect a reduced depth of a squat in the eccentric

phase of a vertical jump. Unlike the Deep Squat, the spine must remain erect through this

movement. A common adaptation seen in the In-line Lunge is a forward lean of the trunk

during the lunging movement. This may describe a lack of mobility in the hip flexors in

the lead leg that would be used during the eccentric phase of the SSC where elastic

energy is stored; on the other hand, if caused by the rear leg, decreased mobility of the

hip extensors may allude to a decrease in the efficiency of the use of the stored elastic

energy during the concentric take off in the SSC. If a participant performs poorly on the

In-line lunge, they may also perform poorly on a maximal vertical jump.

      Shoulder Mobility. The Shoulder Mobility test's primary effect on a CMJ

relates to the level of shoulder extension during an arm swing that one can utilize during

the eccentric loading phase. Arm swing during a CMJ leads to an increase in the amount

of eccentric load applied to the lower extremity by an increase in the amount of forward

flexion of the trunk (Vanezis & Lees, 2005). Limited mobility seen in the Shoulder

Mobility test may have a negative effect on the maximum height that can be achieved in a

jump as it reduces the arm swing. A decreased amount of shoulder extension used during

the arm swing may result in a smaller vertical height. Muscular limitations that are found

through the Shoulder Mobility test may be responsible for decreased performance in a

maximal CMJ. One limiting factor of the Shoulder Mobility test may be tightness in the

latissimus dorsi. Observed tightness in the latissimus dorsi may limit the amount of

forward flexion of the trunk that one can produce during the eccentric phase of the SSC. This may occur in the CMJ tests that are performed with and without an arm swing.

Active Straight Leg Raise. The Active Straight Leg Raise may also provide insight as to how well a participant will perform a CMJ. This test measures the amount of active flexibility that a participant has in the hamstrings as well as hip mobility in the contralateral leg. Limitations that arise during this test may relate to one's ability to perform a maximal CMJ. For example, poor mobility of the hip may lead to a decreased ability to lower into a deep squat during the eccentric portion of the CMJ. Furthermore, reduced functional flexibility of the hamstrings, as seen by the inability to flex the hamstring to the desired height, may also limit maximal CMJ height. At the bottom of the deep squat, before the amortization phase, the hamstrings are contracted. At the initiation of the concentric phase, the hamstrings actively lengthen as the quadriceps drive the body up into the takeoff of the CMJ. A reduction in the functional flexibility of the hamstrings may prevent the quadriceps from fully contracting, reducing the amount of work that can be done at the hip, the most important joint for jump height production (Vanezis & Lees, 2005), during a CMJ.

Trunk Stability Push Up. The Trunk Stability Push Up test provides information regarding the strength as well as the stability of the trunk and abdominal muscles. Core stability may be useful in the production of height in a CMJ; especially during trials where an arm swing is used. Failure to perform an appropriate Trunk Stability Push Up may relate to poor core strength as well as poor upper body strength. During the Push Up, an individual is encouraged to brace or tighten the abdominal muscles to execute a proper movement. Failure to raise the body as one unit, shoulders

and trunk, may be a consequence of reduced core strength and stability. In the midst of a

CMJ with an arm swing, the trunk flexion recruited increases, which leads to an increase

in jump height (Vanezis & Lees, 2005). If the individual has limited amounts of core

strength, the amount of trunk flexion during an arm swing may become too great, and

result in a limitation in the height of the CMJ. While other FMS™ tests are able to

illustrate limitations to one's ability to have appropriate trunk flexion during a CMJ, such

as the Deep Squat, Hurdle Step and In-line Lunge, the Trunk Stability Push Up identifies

weaknesses in the core that can lead to excessive forward lean opposed to the other tests

that allude to abdominal weakness or hip flexor tightness.

> **Rotary Stability.** Similar to the Trunk Stability Push Up, the Rotary Stability

test may also identify weakness in the trunk and core muscles that may prove to be a

hindrance to performance. To be successful in this FMS™ test, a participant is required

to flex and hold the muscles in the core to stabilize the trunk during contralateral and

ipsilateral movements of the shoulders and hips. Failure to maintain this flexion may

lead to poor CMJ performance. During a CMJ, some trunk flexion in the eccentric

portion of the SSC improves jump height. Without the ability to control the amount of

hip and trunk flexion in the eccentric phase, the flexion may become too great, and

decrease the performance of the jump. Unlike the Deep Squat, Hurdle Step and the In-

line Lunge, that all can denote excessive forward lean, this test can identify weaknesses

specific to the core muscles, like the Trunk Stability Push Up, that lead to trunk stability

limitations during jump performances.

> The FMS™ and CMJ tests are each field tools that can be used to benefit athletes

and exercisers to identify injury risk and to assess performance. The tightness, weakness,

and muscular asymmetries that can be noted throughout the FMS™, with either scoring method, are contributing factors that may indicate how movement impairments ultimately affect performance. A common theme can be demonstrated between measures of functional movement and functional performance when utilizing the FMS™ for CMJ performance.

Conclusion

Functional performance testing, such as measuring CMJ peak height, is a commonly used method to assess the amount of power, strength, and speed that an individual can produce in the lower extremities (Lees et al., 2004; Luebbers et al., 2003; Moran & Wallace, 2007; Parchmann & McBride, 2011; Salles et al., 2011; Vanrenterghem et al., 2008). Peak performance in a CMJ may be limited by one's ability to achieve depth in the eccentric phase of a CMJ, stiffness in the SEC of the muscle, the effectiveness of the SSC to use elastic energy and the amount of jump practice prior to testing. It is possible that the FMS™ may be able to identify some of these limiting factors that affect CMJ performance.

The relationship between the FMS™ and athletic performance has been attempted with little success; however, previous literature has used a 21-point scale to score the FMS™, a less specific method of grading movement patterns. In an attempt to bridge the gap in the literature between the FMS™ and performance, future research should identify if a relationship exists between athletic performance measures and the FMS™ 100-point scale. Through the use of the 100-point scale, those with greater mobility and stability as scored on the FMS™ may have the capacity to achieve higher peak CMJ heights.

The primary purpose of this study was to examine the relationship between the FMS™ total score, scored on a 100-point and 21-point scale, and CMJ height. The secondary purpose of the study was to perform an exploratory analysis examining the relationship of the 21-point live scoring method as well as a 21-point video scoring method of the FMS™.

CHAPTER III: METHODS

Introduction

The primary purpose of this study was to examine the relationship between a Functional Movement Screen™ (FMS™) total score, scored on a 100-point and 21-point scale, and countermovement jump (CMJ) height. The secondary purpose of the study was to perform an exploratory analysis examining the relationship of the 21-point live scoring method as well as a 21-point video scoring method of the FMS™. This study was the first of its kind to assess the possible relationship between the FMS™, scored on a 100-point scale, and athletic performance. The findings of this study provide new insight for a tool that is currently a reliable tool used for injury risk stratification as well as build a foundation for functional strength training to improve athletic performance. The methodology utilized in this study was consistent with the purposes of this study, including the participants, instrumentation and equipment, measurement procedures, and data processing, and will be described in the following sections. This study was approved by the Institutional Review Board (IRB) of the University of Wisconsin-Milwaukee (UW-M) on April 1, 2013 (IRB Protocol Number = 13.313).

Participants

A sample of 36 male participants participated in the study. The results from an estimated power analysis using G-Power (Faul, Erdfelder, Lang & Buchner, 2007) based on a power of 0.8 and a moderate effect size of 0.5, indicated that the sample size would need to be at least 27. This study exceeded the minimum number of participants to provide more power for additional analyses; a total of 36 participants were recruited. The participants for this study were recruited from the UW-M campus and the surrounding

Milwaukee, WI area. Details of this study were advertised through the use of flyers (Appendix A), undergraduate student lecture announcements, and word of mouth. Selection for this study was contingent upon the Criteria for Inclusion. Participants did not receive monetary compensation for their participation in this study.

Criteria for exclusion. Prior to explanation of study details, participation eligibility was dictated by a set of exclusion criteria. A participant was ineligible for this study if: (a) he had a bone abnormality; (b) had an injury, orthopedic surgery, or had received rehabilitation services for an injury within the last year (i.e., of the shoulder, hip, knee, and/ or ankle); (c) had been told by a medical professional that he should avoid jumping, landing, and/ or running exercise; (d) had a current heart condition and/ or chest pain; (e) suffered from dizziness; (f) had a hearing impairment (participants needed to be able to hear the auditory stimulus from the MyoTest to begin CMJ trials); (g) had previous experience using the FMS™; (h) was taking prescribed medication for an illness; (i) was at the time or had ever been an intercollegiate Division I athlete; (j) was taking part in organized training to actively increase vertical jump height, or; (k) did not meet any of the following gender, age, body mass index, and/ or activity level criteria for this study.

Gender. Only males were recruited for participation this study. In the literature, FMS™ total scores on a 21-point scale between males and females have not shown differences between genders; however, differences existed within the individual component test scores that made up the total score (Schneiders et al., 2011). Researchers examining the FMS™ as a method of movement pattern assessment have recruited both males and females; however, males are typically more heavily represented, if not

exclusively represented, in the populations studied (Frost et al., 2012; Goss et al., 2009; Kiesel et al., 2007; Kiesel et al., 2011; O'Connor et al., 2011). The results of these studies are more generalizable to men than they are to women. While there is literature in existence on the female performance on the FMS™, males were solely recruited for this study to add to the primary literature regarding the FMS™.

The total score of a FMS™ may be similar on the 21-point scale between genders. However, gender could be a confounding variable when considering functional performance. Males were recruited in an attempt to remove gender as a confounding variable in this study and provide greater relevance for comparing the 21-point score to the 100-point score within the context of the current literature. Evidence is available in the literature that demonstrates that differences exist between male and female jump heights. In Cardinale & Stone (2006), comparisons were made between CMJ heights and gender. Males were shown to have significantly ($p < 0.001$) higher vertical jump heights than females (Cardinale & Stone, 2006). Mixed-gender samples may mislead the relationship between functional movement and functional performance. In order to reduce the influence that gender may have on the relationship of the FMS™ and CMJ height, only males will be recruited in this proposed study.

Age. The age of the participants recruited was a criterion for inclusion; age of participants was limited to a range of 18-30 years. The majority of the current literature that uses the FMS™ as a method of movement assessment has recruited participants within the age range of 18-30 years (Butler et al., 2010; Chorba et al., 2010; Frost et al., 2012; Goss et al., 2009; Onate et al., 2012). In an attempt to build upon the previously

established research, participants for this study were also recruited within a similar age range.

Age may also be a factor that may affect performance. With age, the structure and function of tendons has been shown to decrease with age (Tuite et al., 1997). Reports of age-related degeneration have been identified as early as one's early 30's (Bosco & Komi, 1980). By this rationale, this study narrowed the age range of participants to 18-30 years to limit the subsequent impact that age had on the relationship between the FMS™ score and CMJ height measurements.

Body mass index. Participation in this study was also dependent on the individual's Body Mass Index (BMI). A negative correlation has been identified in the literature between BMI and FMS™ total score (Perry & Koehle, 2013). Individuals that have a BMI > 30 have been shown to have significantly lower scores on the FMS™ than participants with a BMI under 30 (Perry & Koehle, 2013). To remove the effects that body size has been shown to have on the relationship between the FMS™ total score and CMJ height, only those with a BMI < 30 were included in this study.

Activity level. The amount of activity and level of fitness was also controlled for in those who participated in this study. All participants for this study provided a self-report of how often they engaged in regular exercise based on the American College of Sports Medicine (ACSM) minimum guidelines. Participants needed to meet the minimum exercise requirements (i.e., ≥ 30 min of moderate intensity exercise five days/ week or ≥ 20 min vigorous exercise three days/ week; Garber et al., 2011) for at least the six consecutive months prior to participation in this study in order to be eligible. This was gauged with an exercise history questionnaire. Within this questionnaire,

participants were asked to describe through what type(s) of activity they met the

minimum ACSM guidelines.

   Participants Recruited. The recruitment process of participants for this

study is illustrated in Figure 1. A total of 45 participants were recruited for this study.

Of these 45, 37 underwent and completed Phase I of this study. The nine that did not

advance through the first phase of testing were excluded due to a: BMI outside the

inclusion criteria ($n = 2$), activity level outside the inclusion criteria ($n = 1$), change in

health status ($n = 2$), or were a no show to Phase I ($n = 4$). Of the 37 that completed

Phase I, 36 advanced through and completed Phase II of this study. The individual that

did not advance to Phase II voluntarily withdrew from the study after Phase I. All

participants were recruited from UW-Milwaukee (UW-M) campus and the Greater

Milwaukee area.

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                    ┌─────────────────────┐
                    │      n = 45         │
                    │ Contacted with interest│
                    │    and scheduled    │
                    └─────────────────────┘

  ┌─────────────────────┐          ┌─────────────────────┐
  │      n = 37         │          │      n = 8          │
  │   Meet Criteria for │          │ Did not meet Criteria for│
  │ Inclusion and advance│         │     Inclusion       │
  │   through Phase I   │          └─────────────────────┘
  └─────────────────────┘

┌─────────────────┐  ┌─────────────────────┐
│    n = 36       │  │      n = 1          │
│ Complete Phase II│ │  Dropped out prior to│
└─────────────────┘  │     Phase II        │
                     └─────────────────────┘
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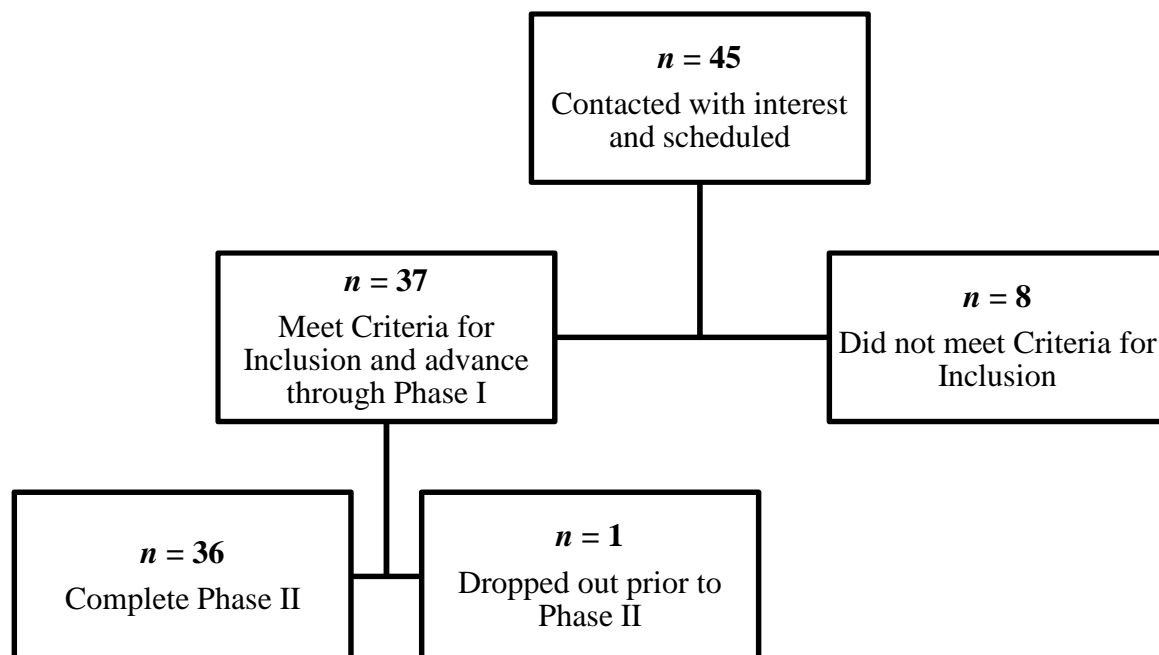
Figure 1. Flowchart of participant recruitment

Participant characteristics. The mean age of the participants that completed this study was 21.8 (± 1.6) years. Mean height of the participants was 177.9 (±7.0) centimeters (cm), mean bodyweight was 78.1 (±11.5) kilograms (kg), and mean body mass index (BMI) was 24.6 (±2.7).

Correlational Design

This study took place over the course of two days. Each of the test days was conducted in the Human Performance and Sport Physiology (HPSP) Laboratory, located within the UW-M Pavilion, Room 365 (3409 N. Downer Ave, Milwaukee, WI 53211). Criteria for inclusion were met by the participants before the beginning of Day 1. Participants were asked to refrain from smoking (or use of any other tobacco product) as well as caffeine intake 4 hours prior to participation in this study. Furthermore, participants were asked to abstain from heavy weightlifting and/ or maximal aerobic exercise, for the 24-48 hours between testing days. To maintain the highest amount of accuracy throughout this study, all measurements of the anthropometrics, FMS™, and countermovement jumps were be conducted by the primary student investigator (Joshua K. Conlon).

Day 1. On the first day of testing, the participant was given an Informed Consent Document (Appendix D) to read and complete prior to the study explanation detail. Participants were also given an exercise history questionnaire (Appendix E) to read and complete that verified that the participant fit within the range of physical activity that was recruited. The exercise questionnaire was not included into the data analysis; however, rather it was used to assess the mode and quantity of exercise that an individual partook in on a weekly basis. This information was used to better describe the physical activity

history of the participants and to verify that participants had fulfilled the minimum activity level requested in the Criteria for Inclusion.

Height and weight. Both height and weight measurements were be taken with a weigh beam eye-level physician scale and mounted stadiometer (Deteco, Webb City, MO). Height was recorded to the nearest centimeter (cm) and weight in kilograms (kg) to the nearest tenth. From the anthropometric data, body mass index (BMI) was calculated by dividing weight (kg) by height squared (m^2). The BMI score was rounded to the nearest tenth decimal place. Height and weight measurements were used to confirm the self-reported height and weight used to estimate BMI as part of the Criteria for Inclusion Questionnaire.

Functional Movement Screen™. All seven tasks of the FMS™ were subjectively scored by the primary investigator. The participant was instructed to perform each of the seven movement tests to the best of their ability as described by the investigator. The movements were scored on a 21-point live scale with a paper and pencil scoring sheet that followed the guidelines of the 21-point scale. The seven movement tests were also video recorded to be later rescored on a 21-point and 100-point scale. The seven tasks that were performed were: Deep Squat, Hurdle Step, In-line Lunge, Shoulder Mobility, Active Straight Leg Raise, Trunk Stability Push Up, and Rotary Stability. While the 21-point scale has a maximum of 3 points per test, the 100-point scale maximum score ranges were between 8-20 possible points depending on the component test.

21-point scale. The current study included a 21-point scoring that evaluated both live as well as a post hoc video review of the live movement tests. The live 21-point

scale was scored in person on the first day of testing by the student PI as the participant executed each movement. The tests were simultaneously video recorded. After the first day of testing, the tests were then be rescored through a review of the video recording of the live tests on an identical 21-point scale. Scoring for the 21-point scale followed the guidelines laid out in previous literature (Cook et al., 2006a; Cook et al., 2006b).

100-point scale. The study also used the 100-point scoring scale to add more precision to the scoring of the live movement tests. The total 100-point scoring method was evaluated post hoc using the video recorded FMS™ tests. The scoring rubric for this method was identical to that outlined in previous literature (Butler et al., 2012). The 100-point scale scoring guidelines evaluate the movements similarly to the 21-point scale; however, test point values are weighted more heavily based on the individual test's complexity.

Video recording: All seven of the FMS™ tests were video recorded on the first day of testing. The tests were video recorded with an iPad-imbedded camera from three different perspectives (i.e., from the front, from the side, from behind) in both the frontal and sagittal planes (Butler et al., 2012; Frost et al., 2012). The video recorded movements were used to re-score the live FMS™ tests post hoc on both a total 21-point and 100-point scale. The video-rated 21-point scale was used for an exploratory analysis to determine if differences were present between the results of the 21-point live and 21-point video-rated scoring procedures. Previous literature using the 100-point scale for scoring the FMS™ tests has used video to record the movement tests. This allowed the reviewer(s) adequate time and frequency of viewings in order to score with the more involved scale with the depth that is required (Butler et al., 2012; Frost et al., 2012).

Description of the FMS™ tests. Each of the tests for the FMS™ is described below as the participant was instructed and is adapted from the literature that originated the 100-point scale (Butler et al., 2012). Each movement was completed by the participant to the best of his ability.

Deep Squat: This test required the participant to hold a light weight plastic dowel rod over the head with arms extended throughout a squat motion. The participant was asked to squat down as low as they comfortably could. This task was repeated up to five times (18-point maximum).

Hurdle Step: A test which involved holding the aforementioned dowel rod across the shoulders with a concomitant step, one leg at a time, over a rubber tube that was anchored to two stationary poles. The height of the rubber band was level with the tibial tuberosity, just below the knee. This task was repeated up to five times. Each side was scored separately (18-point maximum; 9 per side).

In-line Lunge: This test involved the participant lunging forward while standing on top of the FMS™ board. The participants were asked to touch the knee of the back leg to the heel of the front foot while extending the back. This was repeated up to five times. Each side was scored separately (20-point maximum; 10 per side).

Shoulder Mobility: This test was preceded by a clearance test that assessed for pain that would inhibit the completion of the test. The clearance test required the participant to reach a hand to the opposite shoulder so that the palm came in contact with the shoulder near the clavicle. The elbow was then raised so that it pointed forward while keeping the palm in contact with the shoulder. This occurred for both sides. If no pain was felt, the (YES) was circled, inferring that they passed the test, and the participant was

allowed to perform the Shoulder Mobility test. However, if pain was felt, the (NO) was

circled next to Shoulder Mobility, and the individual did not perform the Shoulder

Mobility test.   The Shoulder Mobility test was used to assess the range of motion of the

shoulder. The participant reached each hand, as a fist, toward the center of the back, one

over the top and one underneath, to bring them as close together as possible in a single

motion. The distance that separated the two hands was measured. This test was repeated

three times. Both shoulders were assessed and each side was scored separately (8-point

maximum; 4 per side).

Active Straight Leg Raise: A single, straight-leg raise, which involved the

participant lying on his back and raising one leg up from the ground while the knee was

kept flat on the ground. This test was repeated up to five times. Both legs were assessed

and scored separately (12-point maximum; 6 per side).

Trunk Stability Push Up: This movement test was preceded by a clearance test

that assessed for pain. This clearance test is similar to a *cobra stretch*. Prone on the

ground in a standard push up position, the individual will push the upper body up into a

spinal extension as the arms extend. If pain was noted, the (NO) was circled next to the

Trunk Stability Push Up and the test was scored as a zero. This test was primarily a

strength task, involving the performance of a push-up with the hands placed at the level

of the chin or clavicle. This task was repeated up to five times (12-point maximum).

Rotary Stability: This test was preceded by a clearance test and assessed for pain

prior to the execution of this test. This clearance test was initiated from the quadruped

position (arms and legs) in contact with the ground. The participant flexed the neck

bringing their chin toward their chest while simultaneously arching the back. The rotary

Stability test was a measure of core strength and stability, which involved the participant being positioned in a quadruped stance and trying to bring an elbow to the ipsilateral knee. This was repeated up to five times for each side and each side was scored separately (12-point maximum; 6 per side).

Countermovement Jump

Countermovement jump practice trials. At the end of the first testing day, the participant was given basic instructions for how to complete the CMJ as well as an example jump from the primary student investigator. The participant then conducted five practice trials while wearing the MyoTest SPORT unit device to gain experience on performing the task within the confines of the equipment. These practice trials were used in an attempt to diminish the learning effect of performing a CMJ task. The CMJ technique was described to the participant in accordance with the testing protocol (Appendix B).

Myotest SPORT unit. The measurement device that was used to record maximum jump height during the CMJ was the MyoTest SPORT unit. The MyoTest SPORT unit (Myotest Inc., Durango, CO) is an accelerometer that stores flight time and acceleration data that was used to calculate peak jump height. The recorded accelerations were integrated to find vertical velocity by which the overall jump height was estimated (Casartelli et al., 2010). Jump height was calculated through two methods utilized by the MyoTest SPORT unit (Casartelli et al., 2010). The first method estimated peak height by interpreting flight time through the use of the equation (Height = [g x flight time^2]/8). The second method of calculating peak height used takeoff velocity through the use of the equation (Height = max vertical velocity^2/ [2 x g]) (Casartelli et al., 2010). In the

literature, the test-retest reliability of the MyoTest's ability to estimate peak height

through the use of flight time, was high (ICC = 0.92-0.96) (Casartelli et al., 2010). For

this study, the MyoTest data were downloaded to a computer for later analysis and to

determine the jump height using MyoTest Software. For consistency, the MyoTest

device was worn by the participant for all practice trials as well as the data collection

trials in this study.

   CMJ practice script. The participant was instructed on four main points of the

CMJ: the eccentric squatting motion, backward arm swing extension, maintenance of a

straight back during the task, and the upward arm swing. The participant was also

instructed that each of the jumps that were collected would be a maximal effort. With the

MyoTest SPORT unit firmly around the waist, the participant stood upright with their

arms down at the sides, feet shoulder width apart, and awaited the initiation beep

(Myotest). At the sound of a beep, the participant lowered himself into a squat, swung

his arms back into an extension, followed by an immediate jump with a concomitant

upward arm swing driving them to a maximum jump height. The depth at which the

participant squatted was not controlled for; however, the participant was instructed to

squat to a depth that would provide the greatest jump height. The participant was

encouraged to land with bent knees at the end of each practice trial. The participant was

given five practice jumps or until they felt comfortable with the movements of the task.

In literature that has used practice trials to reduce the learning effect of a CMJ task in

inexperienced jumpers, no more than five practice jumps were used prior to data

collection (Aragon-Vargas, 2000; Gerodimos et al., 2008; Harman et al., 1990; Luhtanen

& Komi, 1980).

Day 2. Day 2 was scheduled no more than 48 hours after Day 1. At the start of the second day, participants warmed up with a 5-minute cycling bout at a self-selected intensity and pace on a stationary Monark Ergomedic 828E bicycle ergometer (Monark Exercise, Vansboro, Sweden). Upon completion of the warm-up, the participant was re-equipped with the MyoTest SPORT unit and then given the opportunity to practice the CMJ movement again.

CMJ practice. The participant was reminded of the jump parameters from Day 1 and given five practice CMJ attempts. These attempts served to further familiarize the participant with the CMJ protocol as well as allow the participant to become more comfortable with the CMJ motion within the confines of the equipment. After the five practice jumps were completed, the participant was given a 1-3 minute rest and then advanced to the data collection of the jump trials.

Countermovement jump trials. The participant performed three maximal effort CMJ trials. The MyoTest unit was secured to the belt above the participant's left hip. Once the participant and student PI were ready, the student PI activated the MyoTest for the beginning of the trial. When the beep was heard, the participant followed the practiced jump protocol from Day 1 and Day 2. The participant was instructed to jump as quickly and powerfully as possible and again reminded to land with bent knees at the end of each trial. Upon the completion of a successful CMJ trial, the MyoTest unit saved the peak height value for each participant trial by way of the MyoTest SPORT unit.

Peak height was recorded by the MyoTest for each successful trial. A CMJ trial was deemed unsuccessful if the participant started the jump before the beep (i.e., false start), if the MyoTest SPORT unit was bumped during the arm swing of the jump, or if

the MyoTest was not able to properly record the trial. To guarantee that each trial was a maximal jump, participants received verbal encouragement and feedback both before and after each trial from the student PI. After three successful trials were recorded, the MyoTest Sport unit was removed and the participant's commitment to the study was finished. The jump data was downloaded to a password-protected computer for subsequent jump height analysis.

Statistical Analysis

All statistical analyses were calculated using IBM SPSS Statistics 21 software (IBM Corporation, Armonk, New York). Pearson correlations were performed between CMJ height and each of the FMS™ scoring scales (100 point, 21 live, 21 video). An exploratory analysis was also conducted as a follow-up comparison between the FMS™ scoring scales. Pearson correlations were performed to examine the relationship between each of the scoring scales of the FMS™. An alpha level of significance was set at 0.05 for all comparisons.

CHAPTER IV: RESULTS

Introduction

The primary purpose of this study was to examine the relationship between the Functional Movement Screen™ (FMS™) score on a 100-point scale and the height achieved by a countermovement jump (CMJ). The secondary purpose of the study was to perform an exploratory analysis examining the relationship of the 21-point live scoring method as well as a 21-point video scoring method of the FMS™. It was hypothesized that greater functional movement, scored on the FMS™, would result in greater functional performance, quantified by CMJ height. It was also hypothesized that the FMS™ scored on a live 21-point scale would have a positive correlation to the 21-point video scoring method.

In order to test these hypotheses, a correlational design was used to examine the variables of interest (i.e., functional movement and functional performance). After participants proved to be eligible for participation by fulfilling adequate physical activity, BMI, age and gender requirements, they completed the seven FMS™ movement tests. These tests were scored live on a 21-point scale. Throughout the testing session, each of the movements was videotaped from anterior, lateral, and posterior angles for post hoc scoring on the 100-point scale. The participants were then instructed on how to perform a CMJ and given five practice trials. Test trials were recorded within 48 hours of the first testing session for a total of three maximal CMJ trials.

Outcomes of interest. The primary outcome of interest was the relationship between the measures of functional movement (i.e., FMS™) and functional performance (i.e., CMJ height). The secondary outcome was the relationship between the scoring

methods of the FMS™ (i.e., 21-point live and 21-point video). The subsequent chapter is divided into participant recruitment, characteristics of those that were eligible for this study and rationale for participant exclusion. The outcomes of the primary and secondary purposes are presented as well as a description of the analyses performed. Lastly, this chapter will include a summary of the overall findings of this study.

Functional Movement Screen™ scores.

The overall FMS™ scores ranged from 9-17 on the 21-point live scale, 8-17 on the 21-point video scale, and 28-78 on the 100-point scale. The mean FMS™ scores on the 21-point live and 21-point video scoring methods were 12.8 ($\pm$1.6) and 12.9 ($\pm$1.7), respectively. The mean 100-point scale score was 45.1 ($\pm$10.2).

Table 1. Descriptive Statistics for the FMS™ and CMJ Results

	Minimum	Maximum	Mean	Std. Deviation
FMS 21-point live	9	17	12.8	1.6
FMS 21-point video	8	17	12.9	1.7
FMS 100-point	28	78	45.1	10.2
CMJ Height (cm)	37	73	51.1	7.8

Counter movement jump performance. Performance values for CMJ were reported as the mean of the three trials for each participant. The mean jump height of all participants was 51.1cm ($\pm$7.8).

Outcomes of Interest

Primary outcome. The correlation between the FMS™ and CMJ was significant for each method of scoring the FMS™.

Table 2. FMS™ and CMJ Correlations

FMS	CMJ height (cm)
21-point live	$r = 0.346, p = 0.039$
21-point video	$r = 0.436, p = 0.008$
100-point	$r = 0.428, p = 0.009$

*$p < 0.05$. Correlation matrix of primary outcome variables. Each FMS™ scoring method has a significant relationship to CMJ height.
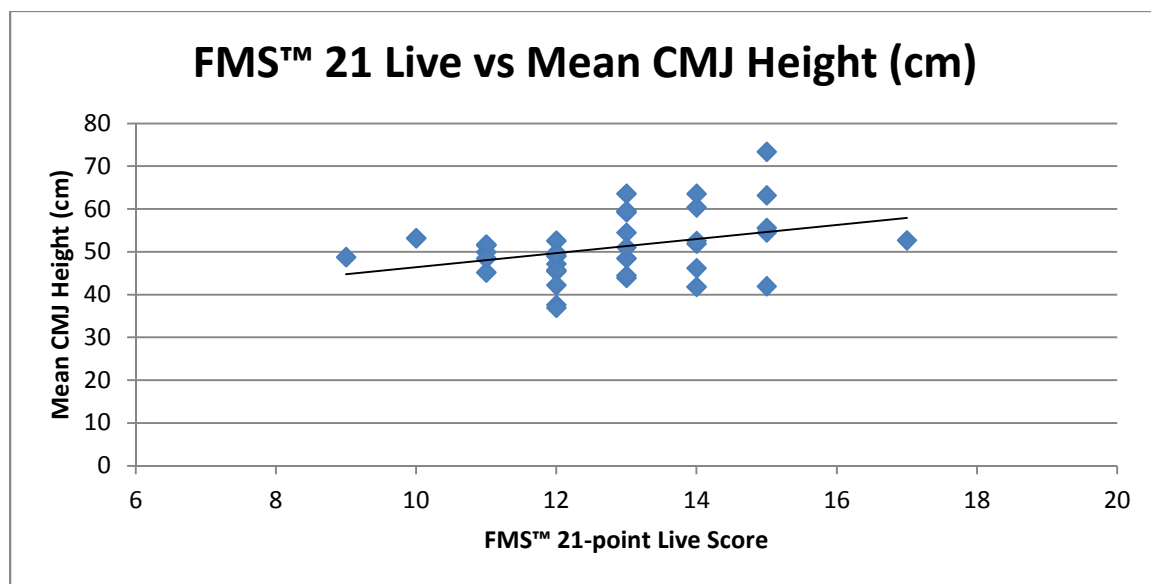

Figure 2.   Aggregate FMS™ 21-point live score vs. CMJ Height (cm). FMS™ 21-point live score was not significantly correlated to Mean CMJ Height ($r = 0.346, p = 0.039$).
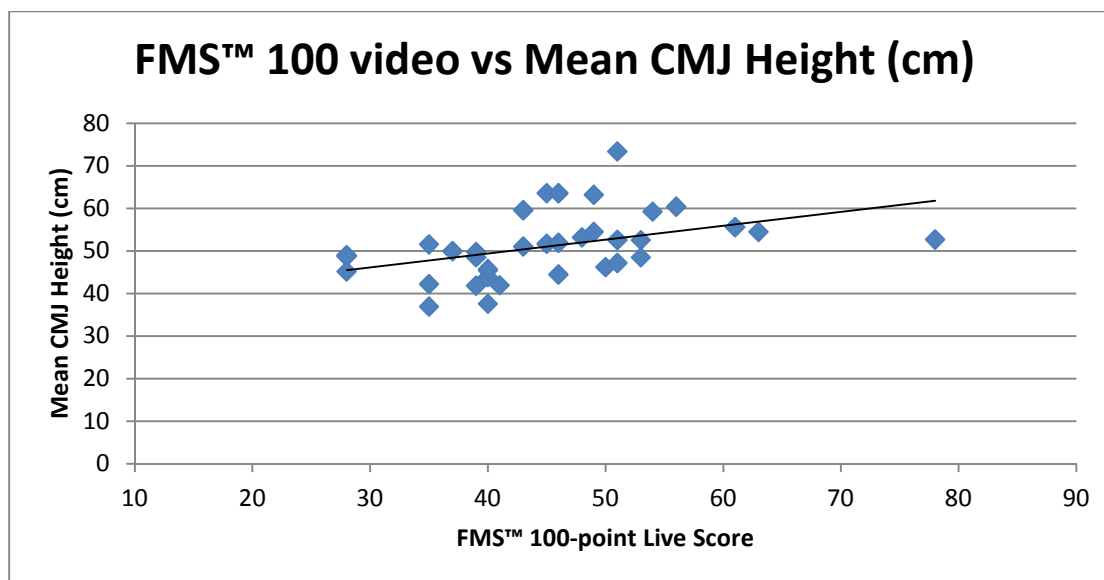
Figure 3. Aggregate FMS™ 100-point video score vs. CMJ Height (cm). FMS™

100-point video score was significantly correlated to mean CMJ height (*r* = 0.428, *p* =

0.009).

Secondary outcomes. Bivariate Pearson correlations were used to examine

the relationship between the 21-point scales and the 100-point scale. These correlations

are described in more detail in Table 3. Each of the scoring scales of the FMS™ was

significantly correlated to one another. The 21-point live scoring method had a significant

correlation to the 21-point video scoring method (*r* = 0.893, *p* < 0.001). The 21-point

live scoring method was also significantly correlated to the 100-point video scoring

method (*r* = 0.714, *p* = *p* < 0.001).

Table 3. FMS™ Scoring Method Correlations

Scoring method	21-point live	21-point video
21-point video	$r = 0.893, p < 0.001$	
100-point	$r = 0.714, p < 0.001$	$r = 0.771, p < 0.001$

*$p < 0.05$. Correlation matrix of secondary outcome variables. The FMS™

scoring methods, live and video, have a significant relationship.

Chapter V: Discussion

Introduction

The use of both functional movement and functional performance testing prior to activity participation is well documented (Cook et al., 2006a; Cook et al., 2006b; Hoffman, Tenenbaum, Maresh & Kraemer, 1996). However, it is unclear whether performance on these two tests is related. Researchers have previously examined the relationship between functional movement and functional performance, and have demonstrated minimal overlap between the Functional Movement Screen™ (FMS™) and measures of performance (i.e., countermovement jump height) (Okada et al., 2011; Parchmann & McBride, 2011).The aim of this study was to examine the relationship between measures of functional movement and functional performance with a more precise method of scoring for the FMS™. The primary purpose of this study was to examine the relationship between the FMS™ total score, scored on a 100-point and 21-point scale, and CMJ height. The secondary purpose of the study was to perform an exploratory analysis examining the relationship of the 21-point live scoring method as well as a 21-point video scoring method of the FMS™.

This study was organized into two phases of data collection. Phase I began with collection of the anthropometric data as well as the successful completion of the FMS™, concluding with an introduction to the countermovement jump (CMJ) which included five practice trials jumps. Phase II was conducted within 48 hours of Phase I, in which participants performed a warm-up, five practice CMJ trials, and three CMJ data trials. A

total of 45 participants were recruited for this study, with 37 advancing through Phase I and 36 completing Phase II.

The results of the current study for total FMS™ scores (Gribble, Brigle, Pietrosimone, Pfile & Webster, 2013; Schneiders et al., 2011; Smith, Chimera, Wright & Warren, 2013) and BMI (Duncan & Stanley, 2012; Duncan, Stanley & Wright, 2013; Perry & Koehle, 2013) for the sample recruited were not similar to previously established norms. However, CMJ height reported for the current study was within established norms for similar samples (Nuñez et al., 2008; Nuzzo et al., 2011; Vanezis & Lees, 2005). Differences in the population, power task and scoring method of the FMS™ may have resulted in differing results between the current study and previously reported results. The following discussion will establish: (a) how the sample population recruited relates to those that have been recruited in previous literature and (b) how limitations in previous literature enhanced the exclusion criteria for the current study.

Comparison of sample to previous literature

Functional movement screen™. The mean score for the live FMS™ 21-point scale, post hoc video 21-point scale, and 100-point scale were 12.8±1.6, 12.9±1.7, and 45.1±10.2, respectively. The mean values for the 21-point scale are below what has been deemed the athletic cut-off (≤14) for participation without risk for injury (Chorba et al., 2011; Kiesel et al., 2007; Kiesel et al., 2011; O'Connor et al., 2011).

The reported mean FMS™ total scores were also below previously established normal total scores. Schneiders et al. (2011) reported mean FMS™ values for the 21-point live scale of 15.8±1.8. Smith et al. (2013) reported mean FMS™ scores for the 21-point live scale of 14.3±1.5. Gribble et al. (2013) reported mean FMS™ scores for the

21-point video scale of 13.69±0.98. Comparatively, the FMS™ scores from the current study were lower than those reported in previous research.

The FMS™ total score means from the current study were lower than previously established means for each of the scales used. The previously established athletic participation *cut-off* score (≤14) was created from highly athletic populations (i.e., professional football; collegiate athletes; military officers). The current sample may have been below this *cut-off* due to differences in physical activity then those used to establish this *cut-off* for athletic participation. Mean FMS™ total scores were also lower than means reported from recreationally active populations. It is possible that the primary investigator was strict in following the scoring rubric of the FMS™. However, it should be noted that this level of movement criticism was maintained for both 21-point scales. To date, adult norms for the FMS™ 100-point scale have not been established. Butler et al. (2012), reported mean values for the FMS™ 100-point scale of 57.2±1.9 for middle school aged children. The results from the current study address an immediate gap in the literature by presenting a set of 100-point scale values for recreationally active adult males.

Countermovement jump. The mean CMJ height for male participants in the current study was 51.1±7.8 cm. These results were within the range of jump performances reported in by previous researchers. (Nuñez et al., 2008; Nuzzo et al., 2011; Vanezis & Lees, 2005). Nuzzo et al. (2011) reported CMJ trial means using the Myotest Sport Unit with lower heights of 44.2±7.5 cm, 44.1±7.5 cm and 44.8±7.4 cm for males. Conversely, Vanezis and Lees (2005) recorded CMJ heights of 57.9±2.1 cm. Nuñez et al. (2008) reported male CMJ mean heights that most closely resembled the

results of this study 52.7±4.8 cm. Similar to the present study, the CMJ trials for these studies required participants to utilize an arm swing. The CMJ results from the current study were consistent with those of prior studies suggesting that the CMJ task used as the comparative task for FMS was at least consistent with prior studies.

Body mass index. A BMI of 30 or greater was an exclusion criteria for participating in this study. The mean BMI of the subjects for the current study was 24.6±2.7. Researchers have established a negative correlation between BMI and FMS™ stating that BMI is a confounding variable to FMS™ performance (Duncan & Stanley, 2011; Duncan et al., 2013; Perry & Koehle, 2013). Perry and Koehle (2013) established BMI norms for adults between 20-39 years of age at 26.0±3.9 (Perry & Koehle, 2013). The established adult norms from Perry and Koehle were of a mixed gender population and may infer that a strictly male adult population of the same age demographic would be greater than 26. Schneiders et al. (2011) also reported a mean BMI of 25.0±2.9 for active, healthy males between the ages of 18-40 years of age. The participants of the present study were below this established norm as well.

A Pearson correlation was conducted to examine the relationship in the present study between BMI and FMS™ scores. The relationship was not found to be significant between BMI and the FMS™ 100-point ($r = -0.011$, $p = 0.951$), live 21-point ($r = -0.023$, $p = 0.895$), and video 21-point ($r = 0.183$, $p = 0.285$). However, the implications may need to be taken with caution. Unlike other FMS™ research, the population in the current study was designed to exclude BMI's greater than 29. The lack of significant correlation between BMI and FMS score in the current study may be due to the small amount of variability in the population BMI in this study.

Sample comparison summary. The sample recruited for the current study performed similarly in CMJ performance to other reported means despite lower mean FMS™ performance and a lower mean BMI. The physical activity restrictions, BMI restriction and gender restriction may have influenced the mean reported values for FMS™ performance. With an understanding of how the current participant populations compares to that of previous research, the subsequent discussion sections will examine the relationship between FMS™ and CMJ and the influence of FMS™ scoring method.

FMS™ and CMJ

Previous researchers have been unable to establish a relationship between these two variables (Okada et al., 2011; Parchmann & McBride, 2011), however the results of the current study indicate that functional movement may influence performance. The current study found a significant relationship between CMJ and FMS™ as measured by the 100-point scale ($r = 0.428$, $p = 0.009$), the 21-point live scale ($r = 0.346$, $p = 0.039$), and the 21-point video scale ($r = 0.436$, $p = 0.008$). Thus there was a significant relationship between the FMS™ and CMJ regardless of the scale used to score the FMS™. The current study was the first to find a significant relationship between functional movement and functional performance, regardless of the scoring method used for the FMS™. It is possible that the differences in population, power task, and measurement method contributed to the current results.

Population characteristics. Unlike previous literature that examined the relationship between the FMS™ and CMJ height (Okada et al., 2011; Parchmann & McBride, 2011), the current study established both minimum (i.e., American College of Sports Medicine guidelines) and maximum (i.e., non-athletes; non-jump training)

physical activity parameters as a requirement for participation. This restriction was established in order to reduce the influence that physical activity extremes would have on performance for either the FMS™ or CMJ height. Other potentially influential factors may have included gender and body mass index (BMI).

Gender may have been a factor that limited the relationship between functional movement and functional performance. Okada et al. (2011) recruited a recreationally active population of males and females that were injury free for at least one year prior to participation and there were not exclusion criteria based on BMI. Parchmann and McBride (2011) also recruited an athletic population with no history of time-loss due to injury in the last 12 months to examine the relationship between functional movement and functional performance. However, unlike in Okada et al. (2011), the population recruited was a mixed gender sample of Division I golf athletes opposed to recreationally active healthy adults. Athletes were not excluded for any BMI values. Performance on the FMS™ for these populations may not have been significantly correlated to CMJ height because of the mixed-gender samples or the inclusion of all BMI values.

Mixed-gender samples that were recruited may have added another confounding variable to the relationship between the FMS™ and CMJ height. Schneiders et al. (2011), stated that total FMS™ scores are not significantly different between genders when scored on a live 21-point scale; however, CMJ heights are significantly different between genders (Alegre, Lara, Elvira & Aguado, 2009). The similar FMS™ total scores within a mixed-gender sample and wide range of CMJ heights may cloud the influence that functional movement has on functional performance. Therefore, the inclusion of another variable (i.e., gender) to the relationship between functional movement and

functional performance may have hindered the significance of the relationships in previous research.

In the current study, BMI was a restriction for participation. A Pearson correlation was used to examine the relationship between BMI and FMS™ performance on the current sample. A significant relationship was not found between BMI and the 21-live ($r = -0.011$, $p = 0.951$), 21-video ($r = -0.023$, $p = 0.895$), and 100-point scales ($r = 0.183$, $p = 0.285$). The low correlation coefficient suggests that BMI did not influence FMS™ performance in the current study and was successfully controlled for in the current study.

The BMI of those recruited in previous studies may have influenced performance on the FMS™. Perry et al. (2013) found a significant negative correlation between the FMS™ and BMI when controlled for age ($r = -0.24$, $p < 0.001$). Duncan and Stanley (2012) have found similar relationships between the FMS™ and BMI in an adolescent population. It is possible that a participant's BMI (i.e., ≥ 30) may have decreased FMS™ performance and compromised the relationship that was found between movement and performance in previous studies.

The exclusion criteria for participation in the current study narrowed and limited participation to a more homogenous group than what was recruited by other researchers. The restriction of BMI and gender, which have been noted to have influence on the variables of interest (i.e., functional movement and performance), may have resulted in the significant relationship between functional movement and functional performance. In order to establish a relationship between the FMS™ and CMJ height, a more restrictive criteria for inclusion may be necessary.

Power task. The method of quantifying functional performance may have

resulted in the significant findings of the current study that were not found in other

literature. In the current study, a CMJ with an arm swing was the power task used to

quantify an individual's functional performance. This task is representative of a full body

power task as it involves motion in both the upper and lower extremity to achieve a quick

displacement of one's center of mass to a maximum height. Since the FMS™ is a full

body movement screen, a full body power task was used for to measure functional

performance. Researchers that examined the relationship between functional movement

and functional performance may have not established a relationship because of the power

task used.

In Okada et al. (2011), the relationship between functional movement and

functional performance was examined. The measure of power used was a backwards

overhead medicine ball (BOMB) throw. Functional movement was assessed using the

live FMS™ 21-point scale. While some of the component scores of the FMS™ tests

were found to have a significant relationship to BOMB throw performance (i.e., right side

Hurdle Step ($r = 0.415$), Trunk Stability Push Up ($r = 0.407$), right side Rotary Stability

($r = 0.391$)), the total score was not significantly correlated to performance (Okada et al.,

2011). While the BOMB throw is a full body power task, this task may be more

dependent on upper extremity mobility, stability and power.

The disparity between Okada et al. (2011) and the current study may reside in this

task difference. Okada et al. (2011) used the BOMB throw as a power performance

measure while a three-trial mean of CMJ height with arm swing was used to assess power

in the current study. While each is a designed to be an explosive task that recruits power

from a full body movement, it may be that the BOMB throw is more dependent on upper body mobility, stability and power whereas the CMJ relies more heavily on lower body mobility, stability and power. It is possible that the component tests of the FMS™ may relate more favorably to performance tasks that rely on lower body functional movement and performance opposed to that of the upper body. Like Okada et al. (2011), Parchmann and McBride (2011) also examined the potential relationship between movement and performance.

The relationship between functional movement and functional performance was also examined by Parchmann and McBride (2011). In Parchmann and McBride (2011) a non-significant relationship was suggested between the FMS™ 21-point live scale and CMJ height ($r = 0.249$) (Parchmann & McBride, 2011). While Parchmann and McBride used the same power task as the current study, each differed in the initial position of the arms prior to an arm swing. There is the potential that the initial position of the arms prior to the execution of a CMJ may have influenced the relationship between CMJ height and FMS™ performance.

There is the potential that a difference in the initial position of the arms prior to CMJ performance may have influenced the relationship between functional movement and functional performance. Part of the FMS™ is the Shoulder Mobility test that examines an individual's shoulder and latissimus dorsi mobility. It is possible that restriction in the upper extremity, as seen in the Shoulder Mobility test, could reduce arm swing follow through and reduce CMJ performance.

A moderate correlation existed in the current study between the FMS™ and CMJ height. However, it is possible that those recruited may have been able to compensate for

movement dysfunction in a CMJ test. For example, poor FMS™ deep squat scores may not have been reflected in CMJ performance as compensatory movement patterns could mask dysfunctional movement in an acute task. Since the FMS™ evaluates movement patterns for chronic injury risk, a stronger correlation may result from a more prolonged power task as movement compensation may affect performance over time (i.e., shuttle runs; sprints; cone drills). It is possible that a more precise power task may have correlated better to functional movement, similar to how the 100-point scale may correlate better to functional performance.

Scoring method. The method that was used to score the FMS™ may have limited the relationship between functional movement and functional performance. In the current study the FMS™ was used as a measure of an individual's functional movement and scored with a 21-point live, 21-point video and 100-point scale. Previous research had used the original 21-point live scale for functional movement assessment. The 100-point scale was used as a more precise scoring method of the FMS™ and may have improved the ability of the FMS™ total score to correlate to functional performance (i.e., CMJ).

The method of scoring used in Okada and colleagues (2011) may have limited the relationship between functional movement and performance. Okada et al. (2011) scored each of the bilateral FMS™ component tests separately by side. A significant relationship between the right side Hurdle Step and right side Rotary Stability was noted to performance (i.e., BOMB throw). However, the total score was not significantly correlated to BOMB throw performance. All FMS™ measurements were done with the 21-point live scale.

Parchmann and McBride (2011) also used the live 21-point scoring method to rate FMS™ performance. While all recruited participants were rated by the same administrator, the use of the 21-point live scale to correlate functional movement to performance may have been a limitation. Like Okada et al. (2011), FMS™ total score and CMJ height were not significantly correlated to one another. The method of scoring in both studies may limited the relationship between the FMS™ and CMJ height as 21-point live scale may lack the precision to inform regarding performance capacity. In addition to the 21-point live scale, the 21-point video and the 100-point scales were used in the current study to score the FMS™.

A moderately significant relationship was found in the current study between all scales of the FMS™ and CMJ height. The ability to pause, rewind and replay the component tests of the FMS™ may have improved the precision of the scoring in the 21-point video and 100-point scales. Opposed to live scoring, freezing a movement in time while viewing a video allows the rater to verify multiple limb locations at a given time to better score according to the standardized rubric.

FMS™ scoring relationship.

The secondary purpose of the current study was to perform an exploratory analysis examining the relationship of the 21-point live scoring method as well as a 21-point video scoring method of the FMS™. Previous literature has established a relationship between the 21-point live and 21-point video scales (Shultz, Anderson, Matheson, Marcello & Besier, 2013). However, the literature cannot support a relationship between either of the 21-point scales and the 100-point FMS™ scoring method.

The current study examined the relationship between the two 21-point scales of measurement for the FMS™ (i.e., live and post hoc video). Video was recorded during the live evaluation of the FMS™ movements from the anterior, lateral, and posterior sides. The current study demonstrated a strong correlation between the two 21-point scales ($r = 0.893$, $p < 0.001$). The findings of the present study add further support to the relationship between each method of scoring on a 21-point scale, allowing implications of the 21-point scale to be applicable regardless of the scoring method used.

The current study corroborates what has been evidenced in previous literature. The reliability between the two methods of measurement for the 21-point scale (i.e., live and video) was examined in the FMS™ literature (Shultz et al., 2013). Shultz et al. (2013) examined the consistency that both the live and video 21-point scales scored the FMS™. The findings from Shultz et al. (2013) demonstrated excellent reliability between the two testing methods (ICC = 0.92). Similar to Shultz et al. (2013), the current study demonstrated excellent reliability (ICC = 0.95) between the two methods of scoring on the 21-point scale.

The 100-point scale is a more precise method of scoring the FMS™; however, it has not been determined if a relationship exists between 100-point and 21-point scales. The 21-point scale is both a valid and reliable method of rating the quality of movement patterns. Despite the validity and reliability, the 21-point scale is limited in its ability to rate overall movement without identifying specific limiting components of a movement. Therefore, the 100-point scale was developed to address the need for a more precise method of rating movement patterns (Butler et al., 2012). Butler et al. (2012), found that

the 100-point scale had high reliability between raters for both the total score (ICC = 0.99) and the component scores of each test (ICC = 0.91-1.00) (Butler et al., 2012).

In the current study, a strong correlation was found between the 100-point scale and the live 21-point ($r = 0.714$, $p < 0.001$) and video 21-point ($r = 0.771$, $p < 0.001$) scales. The 100-point and 21-point scales have a strong relationship which demonstrates that a rater using either scale may be able to identify movement pattern limitations precisely regardless of the scale used. This study was the first to provide new significance to the current body of literature as this relationship between the 100-point and 21-point scales had not been previously established.

Conclusions

Performance on the FMS™ and CMJ height were significantly correlated to one another which supported the primary purpose of the current study. The implications that can be drawn from the primary purpose provide evidence that movement efficiency and greater amount of functional movement may not only be related to reduced injury risk, but also greater performance on a jump task. Overall, greater functional movement may lead to greater acute power production while reducing injury risk.

The scales of scoring the FMS™ were significantly correlated to one another supporting the secondary purpose of the current study. The strong relationship between the scales of the FMS™ signifies that each of the scales evaluate movement function similarly. Despite the significance that was established in this study, the current study was not without limitations.

Limitations

Like other research, the current study was not without its share of limitations. Given the small sample size (n = 36), the generalizability to active populations beyond the sample recruited is limited. Future research should continue to identify the relationship between functional movement and functional performance. This could be accomplished by examining this relationship within larger groups of recreationally active males using the parameters of the current study.

Another limitation to the current study was the inclusion of a male-only population. In the future, researchers should consider expanding to an active female population to determine if the relationship between functional movement and functional performance exists for females as well. The current study excluded both Division I athletes and those with a BMI of 30 or greater from participation. These exclusions resulted in a narrow population of interest. Researchers building upon the current study should investigate the relationship between functional performance of higher athletic populations and the FMS™. It may also be relevant to investigate athletic populations with a BMI greater than 30 to further investigate the influence that BMI has on FMS™ and athletic performance. This may aid in identifying how BMI is a confounding variable for the FMS™. For example, in order to identify the relationship between the FMS™ and BMI in a recreationally active population, a follow-up to the current study could be conducted with males with a BMI of 30 or greater.

The current study was also limited as functional performance was defined and measured with a single power task (i.e., CMJ height) as opposed to multiple expressions of power. Including additional power tasks (i.e., BOMB throw, standing long jump,

sprint speed, sport-specific power expression) may assist in gaining a greater understanding of the relationship between functional movement and functional performance. In particular, more specific power tasks could be used that better represent the recruited sample. For example, the use of a mannequin drag for firefighters or the power that a football player hits a sled would not only better inform researchers to the relationship between functional movement and functional performance, but also better assist the population achieve greater performance.

The FMS™ may also have been a limiting factor in the current study. While the student PI was the only administrator of the FMS™, the instructions prior to each of the FMS™ component tests were not completely standardized. Future research should standardize the instructions that are given to each subject and reduce the possible variability in the instructions. This could be accomplished by providing participants with either a written or video set of instructions for each component test. Similar means were reported for both of the 21-point scales. While each was significant to performance, the 21-video scale had a stronger relationship to CMJ height. Individual differences between aggregate score on the 21-point scales may have accounted for the similarities in the means but differences in significance. Researchers should pursue the validity of the two 21-point scales and identify if the component tests are scored differently on each scale. While it can be seen as a strength that the same student PI was the administrator of the FMS™ and rater for each subject and scale, future research should include multiple raters for each subject and each scale to strengthen the relationship between the FMS™ and a performance variable. The mean total FMS™ scores were lower for the 21-point scale than reported means from other research (Gribble et al., 2013; Schneiders et al., 2011;

Smith et al., 2013). The student PI for this study may have been more critical of

movement patterns than previous researchers. In order to remedy this, future research

should delve in a consistent method of training raters. For example, utilizing both the

live and video scales to evaluate and improve the test-retest reliability for identical

movements. This could create a potential acceptable *cut-off* of test-retest reliability score

for researchers ensuring the strength of future findings.

Significance

  Scientific significance. The current study provides practical significance to the

body of literature by identifying a strong correlation between the scales of the FMS™

(i.e., live 21-point, video 21-point, 100-point). However, only scoring methods rated

using video analysis were significantly correlated to functional performance. From an

injury risk perspective, the current study supports the use of any scoring method of the

FMS™ for injury identification. This indicates that regardless of the methods that

researchers have at their disposal to assess movement patterns, when administered

correctly, the FMS™ is reliable across all scales. Despite the significant relationship, the

nature of the relationship between functional movement and functional performance is

still unknown.

  Practical significance. The current study also has practical significance that can

be gleaned. First of all, a new potential influencing factor to functional performance was

identified, functional movement. Unlike findings from previous research, a significant

relationship was found between functional movement and functional performance for

recreationally active males in the current study. Therefore, strength coaches and

clinicians should take particular note in not only a clients' performance, but also the

functional baseline of movement that their clients have. The FMS™ is a well-established tool for injury risk identification (Chorba et al., 2010; Kiesel et al., 2007; Kiesel et al., 2011; O'Connor et al., 2011). As identified by the current study, there is a significant, albeit moderate, relationship between functional movement and performance. It is encouraged that the FMS™ be used in scouting and combine-style testing as a time efficient and portable screen that provides insight on both injury risk as well as functional performance.

REFERENCES

Aargón-Vargas, L. (2000). Evaluation of four vertical jump tests: Methodology, reliability, validity, and accuracy. *Measurement in Physical Education and Exercise Science*, *4*(4), 215-228.

Alegre, L., Lara, A., Elvira, J., & Aguado, X. (2009). Muscle morphology and jump performance: gender and intermuscular variability. *Journal of Sports Medicine and Physical Fitness*, *49*(3), 320-326.

Asmussen, E., & Bonde-Petersen, F. (1974). Storage of elatic energy in skeletal muscles in man. *Acta Physiologica Scandinavica*, *91*(3), 385-392.

Bobbert, M. (2001). Dependence of human squat jump performance on the series elastic compliance of the triceps surae: a simulation study. *The Journal of Experimental Biology*, *204*, 533-542.

Bosco, C., & Komi, P. (1980). Influence of aging on mechanical behavior of leg extensor muscles. *European Journal of Applied Physiology*, *45*(2-3), 209-219.

Bosco, C., Viitasalo, T., Komi, P., & Luhtanen, P. (1982). Combined effect of elasticenergy and myoelectrical potentiation during stretch-shortening cycle exercise. *Acta Physiologica Scandinavica*, *114*, 557-565.

Bubanj, S., Stanković, R., Bubnaj, R., Bojić, I., Dindić, B., & Dimić, A. (2010). Reliability of myotest tested by a countermovement jump. *Acta Kinesiologica*, *4*(2), 46-48.

Butler, R., Plisky, P., & Kiesel, K. (2012). Interrater reliability of videotaped performance on the functional movement screen using the 100-point scoring scale. *Athletic Training & Sports Health Care*, *4*(3), 2012.

Cardinale, M., & Stone, M. (2006). Is testosterone influencing explosive performance?. *Journal of Strength and Conditioning Research*, *20*(1), 103-107.

Casartelli, N., Müeller, R., & Maffiuletti, N. (2010). Validity and reliability of the Myotest accelerometric system for the assessment of vertical jump height. *Journal of Strength and Conditioning Research*, *24*(11), 3186-3193.

Cavagna, G., & Citterio, G. (1974). Effects of stretching on the elastic characteristics and the contractile component of frog striated muscle. *Journal of Physiology*, *239*, 1-14.

Chorba, R., Chorba, D., Bouillon, L., Overmyer, C., & Landis, J. (2010). Use of a functional movement screening tool to determine injury risk in female collegiate athletes. *North American Journal of Sports Physical Therapy*, *5*(2), 2010.

Cook, G. (2010). *Movement: Functional movement systems*. (pp. 220-225).

Cook, G., Burton, L., & Hoogenboom, B. (2006). Pre-participation screening: the use of fundamental movements as an assessment of function - part 1. *North America Journal of Sports Physical Therapy*, *1*(2), 62-72.

Cook, G., Burton, L., & Hoogenboom, B. (2006). Pre-participation screening: the use of fundamental movements as an assessment of function - part 2. *North American Journal of Sports Physical Therapy*, *1*(3), 132-139.

Cronin, J., & Hansen, K. (2005). Strength and power predictors of sports speed. *Journal of Strength and Conditioning Research*, *19*(2), 349-357.

Domire, Z., & Challis, J. (2007). The influence of squat depth on maximal vertical jump performance. *Journal of Sports Sciences*, *25*(2), 193-200.

Duncan, M., & Stanley, M. (2012). Functional movement is negatively associated with weight status and positively associated with physical activity in British primary school children. *Journal of Obesity*, *2012*.

Duncan, M., Stanley, M., & Wright, S. (2013). The association between functional movement and overweight and obesity in British primary school children. *BMC Sports Science, Medicine, and Rehabilitation*, *5*(11).

Faul, F., Erdfelder, E., Lang, A., & Buchner, A. (2007). G*power 3: a flexible statistical power analysis program for the social, behavioral, and biomedical sciences. *Behavior Research Methods*, *39*(2), 175-191.

Frost, D., Beach, T., Callaghan, J., & McGill, S. (2012). Using the Functional Movement Screen™ to evaluate the effectiveness of training. *Journal of Strength and Conditioning Research*, *26*(6), 1620-1630.

Fukashiro, S., Hay, D., & Nagano, A. (2006). Biomechanical behavior of muscle-tendon complex during dynamic human movements. *Journal of Applied Biomechanics*, *22*, 131-147.

Garber, C., Blissmer, B., Deschenes, M., Franklin, B., Lamonte, M., Lee, I., Nieman, D., & Swain, D. (2011). Quantity and quality of exercise for developing and maintaining cardiorespiratory, musculoskeletal, and neuromotor fitness in apparently healthy adults: Guidance for prescribing exercise. *Medicine & Science in Sports & Exercise*, 1334-1359.

Gerodimos, V., Zafeiridis, A., Perkos, S., Dipla, K., Manou, V., & Kellis, S. (2008). The contribution of stretch-shortening cycle and arm-swing to vertical jumping performance in children, adolescents, and adult basketball players. *Pediatric Exercise Science*, *20*, 379-389.

Goss, D., Christopher, G., Faulk, R., & Moore, J. (2009). Functional training program bridges rehabilitation and return to duty. *Journal of Special Operations Medicine*, *9*(2), 29-48.

Gribble, P., Brigle, J., Pietrosimone, B., Pfile, K., & Webster, K. (2013). Intrarater reliability of the Functional Movement Screen. *Journal of Strength and Conditioning Research*, *27*(4), 978-981.

Harman, E., Rosenstein, M., Frykman, P., & Rosenstein, R. (1990). The effects of arms and countermovement on vertical jumping. *Medicine and Science in Sports and Exercise*, *22*(6), 825-833.

Hartmann, H., Wirth, K., Klusemann, M., Dalic, J., Matuschek, C., & Schmidtbleicher, D. (2012). Influence of squatting depth on jumping performance. *Journal of Strength and Conditioning Research*, *26*(12), 3243-3261.

Hoffman, J., Tenenbaum, G., Maresh, C., & Kraemer, W. (1996). Relationship between athletic performance tests and playing time in elite college basketball players. *Journal of Strength and Conditioning Research*, *10*(2), 67-71.

Kibler, W., Chandler, T., Uhl, T., & Maddux, R. (1989). The musculoskeletal approach to the preparticipation physical examination. *The American Journal of Sports Medicine*, *17*(4), 525-531.

Kiesel, K., Plisky, P., & Voight, M. (2007). Can serious injury in professional football be predicted by a preseason functional movement screen? *North America Journal of Sports Physical Therapy*, *2*(3), 147-158.

Kiesel, K., Plisky, P., & Butler, R. (2011). Functional movement test scores improve following a standardized off-season intervention program in professional football players. *Scandinavian Journal of Medicine & Science in Sports*, *21*, 287-292.

Kritz, M., Cronin, J., & Hume, P. (2009). The bodyweight squat: a movement screen for the squat pattern. *National Strength and Conditioning Association*, *31*(1), 76-85.

Kubo, K., Kawakami, Y., & Fukunaga, T. (1999). Influence of elastic properties of tendon structures of jump performance in humans. *The American Physiology Society*, 2090-2096.

Kurokawa, S., Fukunaga, T., & Fukashiro, S. (2001). Behavior of fascicles and tendinous structure of human gastrocnemius during vertical jumping. *The Jouranal of Applied Physiology*, *90*, 1349-1358.

Leard, J., Cirillo, M., Katsnelson, E., Kimiatek, D., Miller, T., Trebincevic, K., & Garbalosa, J. (2007). Validity of two alternative systems for measuring vertical jump height. *Journal of Strength and Conditioning Research*, *21*(4), 1296-1299.

Lees, A., Jos, V., & De Clercq, D. (2004). The maximal and submaximal vertical jump: implications for strength and conditioning. *Journal of Strength and Conditioning Research*, *18*(4), 787-791.

Lichtwark, G., & Wilson, A. (2005). Effects of series elasticity and activation conditions on muscle power output and efficiency. *The Journal of Experimental Biology*, *208*, 2845-2853.

Luebbers, P., Potteiger, J., Hulver, M., Thyfault, J., Carper, M., & Lockwood, R. (2003). Effects of plyometric training and recovery on vertical jump performance and anaerobic power. *Journal of Strength and Conditioning Research*, *17*(4), 704-709.

Luhtanen, P., & Komi, P. (1980). Force-, power-, and elasticity-velocity relationships in walking, running, and jumping. *European Journal of Applied Physiology*, *44*, 279-289.

MacIntosh, B., & MacNaughton, M. (2005). The length dependence of muscle active force: considerations for parallel elastic properties. *Journal of Applied Physiology*, 1666-1673.

Markovic, G., Dizdar, D., Jukic, I., & Cardinale, M. (2004). Reliability and factorial validity of squat and countermovement jump tests. *Journal of Strength and Conditioning Research*, *18*(3), 551-555.

Minick, K., Kiesel, K., Burton, L., Taylor, A., Plisky, P., & Butler, R. (2010). Interrater reliability of the Functional Movement Screen. *Journal of Strength and Conditioning Research*, *24*(2), 479-486.

Moran, K., & Wallace, E. (2007). Eccentric loading and range of knee joint motion effects on performance enhancement in vertical jumping. *Human Movement Science*, *26*, 824-840.

Nagano, A., Komura, T., & Fukashiro, S. (2004a). Effects of series elasticity of the muscle tendon complex on an explosive activity performance with a counter movement. *Journal of Applied Biomechanics*, *20*, 85-94.

Nagano, A., Komura, T., & Fukashiro, S. (2004b). Effects of the length ratio between the contractile element and the series elastic element on an explosive muscular performance. *Journal of Electromyography and Kinesiology*, *14*, 197-203.

Nuñez, V., Da Silva-Grigoletto, M., Castillo, E., Poblador, M., & Lancho, J. (2008). Effects of training exercises for the development of strength and endurance in soccer. *Journal of Strength and Conditioning Research*, *22*(2), 518-523.

O'Connor, F., Deuster, P., Davis, J., Pappas, C., & Knapik, J. (2011). Functional movement screening: predicting injuries in officer candidates. *Medicine & Science in Sports & Exercise*, 2224-2230.

Okada, T., Huxel, K., & Nesser, T. (2011). Relationship between core stability, functional movement, and performance. *Journal of Strength and Conditioning Research*, *25*(1), 252-261.

Onate, J., Dewey, T., Kollock, R., Thomas, K., Van Lunen, B., DeMaio, M., & Ringleb, S. (2012). Real-time intersession and interrater reliability of the functional movement screen. *Journal of Strength and Conditioning Research*, *26*(2), 408-415.

Parchmann, C., & McBride, J. (2011). Relationship between functional movement screen and athletic performance. *Journal of Strength and Conditioning Research*, *25*(12), 3378-3384.

Peate, W., Bates, G., Lunda, K., Francis, S., & Bellamy, K. (2007). Core strength: a new model for injury prediction and prevention. *Journal of Occupational Medicine and Toxicology*, *2*(3)

Perry, F., & Koehle, M. (2013). Normative data for the Functional Movement Screen in middle-aged adults. *Journal of Strength and Conditioning Research*, *27*(2), 458-462.

Salles, A., Baltzopoulos, V., & Rittweger, J. (2011). Differential effects of countermovement magnitude and volitional effort on vertical jumping. *European Journal of Applied Physiology*, *111*, 441-448.

Schneiders, A., Davidsson, Å., Hörman, E., & Sullivan, S. (2011). Functional Movement Screen™ normative values in a young, active population. *The International Journal of Sports Physical Therapy*, *6*(2), 75-82.

Shultz, R., Anderson, S., Matheson, G., Marcello, B., & Besier, T. (2013). Test-retest and interrater reliability of the functional movement screen. *Journal of Athletic Training*, *48*(3), 331-336.

Smith, C., Chimera, N., Wright, N., & Warren, M. (2013). Interrater and intrarater reliability of the Functional Movement Screen. *Journal of Strength and Conditioning Research*, *27*(4), 982-987.

Teyhen, D., Shaffer, S., Lorenson, C., Halfpap, J., Donofry, D., Walker, M., Dugan, J., & Childs, J. (2012). The Functional Movement Screen: A reliability study. *Journal of Orthopaedic & Sports Physical Therapy*, *42*(6), 530-537.

Trimble, M., & Harp, S. (1998). Postexercise potentiation of the h-reflex in humans. *Medicine & Science in Sports & Exercise*, *30*(6), 933-941.

Tuite, D., Renström, P., & O'Brien, M. (1997). The aging tendon. *Scandinavian Journal of Medicine & Science in Sports*, *7*, 72-77.

Vanezis, A., & Lees, A. (2005). A biomechanical analysis of good and poor performers on the vertical jump. *Ergonomics*, *48*(11), 1594-1603.

Vanrenterghem, J., Lees, A., & De Clercq, D. (2008). Effect of forward trunk inclination on joint power output in vertical jumping. *Journal of Strength and Conditioning Research*, *22*(3), 708-714.

Yamauchi, J., & Ishi, N. (2007). Relations between force-velocity characteristics of the knee-hip extension movement and vertical jump performance. *Journal of Strength and Conditioning Research*, *21*(3), 703-709.

Young, W., & Behm, D. (2003). Effects of running, static stretching and practice jumps on explosive force production and jumping performance. *Journal of Sports Medicine and Physical Fitness*, *43*(1), 21-27.

APPENDICES

APPENDIX A

Recruitment Flyer

PARTICIPANTS NEEDED!

A study investigating the relationship between the Functional Movement Screen™ (FMS™) and peak counter movement jump height is being conducted by researchers in the Human Performance & Sport Physiology Lab PAV 365

- **Eligible Participants Include:**
  - MALES between 18-30 years of age.
  - Individuals who:
    - Engage in regular exercise (e.g., 150 minutes/ week of moderate or 75 minutes/ week of vigorous exercise).
    - Are not a member of a competitive, elite level sports team (e.g., UWM athletics team).
    - Are not taking prescribed medication for a symptomatic illness, have not had an injury, surgery, or bone abnormalities on their knees, hips, or ankles, have not had recent (one year) physical rehabilitation, do not have a heart condition or any chest pain, do not suffer from dizziness, do not have prior experience with the Functional Movement Screen™ (FMS™) and/or do not have hearing impairments.
    - Must have a BMI less than 30
- This study will take place over two total testing sessions. Estimated total commitment time is 1.5 – 2 hours. Approximately 45 minutes per day.
- Participants will perform a series of 7 movement screen tests including a Deep Squat, Hurdle Step, In-line Lunge, Shoulder Mobility, Active Straight Leg Raise, Trunk Stability Push Up, and a Rotary Stability test.
- Participants will perform a counter movement jump (vertical jump) and researchers will measure various performance variables.
- This study is completely non-invasive & no side effects/injuries are expected.

Please contact Josh Conlon (jkconlon@uwm.edu) if you are interested in participating. All testing sessions will be held in the Human Performance & Sport Physiology Lab in Room 365 of the Pavilion.

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APPENDIX B

Description of Testing Protocol

Testing Protocol

Before the participant can advance to Phase 1, the participant must pass the Criteria for Inclusion Questionnaire (see Appendix C).

Phase I Protocol:
- The participant will read and sign the Informed Consent paperwork, agreeing to the study's protocol (see Appendix D).
- The participant will complete the Exercise History Questionnaire (Appendix E)
- The researchers will explain the testing protocol to the participant and answer any questions.
- The participant will have both their height and their weight measured. Their BMI will be calculated from these measurements.
- If the participant gives Informed Consent and meets the physical activity and criteria for exclusion requirements, the participant will move to the FMS™ tests. If the participant does not, their participation in the study is over.
- The participant will perform each of the seven component tests of the FMS™. Each test will be scored on a 21-point live scale. Each test will also be simultaneously video recorded.
- Upon completion of the FMS™, the participant will be allowed to practice the counter movement jump to become familiarized with the movement. The participant will then be fitted with the Myotest unit and belt.
- Five practice jumps will be provided. Countermovement jump instructions will be given.
- After completion of the five practice jumps, Phase I will be completed. Participants will return within 24-48 hours to complete Phase II.

Phase II Protocol:
- The participant will first perform a brief, five minute warm-up on the bicycle ergometer with a light, self-chosen, resistance level.
- The participant will then be fitted with the Myotest unit and belt.
- Five practice jumps will be provided. Countermovement jump instructions will be given.
- After the five practice jumps, the participant will be given 1-3 minutes of rest.
- The participants will perform this vertical jump three successful times and will be given as many attempts as needed to do so. 1-3 minutes of rest will be provided between each trial.
- After three successful jump trials are completed, the Myotest will be removed and the participant's investment to the study will be over.

Counter Movement Jump Instructions
- The participant will begin each jump (trial) with their arms by their sides.
- The participant will be instructed to listen for the sound of the second beep (stimulus) from the Myotest. The participant will squat in a downward motion

and propel themselves upward, and jump off the ground as high and as fast as they can, with their hands remaining on their hips.

- A trial will be considered unsuccessful and will be subsequently discarded if:
    - The participant starts their movement before the proper stimulus (false start)
    - The participant initial movement of their arms is forward.
    - The Myotest unit cannot properly assess the trial

APPENDIX C

Criteria for Exclusion

Human Performance & Sport Physiology Lab
Department of Kinesiology
University of Wisconsin-Milwaukee
3409 N. Downer Ave
Pavilion – Physical Therapy, Room 365
Milwaukee, WI 53211
Criteria for Inclusion Questionnaire

Eligible to Participate: YES   NO

ID#:____ _____

Date:_____

The Relationship between the Functional Movement Screen^{TM} and Countermovement jump height –
Joshua K. Conlon Thesis

The following questions will help determine if you meet the criteria for inclusion into the study. It is important that you accurately answer each question.

Please answer the following questions with a yes or no response.	YES	NO
1. Are you currently between the ages of 18 and 30 years old?		
2. Do you consider yourself a physically active individual?		
3. Have you engaged in at least 150 minutes of moderate intensity physical activity or at least 75 minutes of vigorous intensity physical activity per week, for the last 6 months?		
4. In the last year (including now), have you trained for or competed in a competitive sport or another competitive physical activity (e.g., a marathon, collegiate athletic team)?		
5. Is your estimated BMI greater than 30? BMI is calculated by taking height in cm and dividing by weight in kg squared.		
6. Do you currently take any prescribed medications for treatment of a symptomatic illness or condition?		
7. Have you received rehabilitation services for an injury within the last year (i.e., of the shoulder, hip, knee, and/ or ankle)		
8. Have you had any surgery on your shoulder, hip, knee, and/or ankle within the last year?		
9. Do you have any bone, joint, or muscle abnormalities (i.e. arthritis, muscle pain)?		
10. Has your doctor ever said that you have a heart condition and that you should only do physical activity recommended by a doctor?		
11. Has a medical professional every told you that you should avoid jumping, landing, and/ or running exercise?		
12. Do you feel pain in your chest when you do physical activity?		
13. In the past year, have you had chest pain when you are <u>not</u> doing physical activity?		
14. Do you often feel faint or have severe spells of dizziness?		
15. Do you feel any pain in your joints and/or limbs when jumping or stretching?		
16. Do you have previous experience participating in the use of the Functional Movement Screen™ (FMS™)?		
17. Are you participating in an organized exercise program to actively improve your vertical jump height?		
18. Do you have any hearing impairments or difficulty hearing certain auditory tones?		

APPENDIX D

Informed Consent Document

UNIVERSITY OF WISCONSIN – MILWAUKEE
CONSENT TO PARTICIPATE IN RESEARCH

1. General Information

Study title:
The Relationship between the Functional Movement Screen™ and Countermovement jump height

Person in Charge of Study (Principal Investigator):
Kyle T. Ebersole, Ph.D., LAT (PI/Adviser)
Associate Professor, Department of Kinesiology
College of Health Sciences

Joshua K. Conlon, B.S., CSCS (Thesis)
Masters of Kinesiology Graduate Student, Department of Kinesiology
College of Health Sciences

2. Study Description

You are being asked to participate in a research study. Your participation is completely voluntary. You do not have to participate if you do not want to.

Study description:
The primary purpose of the proposed study is to determine the relationship between a Functional Movement Screen™ (FMS™) total score, scored on a 100-point and 21-point scale, and peak countermovement jump (CMJ, which is like a vertical jump) height. The secondary purpose of this proposed study is to perform an exploratory analysis examining the validity of the 21-point live scoring method as well as a 21-point video scoring method of the FMS™. This will be accomplished by examining the differences in various physiological measurements (i.e., height and weight) and FMS™ scores. It is possible that how well someone can move may be related to how well they can perform the jump task. The goal of this study is to examine the possible relationship between the FMS™ (a test of how well someone can move) and CMJ peak height by using a more detailed scale of measurement when scoring the FMS™.

All activities in this study will take place in the Human Performance & Sport Physiology Laboratory (HPSPL) located in Room 365 of the Pavilion. This study will take place over the course of two days. Participants will be recruited until a total of 60 have completed all tests through the two days. The 60 participants will all be males between the ages of 18 to 30 and have a BMI (body mass index) of less than 30. Participants will be recreationally active, but not currently training for or competing in a competitive sport (e.g., a NCAA Division I sport) or activity (e.g., a marathon). The time commitment for participants will depend on how far they advance through the study's phases. On Day 1 the participants will complete all required paperwork such as the Consent Form and the Exercise History Questionnaire. This is expected to last 10-15 minutes. Day 1 will then include height and weight measurements. Body mass index (BMI) will be calculated from this data. Participants will then be introduced to the FMS™ and

perform each of the 7 FMS™ tests according to the researcher's instructions. Day 1 will conclude with CMJ instruction and practice jumps. The participants will become familiar with the CMJ task and the researchers will answer any questions the participants may have. The FMS™ tests and CMJ practice is expected to last 30-40 minutes. On Day 2 researchers will conduct the CMJ testing. Day 2 is expected to last 45 minutes.

3. Study Procedures

What will I be asked to do if I participate in the study?
If you fulfill the criteria for inclusion requirements and agree to participate, you will be asked to come to Human Performance & Sport Physiology Laboratory located in Room 365 of the Pavilion for all testing phases. This study will be divided into three phases. The phases are described in detail below and will be completed in the order listed.

Day 1:
- During Day 1, you will read and give informed consent to the study protocol. You will be allowed to ask questions prior to signing the informed consent document.
- Once you have signed the informed consent, and been included in to the study, you will be given a study ID (e.g., EXS1) that will be used to code all of your data collected during the study.
- You will also complete an exercise history questionnaire. This questionnaire will be used to see both the amount and what kinds of exercise and physical activity you have and are currently partaking in.
- Your height, body weight, age, and birthdate will be measured and recorded and your body mass index (BMI) will be calculated and recorded. If your BMI is >30, you will not be included in this study and any data collected up to this point will be destroyed.
- You will perform the seven Functional Movement Screen™ (FMS™) tests. The seven tests include: Deep Squat, Hurdle Step, In-line Lunge, Shoulder Mobility, Active Straight-Leg Raise, Trunk Stability Push-Up and Rotary Stability.
    - o Deep Squat: You will hold a lightweight plastic dowel rod over the head with your arms extended and squat as far down as you can. This task will be repeated up to five times.
    - o Hurdle Step: You will hold the dowel rod across your shoulders and step, one leg at a time, over a rubber tube that is attached to two stationary poles. This task will be repeated up to five times on each side.
    - o In-line Lunge: You will lunge forward and try to touch your back knee to the heel of the front foot. This test will be repeated up to five times on each side.
    - o Shoulder Mobility: You will bring both hands behind your back. One hand will come from the head down the spine and the other hand coming from the waist up the spine. The distance separating the two hands will be measured. Both shoulders will be measured. This test will be repeated up to five times.
    - o Active Straight-Leg Raise: You will lie on your back and raise one leg up from the ground while keeping the other leg straight. Both legs will be measured. This test will be repeated up to five times.
    - o Trunk Stability Push Up: You will perform a push-up with your hands placed at the level of the chin or clavicle. This task will be repeated up to five times.
    - o Rotary Stability: You will start in a 4-point stance (on your hands and knees) and try to bring your right elbow to your right knee. This is then repeated with the left elbow coming to the left knee. This test will be repeated up to five times.

- The researchers will then verbally explain the directions of the counter movement jump (CMJ) task that will be used during Day 2 of this study (see below). You will be given an opportunity to practice the CMJ five times while wearing the belt.
- For these practice trials, you will be fitted with the MyoTest SPORT unit and belt. The MyoTest SPORT unit is a small device that will measure the height, jump force, work output, and velocity of each of your CMJ trials. This device is attached to a belt that you will have around your waist.
- The researchers ask that you refrain from smoking (or any other tobacco product) and caffeine intake the four hours preceding Day 2, as well as any heavy resistance training the 48 hours preceding Day 2.
- The total time to complete the activities for Day 1 will be approximately 45 minutes.

Day 2:
- During Day 2, you will first perform a brief, five minute warm-up on a stationary exercise bicycle with a light, self-selected, resistance level.
- You will put on the MyoTest belt and accelerometer and perform five practice jumps abiding by the CMJ instructions from Day 1.
    - o CMJ Instructions:
        - ▪ You will begin each jump (trial) with your arms resting at your sides. Your feet will be shoulder width apart.
        - ▪ You will listen for the sound of the beep (stimulus) from the MyoTest SPORT unit.
        - ▪ You will squat in a downward motion while swinging your arms backward. Once at the bottom of your squat, you will then immediately jump up as fast as you can, swinging your arms upward.
        - ▪ You are encouraged to land each jump trial with bent knees.
- The MyoTest SPORT unit will be active during the practice trials to make sure that it is recording properly. The researchers will also confirm that you are using correct form during the CMJ.
- You will then be given 1-3 minutes of rest before the data collection trials.
- You will perform CMJ trials until three successful CMJ trials are recorded. The researchers will record information from the MyoTest between each successful trial. A trial will be considered unsuccessful if: you start your movement before the MyoTest signals for you to start (false start), the MyoTest SPORT unit cannot properly measure the trial, or if the MyoTest SPORT unit is bumped or knocked off during the trial.
- After three successful trials are recorded, the MyoTest SPORT unit will be removed and your commitment to this study will be over.
- The total time to complete the activities for Day 1 will be approximately 45 minutes.

Video Recording
Your FMS^{TM} testing will be video recorded on an iPad. The video files will be scored at a later point to create the 100-point score as well as to re-score the test on a 21-point scale. This will allow for comparisons between the two different scale types for the FMS^{TM}. All video files will be removed from the iPad device and stored according to your initials on a protected laptop to prevent a linking of this identifiable information to all other data that will be stored according to your study ID code. The video files will be used by the researchers only to link score the FMS test.

4. Risks and Minimizing Risks

What risks will I face by participating in this study?
There are no expected risks for participating in this research study. It is possible, although very unlikely, that you may experience minor musculoskeletal injuries such as muscle strain, muscle soreness, and/or tightness associated with the FMS™ tests and CMJ trials. Since part of the inclusion criteria for this study was participation in regular exercise, it is expected that the risks associated with these tasks are unlikely, and that this risk is no different than any other form of physical activity. The researchers will attempt to avoid possible musculoskeletal injuries by having you properly warm-up before starting data collection.

Although an injury due to participation in this study is unlikely, participants suffering an injury will be directed to Norris Health Center (UWM students only) or to a personal physician. Any injury requiring emergency medical care will be managed by activating the emergency response system (i.e., dialing 9-911 on campus phone).   You will be responsible for any medical cost associated with any injury occurring as a result of participation in this study.

5. Benefits

Will I receive any benefit from my participation in this study?
Each participant will receive a free FMS™ test along with recommendations for exercises to improve their movement ability.

6. Study Costs and Compensation

Will I be charged anything for participating in this study?
You will not be responsible for any of the costs from taking part in this research study.

Are subjects paid or given anything for being in the study?
Each participant will receive exercise recommendations to improve their movement ability based on their FMS™ scores.

No monetary compensation of any kind will be awarded.

7. Confidentiality

What happens to the information collected?
All information collected about you during the course of this study will be kept confidential to the extent permitted by law. We may decide to present what we find to others, or publish our results in scientific journals or at scientific conferences. Only the PI (Ebersole), student PI (Conlon), or approved graduate students assisting with the study will have access to the information.

However, the Institutional Review Board at UW-Milwaukee or appropriate federal agencies like the Office for Human Research Protections may review this study's records.

Information used to personally identify you will be collected (name and contact info) for this project and will only be used to contact you during this study. This information will not be used in the data analysis, nor will it be released to others. Your identity will be kept confidential, except as might be required by law. You will be given a study ID code (i.e., EXS1) that will be used to code all of your data collected during the study. An identity key file containing your name, study ID code, and contact information will be stored (in a locked file in the Human Performance & Sport Physiology Laboratory in PAV 365) separate from all collected data for the purpose of contacting you during the study. All experimental data and associated questionnaires will be stored in a file based on your unique study ID code (i.e., EXS1) and separate from any personally identifying contact information. At no time will the coded data files include names or contact information. The video files will only be stored on an encrypted laptop according to your initials as a way to prevent someone not associated with this study from linking this identifiable information to all other data that will be stored according to your study ID code. Upon conclusion of the study, the video files will be destroyed. It is possible that a portion of your FMS video will be retained by the researchers as an exemplar to demonstrate how movement was related to jumping performance. In this case, if your video is used as an exemplar, all identifying information (i.e., face) will be removed before it is shared.

Results obtained from this research study will be disseminated in journal articles and scientific meetings. The data will be stored in a locked file cabinet in PAV 365 for 10 years for future use.

8. Alternatives

Are there alternatives to participating in the study?
There are no known alternatives available to you other than not taking part in this study

9. Voluntary Participation and Withdrawal

What happens if I decide not to be in this study?
Your participation in this study is entirely voluntary. You may choose not to take part in this study. If you decide to take part, you can change your mind later and withdraw from the study. You are free to not answer any questions or withdraw at any time. Your decision will not change any present or future relationships with the University of Wisconsin Milwaukee.

If you voluntarily withdraw or are withdrawn from the study prior to its completion, we will use the information collected to that point. Withdrawal from the study prior to your commitment

being completed will result in no extra credit awarded. Withdrawal from the study will in no way affect your class standing as a student at UW-Milwaukee.

10. Questions

Who do I contact for questions about this study?
For more information about the study or the study procedures or treatments, or to withdraw from the study, contact:

Joshua K. Conlon
Masters of Kinesiology Graduate Student
College of Health Sciences
Dept. of Kinesiology
PAV – PT, Room 375
jkconlon@uwm.edu

or

Kyle T. Ebersole, Ph.D.
College of Health Sciences
Dept. of Kinesiology
PAV – PT, Room 356
(414) 229-6717
ebersole@uwm.edu

Who do I contact for questions about my rights or complaints towards my treatment as a research subject?
The Institutional Review Board may ask your name, but all complaints are kept in confidence.

Institutional Review Board
Human Research Protection Program
Department of University Safety and Assurances
University of Wisconsin – Milwaukee
P.O. Box 413
Milwaukee, WI 53201
(414) 229-3173

11. Signatures

Research Subject's Consent to Participate in Research:
To voluntarily agree to take part in this study, you must sign on the line below. If you choose to take part in this study, you may withdraw at any time. You are not giving up any of your legal rights by signing this form. Your signature below indicates that you have read or had read to you this entire consent form, including the risks and benefits, and have had all of your questions answered, and that you are 18 years of age or older.

_____

Printed Name of Subject/ Legally Authorized Representative

_____   _____
Signature of Subject/Legally Authorized Representative   Date

Principal Investigator (or Designee)
I have given this research subject information on the study that is accurate and sufficient for the subject to fully understand the nature, risks and benefits of the study.

_____   _____
Printed Name of Person Obtaining Consent   Study Role

_____   _____
Signature of Person Obtaining Consent   Date

APPENDIX E

Exercise History Questionnaire

Human Performance & Sport Physiology Laboratory
University of Wisconsin-Milwaukee

Exercise History Questionnaire

Participant ID Code: _____   Date: _____

1. In the last 6 months, how many days a week have you spent 30 minutes or more in moderate to strenuous exercise?

   0   1   2   3   4   5   6   7

2. If you have been exercising, what activity have you done most often?

   Walk   Swim   Dance   Bike   Run   Other

3. If you answered **Other** for question 2, what is the primary other activity that you have done?

4. If you have been exercising, how long (minutes) has each exercise session been?

   Less than 5   5-19   20-30   More than 30

5. If you have been exercising, would you say the intensity has been:

   Easy   Moderate   Somewhat Hard   Hard

6. If you have never exercised or are no longer exercising, what is your main reason?

7. Have you (or are you currently) trained/competed for a sport or other competitive physical activity (e.g., a marathon) in the last year?

   Yes   No

8. Did you compete in an organized, competitive sport at one point of your life?

   Yes   No

9. If yes for Question 8, what type of sport and what position (or event) did you play (if applicable)?

Sport: _____

Position: _____

10. Do you frequently lift moderately heavy objects as part of your daily activities?

$\qquad$ Yes $\qquad$ No

11. Do you frequently climb stairs as part of your daily activities?

$\qquad$ Yes $\qquad$ No

12. Do you regularly engage in informal physical activities?

$\qquad$ Yes $\qquad$ No

    a. If you circled **Yes** for question 12, please specify:

APPENDIX F

Institutional Review Board Protocol Summary

IRBManager Protocol Form

Instructions: Each Section must be completed unless directed otherwise. Incomplete forms will delay the IRB review process and may be returned to you. Enter your information in the **colored boxes** or place an **"X"** in front of the appropriate response(s). If the question does not apply, write **"N/A."**

SECTION A: Title

A1. Full Study Title:

The Relationship between the Functional Movement Screen™ and Countermovement jump height.

SECTION B: Study Duration

B1. What is the expected start date? *Data collection, screening, recruitment, enrollment, or consenting activities may not begin until IRB approval has been granted. Format: 07/05/2011*

Upon IRB approval

B2. What is the expected end date? *Expected end date should take into account data analysis, queries, and paper write-up. Format: 07/05/2014*

8/20/2014

SECTION C: Summary

C1. Write a brief descriptive summary of this study in Layman Terms (non-technical language):

Pre-participation screening has become a staple in the evaluation of athletes and exercises. One reliable pre-participation screening tool (Minick et al., 2010; Onate et al., 2012; Teyhen et al., 2012) that has been used to identify injury risk on a number of athletic populations (Chorba et al, 2010; Goss et al, 2009; Kiesel et al, 2007; Kiesel et al, 2009; O'Connor et al, 2011; Peate et al, 2007) is the Functional Movement Screen™ (FMS™). The FMS™ is a series of seven movement tests that are designed to measure the balance between mobility and stability by putting participants in positions representing fundamental movement patterns (Cook et al., 2006a; Cook et al., 2006b). The literature has shown a relationship between total FMS™ score and injury risk through an established "cut-off" score of ≤14 (Kiesel et al., 2007). The "cut-off" score has been used in pre-participation screening to clear an athlete for sport-participation.

In the performance literature, there are a variety of athletic tests that can indicate task-specific performance. Vertical jump performance tests are commonly used as athletic performance markers in athletic populations as a method of measuring power, strength, and speed (Aragon-Vargas, 2000; Luebbers et al., 2003). Specifically, one method of vertical jumping reflects sport-specific power, strength and speed is the countermovement jump (CMJ) (Cronin & Hansen, 2005; Hori et al., 2008; Vanezis & Lees, 2005). CMJ has been shown to relate to 1RM (repetition max) hang clean (Hori et al., 2008) indicating that CMJ performance may indicate performance in a sport that requires power and/ or strength. CMJ has also been shown to be an indicator of speed performance. In a study that compared a variety of power tasks, CMJ was shown to have the highest correlation to a 40-yard dash time (Cronin & Hansen, 2005).

The evaluation methods of interest in this study are the FMS™ and countermovement jump (CMJ) testing for injury risk assessment and athletic performance, respectively.

Previous literature has studied that relationship between the FMS™ and athletic performance without success (Okada et al., 2011; Parchmann & McBride, 2011). This literature has used the traditional 21-point FMS™ scoring method when studying the relationship between functional movement and jump height. In this proposed study, a 100-point scoring method (Butler et al., 2012) will be used to increase the specificity of the seven FMS™ tests.

C2. Describe the purpose/objective and the significance of the research:

The primary purpose of the proposed study is to determine the relationship between a Functional Movement Screen™ (FMS™) total score, scored on a 100-point and 21-point scale, and peak countermovement jump (CMJ) height. The secondary purpose of this proposed study is to perform an exploratory analysis examining the validity of the 21-point live scoring method as well as a 21-point video scoring method of the FMS™.

Scientific Significance:
The scientific significance that this study offers is that it will be the first study to test the possible relationship between athletic performance (i.e., CMJ) and the FMS™, scored on a 100-point scale. Through the use of the Myotest SPORT unit, this study also is the first to address how power production in an explosive task, CMJ, is influenced by the physiological properties of the participant's lower extremity muscles.

The results of this study may shed light on how individuals that have greater amounts of mobility and dynamic stability, as well as fewer compensatory movements, may be better performers. With a relationship between functional movement and injury risk already established, this proposed study may demonstrate that those whom are at a lower risk for injury may also be better jumpers. A relationship may be made that the FMS™ may be able to target areas more at risk for injury that will also limit performance. Continued research in this area may expand the realm of influence to greater populations such as children, older adults, and rehabilitation patients.

C3. Cite any relevant literature pertaining to the proposed research:

Aragon-Vargas, L. (2000). Evaluation of four vertical jump tests: Methodology, reliability, validity, and accuracy. *Measurement in Physical Education and Exercise Science*, *4*(4), 215-228.

Butler, R., Plisky, P., & Kiesel, K. (2012). Interrater reliability of videotaped performance of the functional movement screen using the 100-point scale. *Athletic Training & Sports Health Care*, *4*(3), 103-109.

Chorba, R., Chorba, D., Bouillon, L., Overmyer, C., & Landis, J. (2010). Use of a functional movement screening tool to determine injury risk in female collegiate athletes. *North American Journal of Sports Physical Therapy*, *5*(2), 47-54.

Cook, G., Burton, L., & Hoogenboom, B. (2006). Pre-participation screening: The use of fundamental movements as an assessment of function - part 1. *North American Journal of Sports Physical Therapy*, *1*(2), 62-72.

Cook, G., Burton, L., & Hoogenboom, B. (2006). Pre-participation screening: The use of fundamental movements as an assessment of function - part 2. *North American Journal of Sports Physical Therapy*, *1*(3), 132-139.

Cronin, J., & Hansen, K. (2005). Strength and power predictions of sports speed. *Journal of Strength*

and Conditioning Research, *19*(2), 349-357.

Goss, D., Christopher, G., Faulk, R., & Moore, J. (2009). Functional training program bridges rehabilitation and return to duty. *Journal of Special Operations Medicine*, *9*(2), 29-48.

Hori, N., Newton, R., Andrews, W., Kawamori, N., McGuigan, M., & Nosaka, K. (2008). Does performance of hang power clean differentiate performance of jumping, sprinting, and changing of direction?. *Journal of Strength and Conditioning Research*, *22*(2), 412-418.

Kiesel, K., Plisky, P., & Voight, M. (2007). Can serious injuryin professional football be predicted by a preseason functional movement screen?. *North American Journal of Sports Physical Therapy*, *2*(3), 147-158.

Kiesel, K., Plisky, P., & Butler, R. (2011). Functional movement test scores improve following a standarized off-season intervention program in professional football. *Scandinavian Journal of Medicine & Science in Sports*, 287-292.

Luebbers, P., Potteiger, J., Hulver, M., Thyfault, J., Carper, M., & Lockwood, R. (2003). Effects of plyometric training and recovery on vertical jump performance and anaerobic power. *Journal of Strength and Conditioning Research*, *17*(4), 704-709.

Minick, K., Kiesel, K., Burton, L., Taylor , A., Plisky, P., & Butler, R. (2010). Interrater reliability of the functional movement screen. *Journal of Strength and Conditioning Research*, *24*(2), 479-486.

O'Connor , F., Deuster, P., Davis, J., Pappas, C., & Knapik, J. (2011). Functional movement screening: Predicting injuries in officer candidates. *Journal of the American College of Sports Medicine*, 2224-2230.

Okada, T., Huxel , K., & Nesser, T. (2011). Relationship between core stability, functional movement, and performance. *Journal of Strength and Conditioning Research*, *25*(1), 252-261.

Onate, J., Dewey, T., Kollock, R., Thomas, K., Van Lunen, B., DeMaio, M., & Ringleb, S. (2012). Real-time intersession and interrater reliability of the functional movement screen. *Journal of Strength and Conditioning Research*, *26*(2), 408-413.

Parchmann, C., & McBride, J. (2011). Relationship between functional movement screen and athletic performance. *Journal of Strength and Conditioning Research*, *25*(12), 3378-3384.

Peate, W., Bates, G., Lunda, K., Francis, S., & Bellamy, K. (2007). Core strength: A new model for injury prediction and preventino. *Journal of Occupational Medicine and Toxicology*, *2*(3),

Teyhen, D., Shaffer, S., Lorenson, C., Halfpap, J., Donofry, D., Walker, M., Dugan, J., & Childs, J. (2012). The functional movement screen: A reliability study. *Journal of Orthopedic & Sports Physical Therapy*, *42*(6), 530-538.

SECTION D: Subject Population

Section Notes…

- D1. If this study involves analysis of de-identified data only (i.e., no human subject interaction),

> IRB submission/review may not be necessary. Visit the Pre-Submission section in the IRB website for more information.

D1. Identify any population(s) that you will be <u>specifically targeting</u> for the study. Check all that apply: (Place an "X" in the column next to the name of the special population.)

	Not Applicable (e.g., de-identified datasets)		Institutionalized/ Nursing home residents recruited in the nursing home
X	UWM Students of PI or study staff		Diagnosable Psychological Disorder/Psychiatrically impaired
X	Non-UWM students to be recruited in their educational setting, i.e. in class or at school		Decisionally/Cognitively Impaired
	UWM Staff or Faculty		Economically/Educationally Disadvantaged
	Pregnant Women/Neonates		Prisoners
	Minors under 18 and ARE NOT wards of the State		Non-English Speaking
	Minors under 18 and ARE wards of the State		Terminally ill
X	Other (Please identify): UWM students that are not students of the PI or study staff		

D2. Describe the subject group and enter the total number to be enrolled for each group. For example: teachers-50, students-200, parents-25, parent's children-25, student control-30, student experimental-30, medical charts-500, dataset of 1500, etc. Enter the total number of subjects below.

Describe subject group:	Number:
Males between 18-30 yrs of age	60
TOTAL # OF SUBJECTS:	60
TOTAL # OF SUBJECTS (If UWM is a collaborating site):	

D3. List any major inclusion and exclusion criteria (e.g., age, gender, health status/condition, ethnicity, location, English speaking, etc.) and state the justification for the inclusion and exclusion:

Participants must be males between the ages of 18-30. Participants will be included based on their self-reported responses to the Criteria for Inclusion Questionnaire. Recruitment will continue until 60 participants have been completed the study.

All participants will be screened with the Criteria for Inclusion Questionnaire which includes specific questions regarding lower extremity injuries and possible contraindications to physical activity. Participants will be excluded if they are taking prescribed medication for a symptomatic illness, had an injury, surgery, or bone abnormalities on their knees, hips, or ankles, have a heart condition or any chest pain, suffer from dizziness, have hearing impairments, are currently or have trained or competed in a competitive sport (e.g., Division I sports team) or physical activity (e.g., a marathon) in the last year, have previous experience with the FMS™, have a body mass index (BMI) greater than 30, or do not meet the minimum requirements of physical activity as described by the American College of Sports Medicine (ACSM). No special expertise is needed to screen the participants.

The criteria for inclusion allows for comparison between the novel study approach and the existing literature.

SECTION E: Informed Consent

Section Notes…

- E1. Make sure to attach any recruitment materials for IRB approval.
- E3. The privacy of the participants must be maintained throughout the consent process.

E1. Describe how the subjects will be recruited. (E.g., through flyers, beginning announcement for X class, referrals, random telephone sampling, etc.). If this study involves secondary analysis of data/charts/specimens only, provide information on the source of the data, whether the data is publicly available and whether the data contains direct or indirect identifiers.

Participants will be recruited through flyers posted in approved places on the UWM campus and word of mouth across the UW-M campus as well as the Milwaukee community. Responses to solicitation will be voluntary.

E2. Describe the forms that will be used for each subject group (e.g., short version, combined parent/child consent form, child assent form, verbal script, information sheet): If data from failed eligibility screenings will be used as part of your "research data", then these individuals **are** considered research subjects and consent will need to be obtained. Copies of all forms should be attached for approval.

If requesting to waive documentation (not collecting subject's signature) or to waive consent all together, state so and complete the "Waiver to Obtain-Document-Alter Consent" and attach:

1. **Criteria for Inclusion Questionnaire:** If a participant meets all the requirements for the study, then he will be invited to participate in the study and complete the informed consent.
2. **ID Code Sheet:** Upon completion of the informed consent, all participants will receive a unique ID code. The attached ID code and name sheet will be completed by hand and not entered into a permanent computer file and will only be used to contact individuals for purposes of the study.
3. **Exercise History Questionnaire:** Asks questions regarding current and past physical activity participation in order to obtain additional information regarding type of exercise activities the participants engage in.

E3. Describe who will obtain consent and where and when consent will be obtained. When appropriate (for higher risk and complex study activities), a process should be mentioned to assure that participants understand the information. For example, in addition to the signed consent form, describing the study procedures verbally or visually**:**

The student PI (J. Conlon) will talk to interested candidates via phone, email, or in-person at the Human Performance & Sport Physiology Laboratory (HPSPL; PAV 365) to determine if the meet all the criteria for inclusion. The student PI will make inclusion/exclusion decisions based on the self-reported (yes or no) responses on the Criteria for Inclusion questionnaire. If a participant answers "yes" to any of the questions 4-18, or "no" to any of questions 1-3, they will be excluded. Participation will be strictly voluntary and participants may withdraw from the study at any time. Consent will be obtained by the student PI (J. Conlon). Consent will be obtained (in a private area) from the participants via in-person paper-pencil forms, prior to the completion of any questionnaires. The informed consent will be verbally explained to each participant. Following an opportunity to read the informed consent and ask any questions, participants will be asked sign the Consent Form. Without fully completing the consent form, the participants will not be allowed to participate in the study. Participation in this study is strictly voluntary.

SECTION F: Data Collection and Design

Section Notes…

- F1. Reminder, all data collection instruments should be attached for IRB review.
- F1. The IRB welcomes the use of flowcharts and tables in the consent form for complex/ multiple study activities.

F1. In the table below, chronologically describe all study activities where human subjects are involved.

- In **column A**, give the activity a short name. E.g., Obtaining Dataset, Records Review, Recruiting, Consenting, Screening, Interview, Online Survey, Lab Visit 1, 4 Week Follow-Up, Debriefing,

etc.

- In **<u>column B</u>**, describe in greater detail the activities (surveys, audiotaped interviews, tasks, etc.) research participants will be engaged in. Address where, how long, and when each activity takes place.

- In **<u>column C</u>,** describe any possible risks (e.g., physical, psychological, social, economic, legal, etc.) the subject may *reasonably* encounter. Describe the **safeguards** that will be put into place to minimize possible risks (e.g., interviews are in a private location, data is anonymous, assigning pseudonyms, where data is stored, coded data, etc.) and what happens if the participant gets hurt or upset (e.g., referred to Norris Health Center, PI will stop the interview and assess, given referral, etc.).

A. Activity Name:	B. Activity Description:	C. Activity Risks and Safeguards:
Recruitment	The student PI will recruit participants through the use of flyers, word of mouth, and speaking in undergraduate lectures. The researchers will ask that the perspective participant to refrain from smoking (or any other tobacco product) and caffeine intake the four hours before coming into PAV 365 as well as to abstain from any heavy resistance training in the preceding 48 hours. These measures will be taken in case the individual qualifies for the study.	Recruitment involves minimal risk to participants. The PI will verbally and in written form remind all contacts that participation is strictly voluntary.
Screening	Participant will complete the Criteria for Inclusion Questionnaire prior to the start of each testing session.	This screening process involves minimal risk to participants. Data will be stored in a locked file in PAV 365 where only the student PI (J. Conlon) and faculty advisor (K. Ebersole) as well as designated Graduate students will have access. This data will be categorized by ID code (e.g., EXS1) and not by participant name. The data will only be shared in aggregate group form similar to what would be presented in a manuscript.
Consenting	During Day 1, the participant will be read and give informed consent to the study protocol. The participant will be allowed to ask questions prior to signing the informed consent document.	Data will be stored in a locked file in PAV 365 where only the student PI (J. Conlon) and faculty advisor (K. Ebersole) as well as

	Once the participant has signed the informed consent, and been included in to the study, they will be given a study ID (e.g., EXS1) that will be used to code all of their data collected during the study.	designated Graduate students will have access. This data will be categorized by ID code (e.g., EXS1) and not by participant name so that the data is unidentifiable. The only identifiable data will be the video recorded movement tests (see below). The data will only be shared in aggregate group form similar to what would be presented in a manuscript.
Exercise History Questionnaire	The participant will complete a paper-pencil exercise history questionnaire. This questionnaire assesses the frequency and type of physical activity they have and are currently partaking in.	Data will be stored in a locked file in PAV 365 where only the student PI (J. Conlon) and faculty advisor (K. Ebersole) as well as designated Graduate students will have access. This data will be categorized by ID code (e.g., EXS1) and not by participant name. The data will only be shared in aggregate group form similar to what would be presented in a manuscript.
Height and Weight	The participant's height, body weight, age, and birthdate will be measured and recorded. Height and weight measurements will be taken using a weigh beam eye-level physician scale and mounted stadiometer (Detecto, Webb City, MO). The participant's body mass index (BMI) will then be calculated and recorded from the height and weight measurements. These measurements will be used to describe the participants in aggregate form. In addition, actual height and body weight measures will confirm the self-reported height and weight used to estimate BMI as part of the Criteria for Inclusion Questionnaire. If a participant's actual measured BMI is >30 upon these measurements, the participants involvement in the study will be terminated and the data collected will be destroyed.	The potential risks for injury due to performing any of the movement tasks in this study are minimal. Data will be stored in a locked file in PAV 365 where only the student PI (J. Conlon) and faculty advisor (K. Ebersole) as well as designated Graduate students will have access. This data will be categorized by ID code (e.g., EXS1) and not by participant name. The data will only be shared in aggregate group form similar to what would be

		presented in a manuscript.
Functional Movement Screen Tests	The participant will perform a battery of seven movement tests as designed by the FMS™. All seven tasks of the FMS™ will be subjectively scored by the guidelines of the 100-point scale (Butler et al., 2012). No warm-up will be provided prior to the FMS™. Each of the participant's movement tests will be scored in person on Day 1 with a paper and pencil scoring method. In addition, each of the movement tests will be video recorded with an iPad camera. Each of the tests will be recorded from both the frontal and sagittal plane. Video recording will be used to re-score the FMS™ tests from Day 1 to examine differences between 21-point live scored tests and the post hoc rescoring of the tests to a 100 point scale through the review of the video recording. In addition, the video files will be used to compare a 21 point-live to a 21-point scored FMS from a video. The seven tasks include: 1. A deep squat, which involves holding a light weight plastic dowel rod over the head with arms extended and squatting as far down as the participant is able to go. This task will be repeated up to five times. (18-point maximum) 2. A hurdle step, which involves holding the aforementioned dowel rod across the shoulders while stepping, one leg at a time, over a rubber tube that is anchored to two stationary poles. The height of the rubber tube is level with the tibial tuberosity, just below the knee. This task will be repeated up to five times. Each side will be scored separately. (18-point maximum; 9 points maximum per side) 3. An in-line lunge, which involves the participant lunging forward and trying to touch the knee of the back leg to the heel of the front foot. This test will be repeated up to five times. Each side	The potential risks for injury due to performing any of the movement tasks in this study are minimal. It is unlikely, but possible that participants may experience muscle soreness or tightness following the testing. It is also possible, although unlikely, that a participant may experience minor musculoskeletal strains. All personnel involved in testing are trained in adult cardiopulmonary resuscitation (CPR) and first aid procedures. The session will be terminated in the event that the participant indicates any discomfort such as chest pain, leg pain or cramping or other sign and symptom that could be associated with a medical condition. The testing will also be terminated if requested by the participant. In the event that an exercise session is terminated for a possible medical reason, laboratory personnel will manage the situation per the standard first aid guidelines and procedures of the American Red Cross and refer to their personal physician or contact the Emergency Medical System in the case of an emergency.

	will be scored separately. (20-point maximum; 10 points maximum per side).	
	4. A measure of shoulder mobility, which involves the participant reaching behind their back with one hand coming from the head down the spine and the other hand coming from the waist up the spine. The distance separating the two hands will be measured. Both shoulders will be assessed and each side will be scored separately. This test will be repeated up to five times. (8-point maximum; 4 points maximum per side).	
	5. A single, straight-leg raise, which involves the participant lying on his/her back and raising the leg up from the ground while keeping the knee straight. Both legs will be assessed and scored separately. This test will be repeated up to five times. (12-point maximum; 6 points maximum per side).	
	6. A push-up, which involves performing a push-up with the hands placed at the level of the chin or clavicle. This task will be repeated up to five times. (12-point maximum)	
	7. A measure of rotary stability, which involves the participant being positioned in a 4-point stance (arms and legs) and trying to bring the right elbow to right knee. This is then repeated with the left elbow coming to the left knee. Each side will be scored separately. This test will be repeated up to five times. (12-point maximum; 6 points maximum per side). After the FMS™, the researchers will verbally explain the protocol of the counter movement jump (CMJ) that will be administered during Day 2 of this study to the participant. The researchers will ask that the participant refrain from smoking (or any other tobacco product) and caffeine intake the four hours preceding the data collection on Day 2, as well as abstain from any heavy resistance training in the preceding 48 hours.	
Video Recording	In order to accurately score the FMS™ tests on the 100-point scale, each of the movement tests must be video recorded. The video recording will also be used to examine possible differences between a 21-	Collection of the video recorded movement tests involves minimal risk to participants. The video

| | point live scoring | recording of the movement tests will capture the full body, face included, throughout each of the movement test trials. In order to protect this identifiable information, all video files will be saved by participant initials based on printed name from the ID code sheet. This will provide a non-direct link between this identifiable data and the other study data that is stored by ID code. The only way to link the identifiable and de-identified data will be through the master ID code sheet described above and only retained by the student PI and faculty PI. |
| | | Once the FMS is scored from the video files on the I-pad, all video files (saved with participant initials) will be stored on an encrypted laptop. Upon conclusion of the study, exemplar video files will be retained for the purpose of improving dissemination of data in conference presentation format. In this case, any video file presented in the dissemination efforts will be completely de-identified by blocking or hiding the face prior to dissemination. Only video files that can be completely de-identified will be used. All other video files will be destroyed upon conclusion of the study. Only the student PI (J. Conlon) and faculty advisor (K. Ebersole) as well as |

		designated Graduate students will have access to the video recorded movements.
Practice Jumps	After completing the FMS test, the participant will be fitted with the Myotest Sport unit and belt. The Myotest unit is a small accelerometer based device that will measure the peak height (cm) of each of the participant's CMJ trials. This device is attached to a Velcro belt that the participant will have secured around their waist. These jumps will not be recorded. Their purpose is to familiarize that participant with the CMJ jump protocol and the MyoTest belt. CMJ practice jump instructions: 1. The participant will begin each jump (trial) with their hands relaxed by their side and feet shoulder width apart. 2. The participant will listen for the sound of the beep (stimulus) from the MyoTest. 3. At the sound of the beep, the participant will lower himself into a deep squat swinging their arms back as they squat down while maintaining a straight back. 4. At the bottom of the jump, the participant will immediately jump upward, swinging their arms forward and upward with as they jump. 5. The participant will be encouraged to bend their legs upon landing from each jump trial.	It is possible that participants may experience minor musculoskeletal muscle strains, muscle soreness, and/or tightness as they might with any form of physical activity The practice sessions will be terminated in the event that the subject indicates any discomfort such as leg pain or cramping or other sign and symptom that could be associated with a medical condition. The testing will also be terminated if requested by the participant. In the event that a testing session is terminated for a possible medical reason, laboratory personnel will manage the situation per the standard first aid guidelines and procedures of the American Red Cross and refer to Norris Health Center or contact the Emergency Medical System.
Warm-up (Day 2)	Upon arriving at the lab for the second day of testing, the participant will perform a brief, five minute warm-up on a bicycle ergometer with a light, self-selected, resistance level.	The warm-up is designed to be submaximal and at a pace and resistance self-selected by the participant. The risks associated with this warm-up are no greater than those of every day physical activity.
Practice Jumps	The participant will then perform five CMJ trials to re-familiarize the participant with the jump protocol	It is possible that participants may experience

	that was practiced on Day 1. The researchers will also watch that the participant is using correct form during the CMJ.	minor musculoskeletal muscle strains, muscle soreness, and/or tightness as they might with any form of physical activity. The practice sessions will be terminated in the event that the subject indicates any discomfort such as leg pain or cramping or other sign and symptom that could be associated with a medical condition. The testing will also be terminated if requested by the participant. In the event that a testing session is terminated for a possible medical reason, laboratory personnel will manage the situation per the standard first aid guidelines and procedures of the American Red Cross and refer to Norris Health Center or contact the Emergency Medical System.
Jump Trials	The participant will perform three successful CMJ trials that will be recorded for data analysis. The researchers will hand record information from the Myotest between each successful trial onto a data sheet. A trial will be considered unsuccessful if: the participant starts their movement before the proper stimulus (false start), the Myotest is bumped or falls off during the arm swing, or the Myotest Sport unit cannot properly record the trial After three successful trials are recorded, the Myotest Sport unit will be removed and the participant's commitment to this study is over.	It is possible that participants may experience minor musculoskeletal muscle strains, muscle soreness, and/or tightness as they might with any form of physical activity. The testing sessions will be terminated in the event that the subject indicates any discomfort such as leg pain or cramping or other sign and symptom that could be associated with a medical condition. The testing will also be terminated if requested by the participant.

		In the event that a testing session is terminated for a possible medical reason, laboratory personnel will manage the situation per the standard first aid guidelines and procedures of the American Red Cross and refer to Norris Health Center or contact the Emergency Medical System.
Data Analysis	Data analysis will be conducted with Microsoft Excel and SPSS 21. Statistical measurement of interest for this study would be descriptive statistics and correlational analyses between the various measures.	Data analysis involves minimal risk. Safeguards include storing the data on an encrypted, password protected laptop as well as in a password protected online database through the secure password-protected folder on the UW-M network's research drive.

F2. Explain how the privacy and confidentiality of the participants' data will be maintained after study closure:

The information gathered in this study will be used only for research and publication purposes. Aggregate data obtained from the participants will be used to assist in understanding the possible relationship between movement ability and athletic performance. Data, in aggregate form, may be presented at scientific meetings and in the scientific literature. In no case will individual participants be identified by name.

A master identity code sheet containing subject names, participant ID code, and contact information will be stored (in a locked file in the office of the faculty PI, PAV 364) separate from all collected data for the purpose of contacting subjects for follow-up testing. All experimental data and associated questionnaires will be stored in a file based on a participant ID code (e.g., EXS1) unique to each participant and separate from any contact information. At no time will the coded data files include names or contact information. If a participant withdraws from the study at any point, other than being terminated upon confirmation of BMI, all data collected up to the point of withdrawing will be kept, but will not be used in this study.

Video recorded movement tests will be stored on an iPad that will be locked in the office of the faculty advisor (K. Ebersole). It will be both removed from and returned to this cabinet by the student PI (J. Conlon) or the faculty advisor. All video files will be saved according to participant

initials to eliminate the direct link between identifiable video information to other data stored by a unique study ID code. In the case of the video files, all video files in possession by the student PI and faculty PI will be destroyed upon conclusion of the study. Only exemplar videos that can be completely de-identified will be kept for assistance in dissemination of data (see F1 above).

The information gathered in this study will be used only for research and publication purposes in the form of aggregate data only. In no case will individual participants be identified by name. Aggregate data obtained from the participants will be used to assist in understanding the possible relationship between movement ability and athletic performance. Data, in aggregate form, may be presented at scientific meetings and in the scientific literature.

F3. Explain how the data will be analyzed or studied (i.e. quantitatively or qualitatively) and how the data will be reported (i.e. aggregated, anonymously, pseudonyms for participants, etc.):

The information gathered in this study will be used only for research and publication purposes. Aggregate data obtained from the participants will be used to assist in understanding the possible relationship between movement ability and athletic performance. Data, in aggregate form, may be presented at scientific meetings and in the scientific literature. In no case will individual participants be identified by name.

SECTION G: Benefits and Risk/Benefit Analysis

Section Notes…

- Do not include Incentives/ Compensations in this section.

G1. Describe any benefits to the individual participants. If there are no anticipated benefits to the subject directly, state so. Describe potential benefits to society (i.e., further knowledge to the area of study) or a specific group of individuals (i.e., teachers, foster children). Describe the ratio of risks to benefits.

Participants will receive a free FMS™ test along with recommendations for exercises to improve their movement.

No monetary compensation will be given to participants.

G2. Risks to research participants should be justified by the anticipated benefits to the participants or society. Provide your assessment of how the anticipated risks to participants and steps taken to minimize these risks, balance against anticipated benefits to the individual or to society.

We believe that the risk-to-benefit ratio for this study is quite low. The risks involved in this study are very minimal in comparison to what the participants are exposed to in the daily routines of life and exercise, or completing any other survey or questionnaire. The benefits from this study will aid in the understanding the possible relationship between movement ability and athletic performance.

It is possible that participants may experience minor musculoskeletal muscle strains, muscle soreness, and/or tightness as they might with any form of physical activity.

The small potential for any risks will be reduced further by recruiting participants who are currently active and accustomed to physical activity. Further, all personnel involved in testing are trained in adult cardiopulmonary resuscitation (CPR) and first aid procedures.

The testing sessions will be terminated in the event that the subject indicates any discomfort such as leg pain or cramping or other sign and symptom that could be associated with a medical condition. The testing will also be terminated if requested by the participant. In the event that a testing session is terminated for a possible medical reason, laboratory personnel will manage the situation per the standard first aid guidelines and procedures of the American Red Cross and refer to Norris Health Center or contact the Emergency Medical System.

SECTION H: Subject Incentives/ Compensations

Section Notes…

- H2 & H3. The IRB recognizes the potential for undue influence and coercion when extra credit is offered. The UWM IRB, as also recommended by OHRP and APA Code of Ethics, agrees when extra credit is offered or required, prospective subjects should be given the choice of an equitable alternative. In instances where the researcher does not know whether extra credit will be accepted and its worth, such information should be conveyed to the subject in the recruitment materials and the consent form. For example, "The awarding of extra credit and its amount is dependent upon your instructor. Please contact your instructor before participating if you have any questions. If extra credit is awarded and you choose to not participate, the instructor will offer an equitable alternative."
- H4. If you intend to submit to the Travel Management Office for reimbursement purposes make sure you understand what each level of payment confidentiality means **(click here for additional information).**

H1. Does this study involve incentives or compensation to the subjects? For example cash, class extra credit, gift cards, or items.

[_x_] Yes

[__] No [SKIP THIS SECTION]

H2. Explain what (a) the item is, (b) the amount or approximate value of the item, and (c) when it will be given. For extra credit, state the number of credit hours and/or points. (e.g., $5 after completing each survey, subject will receive [item] even if they do not complete the procedure, extra credit will be award at the end of the semester)**:**

> Extra credit may be provided by a student's instructor. The amount of credit hours of extra credit points is subject to the instructor's discretion.

H3. If extra credit is offered as compensation/incentive, an alternative activity (which can be another research study or class assignment) should be offered. The alternative activity (either class assignment or another research study) should be similar in the amount of time involved to complete and worth the same extra credit.

> If a student may receive extra credit for participation in this proposed study, it is at the instructor's discretion to provide an alternative activity for those that do not fit the inclusion criteria for this proposed study.

H4. If cash or gift cards, select the appropriate confidentiality level for payments (see section notes):

> **[__] Level 1** indicates that confidentiality of the subjects is not a serious issue, e.g., providing a social security number or other identifying information for payment would not pose a serious risk to subjects.
>
> - Choosing a Level 1 requires the researcher to maintain a record of the following: The payee's name, address, and social security number and the amount paid.
> - When Level 1 is selected, a formal notice is not issued by the IRB and the Travel Management Office assumes Level 1.
> - Level 1 payment information will be retained in the extramural account folder at UWM/Research Services and attached to the voucher in Accounts Payable. These are public documents, potentially open to public review.
>
> **[__] Level 2** indicates that confidentiality is an issue, but is not paramount to the study, e.g., the participant will be involved in a study researching sensitive, yet not illegal issues.
>
> - Choosing a Level 2 requires the researcher to maintain a record of the following: A list of names, social security numbers, home addresses and amounts paid.
> - When Level 2 is selected, a formal notice will be issued by the IRB.

- Level 2 payment information, including the names, are attached to the PIR and become part of the voucher in Accounts Payable. The records retained by Accounts Payable are not considered public record.

[__] **Level 3** indicates that confidentiality of the subjects must be guaranteed. In this category, identifying information such as a social security number would put a subject at increased risk.

- Choosing a Level 3 requires the researcher to maintain a record of the following: research subject's name and corresponding coded identification. This will be the only record of payee names, and it will stay in the control of the PI.
- Payments are made to the research subjects by either personal check or cash.
- Gift cards are considered cash.
- If a cash payment is made, the PI must obtain signed receipts.

SECTION I: Deception/ Incomplete Disclosure (INSERT "NA" IF NOT APPLICABLE)
Section Notes…   • If you cannot adequately state the true purpose of the study to the subject in the informed consent, deception/ incomplete disclosure is involved.

I1. Describe (a) what information will be withheld from the subject (b) why such deception/ incomplete disclosure is necessary, and (c) when the subjects will be debriefed about the deception/ incomplete disclosure.

IMPORTANT – Make sure all sections are complete and attach this document to your IRBManager web submission in the Attachment Page (Y1).

APPENDIX G

Example FMS™ 21-point Data Sheet

Test	Raw Score	Final Score	Notes
1. Deep Squat • Torso // with tibia or toward vertical • Femur < HZ • Knees over feet • Dowel over feet			□ Feet Out □ Foot Flattens □ Knees In □ Knees Out □ FWD Lean □ LB Arch □ LB Rounds □ Arms FWD □ Heel Rises □ Wt shift to R □ Wt shift to L □ "Tail tuck" □ DF Issues □ Torso Rot
2. Hurdle Step • Hips, knees, ankles aligned in sagittal plane • Min. movement of L-spine • Dowel and hurdle remain // • Loss of balance or contact w/hurdle = 1 *Record Height of Band =*	**R (stepping)** **L**		□ Hip ER (knee out) □ Hip IR (knee in) □ Tibial ER (foot out) □ Tibial IR (foot in) □ FWD Lean □ Hip Hike □ Limited Ankle motion □ Trunk Rot R to L □ Trunk Rot L to R ────────── □ Hip ER (knee out) □ Hip IR (knee in) □ Tibial ER (foot out) □ Tibial IR (foot in) □ FWD Lean □ Hip Hike □ Limited Ankle motion □ Trunk Rot R to L □ Trunk Rot L to R
3. In-Line Lunge • Dowel remains in contact w/L-ext • No torso movement • Dowel & feet remain in sagittal plane • Knee touches board behind heel	**R (front)** **L**		□ FWD Lean □ Loss of Balance □ Front Heel Rise □ Rear Heel Rot □ Lateral Flx □ Knee In □ Trunk Rot R to L □ Trunk Rot L to R ────────── □ FWD Lean □ Loss of Balance □ Front Heel Rise □ Rear Heel Rot □ Lateral Flx □ Knee In □ Trunk Rot R to L □ Trunk Rot L to R
4. Shoulder Mobility *Impingement Clearing (NO = pain)* *Right YES NO Left YES NO* • Fists w/in 1 hand length = 3 • Fists w/in 1.5 units = 2 • Fists > 1.5 units = 1	**R (flexed)** **L**		Record Measured Hand Length =
5. Active SLR • Dowel at mid-thigh (bt patella & ASIS) • Dowel at superior patella • Dowel at inferior patella	**R** **L**		□ Pelvis Rotates □ Down Leg rotates □ Down Leg Thigh Lifts □ Pelvis Rotates □ Down Leg rotates □ Down Leg Thigh Lifts
6. Trunk Stability PU *Spinal Ext Clearing (NO = pain)* *YES NO* • Males: 1 rep w/thumbs at top of forehead then chin • Females: 1 rep w/thumbs at chin then clavicle			□ Trunk Rotates to R □ Trunk Rotates to L □ Trunk Rises Before Hips □ Hips Raise Before Trunk
7. Rotary Stability *Spinal Flex Clearing (NO = pain)* *YES NO* • 1 correct unilateral rep w/spine // to board • Knee & elbow touch • II = diagonal	**R (upper moving)** **L**		□ Hip Flexion □ L Leg Can't Extend □ R Shldr Drops □ R Shldr Flexes ────────── □ Hip Flexion □ R Leg Can't Extend □ L Shldr Drops □ L Shldr Flexes

TOTAL SCORE = _____ / 21

APPENDIX H

Example FMS™ 100-point Data Sheet

ID #:   **Date:**

Preferred Throwing Limb: **Preferred Stance Limb:**

Test	Notes	Score
8. Deep Squat (18 points) __ Upper torso is parallel with tibia or toward vertical (6 points) __ Knee aligned over feet (8 points) __ Dowel aligned overhead (4 points) ***with board*** __ Femur below horizontal (2 points) __ Upper torso is parallel with tibia or toward vertical (2 points) __ Knees are aligned over feet (2 points) __ Dowel aligned over feet (2 points)	□ Feet Out □ Foot Flattens □ Knees In □ Knees Out □ FWD Lean □ LB Arch □ LB Rounds □ Arms FWD □ Heel Rises □ Wt shift to R □ Wt shift to L □ "Tail tuck" □ DF Issues □ Torso Rot □ Arms FWD	
9. Hurdle Step- R (stepping) __ Foot clears cord (does not touch) (5 points) __ Hips, knees, and ankles remain aligned in the sagittal plane (2 points) __ Minimal to no movement is noted in lumbar spine (1 point) __ Dowel and hurdle remain parallel (1 point) **L (stepping)** __ Foot clears cord (does not touch) (5 points) __ Hips, knees, and ankles remain aligned in the sagittal plane (2 points) __ Minimal to no movement is noted in lumbar spine (1 point) __ Dowel and hurdle remain parallel (1 point) *Record Height of Band =*	**R** □ Hip ER □ Hip IR □ Tibial IR □ FWD Lean □ Hip Hike □ Tibial ER □ Limited Ankle motion □ Trunk Rot R to L □ Trunk Rot L to R _____ **L** □ Hip ER □ Hip IR □ Tibial IR □ FWD Lean □ Hip Hike □ Tibial ER □ Limited Ankle motion □ Trunk Rot R to L □ Trunk Rot L to R	**R (stepping)** **L**
10. In-Line Lunge R (front) __ Knee touches behind heel (2 points) __ Dowel and feet remain in sagittal plane (2 points) __ Dowel contacts maintained (Head, shoulders, lumbar) (2 points) __ Dowel remains vertical (2 points) __ No torso movement noted (2 points) **L (front)** __ Knee touches behind heel (2 points) __ Dowel and feet remain in sagittal plane (2 points) __ Dowel contacts maintained (Head, shoulders, lumbar) (2 points) __ Dowel remains vertical (2 points) __ No torso movement noted (2 points)	**R** □ FWD Lean □ Loss of Balance □ Front Heel Rise □ Rear Heel Rot □ Lateral Flx □ Knee In □ Trunk Rot R to L □ Trunk Rot L to R _____ **L** □ FWD Lean □ Loss of Balance □ Front Heel Rise □ Rear Heel Rot □ Lateral Flx □ Knee In □ Trunk Rot R to L □ Trunk Rot L to R	**R (front)** **L**
11. Shoulder Mobility – R (flexed) **Record Measured Hand Length =** *Impingement Clearing (NO = pain)* *Right YES NO*	**R**	**R (flexed)**

__ Fists are within one hand length (4 points) __ Fists are within one-and-a-half hand lengths (2 points) __ Fists are not within one-and-a-half hand lengths (0 points) **L (flexed)** *Left YES NO* __ Fists are within one hand length (4 points) __ Fists are within one-and-a-half hand lengths (2 points) __ Fists are not within one-and-a-half hand lengths (0 points)	**L** _____	**L**
12. Active SLR – R (moving) __ Malleolus resides between mid-thigh and ASIS (6 points) __ Malleolus resides between mid-thigh and joint line (2 points) __ Malleolus resides below the joint line (0 points) **L (moving)** __ Malleolus resides between mid-thigh and ASIS (6 points) __ Malleolus resides between mid-thigh and joint line (2 points) __ Malleolus resides below the joint line (0 points)	**R** □ Pelvis Rotates □ Down Leg rotates □ Down Leg Thigh Lifts _____ **L** □ Pelvis Rotates □ Down Leg rotates □ Down Leg Thigh Lifts	**R (moving)** **L**
13. Trunk Stability PU *Spinal Ext Clearing (NO = pain)* *YES NO* __ 1 rep w/ thumbs at top of forehead level (12 points) __ 1 rep w/ thumbs at chin level (5 points) __ Failure at chin level (0 points)	□ Trunk Rotates to R □ Trunk Rotates to L □ Shoulders rise before back □ Back rises before shoulders	
14. Rotary Stability *Spinal Flex Clearing (NO = pain)* *YES NO* **R (upper moving)** __ Unilateral repetition (6 points) __ Diagonal Repetition (2 points) __ Failure of diagonal repetition (0 points) **L (upper moving)** __ Unilateral repetition (6 points) __ Diagonal Repetition (2 points) __ Failure of diagonal repetition (0 points)	□ Hip Flexion □ L Leg Can't Extend □ R Shldr Drops □ R Shldr Flexes _____ □ Hip Flexion □ L Leg Can't Extend □ R Shldr Drops □ R Shldr Flexes	**R (upper moving)** **L**

TOTAL SCORE = _____ / 100

APPENDIX I

Example CMJ Data Sheet

Human Performance & Sport Physiology Lab
Department of Kinesiology
University of Wisconsin – Milwaukee
3409 N. Downer Ave
Pavilion – Physical Therapy, Room 365
Milwaukee, WI 53211

ID #: _____

The Relationship between the Functional Movement Screen[TM] **and Countermovement jump height**– Joshua K. Conlon Thesis

Date: _____

Age: _____   Date of Birth: _____

Height (cm): _____ Weight (kg): _____ BMI: _____

Counter Movement Jump Trials - Myotest				
	1	**2**	**3**	**AVG**
Height (cm)				

APPENDIX J

Functional Pyramid

Functional Skill

Functional Performance

Functional Movement
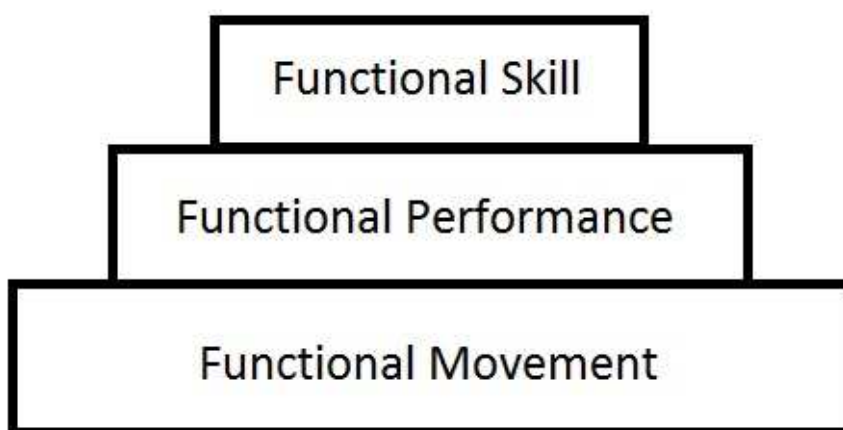
Adapted from Cook (2010)

APPENDIX K

Participant Descriptive Data

ID	Wt (kg)	Ht (cm)	BMI	Age
JT1	73.1	177.8	23.1	24
JT3	77.2	177.8	24.4	18
JT5	82.2	181.6	25.4	21
JT6	82.2	177.2	26.2	23
JT7	58.1	163.8	21.7	21
JT8	82.6	179.7	25.6	22
JT9	74.9	175.3	24.4	22
JT11	84.4	184.2	24.9	20
JT12	64.5	173.9	21.6	19
JT13	78.5	163.2	29.5	24
JT14	61.9	168.3	21.9	22
JT15	80.1	175.3	26.2	22
JT16	98.1	186.7	28.2	22
JT17	77.2	180.3	23.8	21
JT18	73.8	169.5	25.7	21
JT19	86.5	186.7	24.8	19
JT20	76.3	183.5	22.7	23
JT21	78.9	173.9	26.1	24
JT22	66.5	171.5	22.6	20
JT23	72.6	181.6	22.0	23
JT24	96.7	190.5	26.6	21
JT26	91.2	181.6	27.7	21
JT27	99.4	195.6	25.9	22
JT29	75.7	180.3	23.3	21
JT30	88.9	180.3	27.4	25
JT31	69.5	180.3	21.4	24
JT33	84.9	170.2	29.3	22
JT34	68.6	177.8	21.7	21
JT35	64.9	179.1	20.2	21
JT37	70.4	175.3	22.9	23
JT38	84.5	180.3	26.0	21
JT39	92.9	180.3	28.6	24
JT40	52.2	165.1	19.2	22
JT41	97.6	182.9	29.2	21
JT43	68.4	180.3	21.0	23
JT44	75.1	172.7	25.2	21

APPENDIX L

Participant Performance Data

ID	FMS 21-pt live	FMS 21-pt video	FMS 100-pt	CMJ mean (cm)
JT1	11	12	37	49.9
JT3	13	13	54	59.3
JT5	12	14	51	52.6
JT6	14	15	50	46.2
JT7	15	15	49	63.2
JT8	13	13	45	63.6
JT9	14	14	56	60.4
JT11	15	15	63	54.5
JT12	13	12	40	43.9
JT13	13	13	53	48.5
JT14	11	11	45	51.7
JT15	12	12	51	47.2
JT16	13	13	49	54.5
JT17	10	12	48	23.3
JT18	14	13	46	51.9
JT19	15	15	61	55.6
JT20	12	12	28	49.0
JT21	17	17	78	52.7
JT22	13	13	43	59.6
JT23	14	13	39	22.0
JT24	13	13	43	23.0
JT26	9	8	28	15.0
JT27	11	12	28	45.2
JT29	13	12	46	23.7
JT30	12	12	40	21.3
JT31	11	11	35	19.0
JT33	12	11	40	21.0
JT34	15	14	41	23.3
JT35	12	12	40	21.3
JT37	14	15	53	27.3
JT38	15	16	51	27.3
JT39	14	13	46	24.3
JT40	12	12	39	21.0
JT41	11	11	39	20.3
JT43	12	12	35	19.7
JT44	12	12	35	19.7