The Effect of a Dynamic Warm-Up on
Ankle Dorsiflexion and Overhead Squat Performance

A thesis submitted in partial fulfillment of the requirements
For the degree of Master of Science in Kinesiology

By
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Abstract

The Effect of a Dynamic Warm-Up on
Ankle Dorsiflexion and Overhead Squat Performance

By

Joshua Foster
Master of Science in Kinesiology

The purpose of this study was to first examine the effect of a dynamic warm-up (DWU) on both overhead squat (OHS) movement screen score and utilized ankle dorsiflexion (DF). Second, this study investigated the relationship between OHS movement screen scores and utilized ankle DF. Thirty-three university students, 21 males and 12 females, voluntarily participated in the project. Each subject attended two 60-minute testing sessions, one experimental (DWU) and one control condition (CON), approximately one week apart. Subjects’ OHS performance was scored according to Functional Movement Screen™ (FMS) grading criteria; utilized ankle DF was recorded using 3D Motion Analysis. Subjects were given two practice sets; the first, with standard FMS instruction and the second with knowledge of the grading criteria. These data were collected at two time points (pre and post intervention) in each session. Reliability was reported using Intraclass Correlation Coefficients (ICC). Intra-rater reliability was very good (ICC - 0.87) and inter-rater reliability was excellent (ICC - 0.98). ANOVA revealed significant differences in
subjects’ pre utilized ankle DF when categorized into groups based on OHS score (DWU – F(2, 30) = 4.89, p = 0.02; CON – F(2, 30) = 5.5, p = 0.01). Specifically, those differences lie between the highest (three) and lowest (one) scoring groups (DWU – p = 0.01; CON – p = 0.01). A significant proportion of subjects’ OHS Score improved, as compared to the control group (X² (1, N=41) = 11.4, p = 0.001). However, there were no main effects of group (F[1, 32] = 0.03, p = 0.86) or time (F[1, 32] = 0.13, p = 0.73) on utilized ankle DF. The researchers conclude that, within this sample, OHS Score is not a sensitive discriminator of utilized ankle DF and that some subjects’ scores would be more representative of their true movement capacity potential with the inclusion of a DWU. These results do not provide clear evidence as to what the OHS movement screen is assessing. Further research into validating this and additional movement screen component tests is warranted.
CHAPTER 1

INTRODUCTION

Movement screens are utilized as assessment tools to evaluate and quantify movement quality. Practitioners observe and grade subjects’ movement patterns according to established guidelines (Clark, Lucett, Corn, Capuccio, Humphrey, Kraus, Titchenal, & Robbins, 2004; Cook, 2010a). Movement screens have been widely researched using a variety of sport, exercise, and professional service populations (Butler, Contreras, Burton, Plisky, Goode, et al., 2013; Chorba, Chorba, Bouillon, Overmyer, & Landis, 2010; Cowen, 2010; Fox, O’Malley, & Blake, 2014; Frost, Tyson, Beach, Callaghan, & McGill, 2012; Kazman, Galecki, Lisman, Deuster, & O’Connor, 2014; Kiesel, Plisky, & Butler, 2011; Kiesel, Plisky, & Voight, 2007; Lisman, O’Connor, Deuster, & Knapik, 2013; Loudon, Parkerson-Mitchell, Hildebrand, & Teague, 2014; O’Connor, Deuster, Davis, Pappas, & Knapik, 2011; Okada, Huxel, & Nesser, 2011; Parchman & McBride, 2011; Perry & Koehle, 2013; Schneiders, Davidsson, Hörman, & Sullivan, 2011). Additionally, movement screens demonstrate good to excellent inter- and intra-rater reliability values (Elias, 2014; Gribble, Brigle, Pietrosimone, Pfile, & Webster, 2013; Minick et al., 2010; Onate et al., 2012; Shultz, Anderson, Matheson, Marcello, & Besier, 2013; Smith, Chimera, Wright, & Warren, 2013; Teyhen et al., 2012).

One common component test of multiple movement screens is the overhead squat (OHS). This may be due to Cook’s claim that the OHS simultaneously requires stability, mobility, and coordination to perform optimally (Cook et al., 2006a). Kinematic analysis of the utilized lower extremity hip, knee, and ankle ROM while performing the OHS (Butler, Plisky, Southers, Scoma, & Kiesel, 2010) corresponds with above average passive
joint ROM values (Moroz, 2013). Additionally, FMS composite score is closely correlated to the OHS component score (Kiesel, Plisky, & Butler, 2011).

According to Cook (2010a), movement screen scores are influenced by flexibility, ROM, strength, endurance, balance, and neuromuscular control. Aberrant movement patterns are believed to be indicative of specific strength deficiencies and/or mobility restrictions (Clark et al., 2004; Cook, 2010a). The process of identifying and treating aberrant movement patterns with corrective exercise interventions is believed to increase a person’s performance potential and reduce their risk of injury. This, however, is based primarily on anecdotal evidence. Despite widespread utilization and excellent reliability, research investigating movement screens has yet to provide cause-and-effect evidence between observed movement patterns and specific strength/mobility deficiencies. For example, although ankle DF ROM influences OHS performance (Dill, Begalle, Frank, Zinder, & Padua, 2014; Kasuyama, Sakamoto, & Nakazawa, 2009; Macrum, Bell, Boling, Lewek, & Padua, 2012), the score assigned, based on observed movement patterns, is not able to make an absolute diagnosis of ankle DF ROM (Maybry, 2008). Additionally, the claimed associations between performance potential, injury risk, and movement screen score has recently been refuted by several authors (Lockie et al., 2015a; Lockie et al., 2015b; Okada, Huxel, & Nesser, 2011; Parchman & McBride, 2011). This has led researchers to conclude that movement screens lack the capacity to diagnose specific deficiencies (Lockie et al., 2015b).

In preparing one’s body for physical activity, a period of warm-up effectively elevates both core temperature and heart rate (Shrier, 2008), improves range of motion (ROM) (Beedle & Mann, 2007; O’Sullivan, Murray, & Sainsbury, 2009), optimizes muscle
tissue compliance and/or stiffness (depending on the demands of the physical activity to follow), and potentiates upper and lower body maximal strength and power (Fletcher & Jones, 2004; Fradkin et al., 2010; Herman & Smith, 2008; Manoel et al., 2008; McMillian et al., 2006). DWU incorporates vigorous movements at gradually increasing intensities in preparation for the specific activity to follow. The use of DWU before physical activity is substantiated by a large body of evidence demonstrating a positive effect on performance and decreased risk of injury (Behm & Chaouachi, 2011; Fradkin, Zazryn, & Smoliga, 2010; Herman & Smith, 2008; Manoel, Harris-Love, Danoff, & Miller, 2008; McMillian, Moore, Hatler, & Taylor, 2006; Safran, William, & Garrett, 1988). Physiological and performance variables positively affected by DWU include increasing electromyographic activity (Behm & Chaouachi, 2011; Hough, Ross, & Howatson, 2009), maximal voluntary contraction (Herman & Smith, 2008), power (Manoel et al., 2008; Yamaguchi & Ishii, 2005), vertical jump height (Faigenbaum, Bellucci, Bernieri, Bakker & Hoorens, 2005; Hough et al., 2009), and decreasing sprint time (Fletcher & Jones, 2004; Herman & Smith, 2008). Similarly, improvements in lower extremity joint ROM have been observed following dynamic stretching (Beedle & Mann, 2007; O’Sullivan et al., 2009), which is commonly included as a component of DWU (Bishop & Middleton, 2013; Faigenbaum et al., 2005; Herman & Smith, 2008; McMillian, Moore, Hatler, & Taylor, 2006). Given these benefits, DWU is increasingly utilized in sport and fitness programming.

In addition to assessing in greater depth movement screens’ validity, the testing procedures should be verified. Although sport and exercise tasks are usually performed in a warmed-up state, a pre-test warm-up is not included when performing movement screens in general, nor the OHS specifically (Cook, 2006a). Given that a DWU can improve
performance (Faigenbaum et al., 2005; Fletcher & Jones, 2004; Fradkin et al., 2010; Herman & Smith, 2008; Hough et al., 2009; Manoel et al., 2008; McMillian et al., 2006; Yamaguchi & Ishii, 2005) and reduce the risk of injury (Beedle & Mann, 2007; O'Sullivan et al., 2009; Safran et al., 1988), and that screens are used to identify movement patterns which may limit performance or increase risk of injury while being physically active, perhaps a potential cause of movement screens lacking criterion validity in predicting sport performance variables may be due to the lack of warm-up in the testing procedures.

**Statement of the Problem**

The utilization of movement screens to quantify movement quality exceeds the research in support of its validity. As such, movement screen usage is based solely on anecdotal claims and clinical experience. Research does not support the claimed capacity of movement screens to predict performance potential and/or injury risk. Additionally, the purported relationships between observed aberrant movement patterns and strength deficiencies, mobility restrictions, and asymmetries are unsubstantiated by research evidence. As practice, speed, and load alter movement patterns, it is possible that a subject’s state of physical preparation may also affect movement patterns and, in turn, screen score. Therefore, it is necessary to evaluate the effect of a DWU on OHS screen score and utilized ankle DF, as well as to evaluate the relationship between OHS screen score and utilized ankle DF.
Hypotheses

Based upon the current literature, this study seeks to explore and respond to the following hypotheses:

1. Following a DWU, subjects’ OHS screen score will improve.
2. Following a DWU, subjects’ utilized ankle DF will increase (as recorded while performing the OHS).

Assumptions

1. The OHS is reliable across trials and that the raters’ scores will be reliable.
2. Subjects will follow instructions throughout the testing procedures and be coordinated and strong enough to perform the OHS and DWU.
3. The DWU protocol is safe and effective enough to thoroughly prepare the subjects to perform optimally.
4. The DWU protocol will not be overly demanding so as to exhaust the subject.
5. The testing instruments (Cortex Motion Analysis and Basler Digital Video Cameras) will accurately and reliably record the data.

Limitations

1. Improvements in OHS score may be due to motor learning. Efforts to control for this factor were taken by including practice sets and informing subjects of the grading criteria before data collection.

Delimitations

1. The primary delimitation of this study design is that the subjects will be predominantly young college students, which may have limited applicability to a general population. The researcher chose this particular sample because of the
ease to seek out participants who were willing to participate in the study, given its parameters.

2. Another delimitation has to do with the athletic background and prowess of the participants. Although the research may be able to advertise and attempt to screen for athletic types, it is very difficult to populate a sample – with similar athletic backgrounds and prowess – whose results can be extrapolated across the general population.

3. Another delimitation may be subjects’ footwear, as the level of elevation of the heel could result in different degrees of ankle DF while performing these exercises. Ideally, the researcher would be able to provide standard footwear for each of the participants, ensuring that this factor would not play a part in changing the outcome; however, the researcher did not have the resources available to provide these items for all participants.
CHAPTER 2
LITERATURE REVIEW

This chapter describes topics relevant to the research purposes of this thesis and is organized into the following sections: (1) movement screens, (2) the overhead squat (OHS), (3) movement screen reliability, (4) movement screen validity, (5) ankle DF & the effect on OHS performance, (6) motor learning & neuromuscular control, (7) practical impressions of movement screens, (8) warm-up, and (9) conclusion.

Movement Screens

Movement screens are used to observe movement patterns in controlled settings, which are believed to identify performance potential and injury risk in real time sport and exercise environments. Real-time motion analysis of these sport specific skills and movement patterns requires both highly sophisticated instruments and well-trained sport/exercise professionals. To be of value to professionals with less training, movement screen tests should be able to mimic the stability, mobility, and neuromuscular characteristics of the sport specific skills in which performance demand and injury risk is greatest. It is questionable whether this relationship does in fact exist as the current literature demonstrates that movement screens are poorly correlated to sport performance variables and movement screens’ ability to predict injury are questionable as well.

There are many types of movement screens utilized for professional purposes. Two prominent commercial movement screens are the National Academy of Sports Medicine™ (NASM) corrective exercise screen and the Functional Movement Screen™ (FMS). The NASM corrective exercise screen includes the overhead squat (OHS) and the single leg squat (SLS), and uses a simple algorithm to identify potential strength deficiencies,
mobility restrictions, and asymmetries based on observed aberrant movement patterns (Clark, 2004). For example, if the heels rise when performing the OHS, the algorithm suggests that the subject’s soleus is likely overactive and the anterior tibialis is underactive. Treatment recommendations include stretching the soleus and performing the SLS as a strengthening exercise. It is important to note that although the OHS and SLS have been researched, many of the NASM movement screen claims are unsubstantiated with valid research data. See Appendix 1 for the NASM OHS corrective exercise screen algorithm.

The FMS is a widely recognized and utilized commercial movement screen that includes seven exercises, each of which is given a score from zero to three (three being the best possible score) for a total of up to 21 points (Cook, 2006a). This movement screen is designed to be widely accessible to a variety of healthcare professionals including recreational activity instructors, tennis and golf professionals, outdoor activity instructors, sports and conditioning coaches, physical educators, health and safety instructors, dance instructors, yoga instructors, pilates instructors, personal trainers, massage therapists, strength coaches, athletic trainers, physical therapists, chiropractic physicians, and medical physicians (Cook, 2010a). The FMS has been utilized to assess injury risk, performance potential, corrective exercise effectiveness, normative data, and reliability in the following populations. See Table 1.
<table>
<thead>
<tr>
<th>Study</th>
<th>Population</th>
<th>Content/Context</th>
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<tbody>
<tr>
<td>Bushman et al., 2016</td>
<td>Military personnel</td>
<td>Injury risk</td>
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<tr>
<td>Butler et al., 2013</td>
<td>Firefighters</td>
<td>Injury risk</td>
</tr>
<tr>
<td>Chorba et al., 2010</td>
<td>College athletes</td>
<td>Injury risk</td>
</tr>
<tr>
<td>Cowen, 2010</td>
<td>Firefighters</td>
<td>Corrective exercise</td>
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<tr>
<td>Elias, 2014</td>
<td>Untrained raters</td>
<td>Inter-rater reliability</td>
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<tr>
<td>Fox et al., 2014</td>
<td>Novice athletes</td>
<td>Normative data</td>
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<td>Frohm et al., 2012</td>
<td>Physiotherapists</td>
<td>Reliability</td>
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<tr>
<td>Frost et al., 2013</td>
<td>Firefighters</td>
<td>Validity</td>
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<td>Corrective exercise</td>
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<td>Injury risk</td>
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Although the FMS and NASM are widely utilized, other movement screens include the Selective Functional Movement Assessment (SFMA), which is a considerably more detailed screen and contains 80 assessed movements (Cook, 2010b). This screen expands upon the FMS by evaluating movement patterns in those subjects presenting with
musculoskeletal pain. As opposed to the FMS, the SFMA is designed for use by licensed and certified healthcare professionals such as athletic trainers, physical therapists, chiropractic doctors, and medical physicians (Cook, 2010b).

Another movement screen is the Drop-Jump Test (Barber-Westin, Smith, Campbell, & Noyes, 2010; Noyes, Barber-Westin, Fleckenstein, Walsh, & West, 2005). This screen specifically observes movement of the knees in the frontal plane upon landing from the height of just below the subjects’ knees. With this assessment, decreased distance between subjects’ knees upon landing is correlated with increased risk of injury to the anterior cruciate ligament (Hewett, Myer, & Ford, 2006; Krosshaug et al., 2007). The Landing Errors Scoring System (LESS) has been developed from the Drop-Jump Test, and is more detailed in its assessment and measurement parameters (Padua et al., 2009). The LESS’s 17 movement patterns, specific to the lower extremity, are scored by video analysis in order to calculate potential injury risk due to landing, making it the most specific test of those described thus far.

**The Overhead Squat**

Many sport and exercise professionals work with limited injury and performance assessment resources. As such, time-efficient screening processes are of great value. However, they must return valid and reliable information about the subject. According to expert opinion (Cook, 2010a; Kritz, 2009; Schoenfeld, 2010), the body weight squat is a fundamental movement which simultaneously demands mobility of the ankle, hip, and thoracic spine as well as stability of the knee and lumbar spine. The OHS, a variation of a bodyweight squat, is a common component test among multiple movement screens, including FMS and NASM (Clark, 2004; Cook, Burton, & Hoogenboom, 2006a).
According to Cook, OHS performance and overall FMS performance are related. In his most recent publication on the FMS, Cook (2010a) states that a high score on the OHS “casts a long shadow” over the rest of the test and that similar scores can be expected in the other components. This anecdotal claim is supported by Kiesel et al. (2011) who reported, in a group of professional football players, subjects scoring a one on the OHS were approximately five times more likely (OR = 5.27, 95% CI = 1.49-18.65) to receive an overall FMS score of less than 14. According to Kiesel et al. (2007), a score of less than 14 on the FMS is believed to be associated with an increased risk of injury. This is based on analysis of their receiver-operator characteristic (ROC) curve and the corresponding specificity and sensitivity values which maximized true positives and minimized false positives. Other researchers have adopted the 14-point injury prediction cut-off score based on these statistics reported (Chorba, Chorba, Bouillon, Overmyer, & Landis, 2010), confirmed the same cut-off score with their own statistical analysis (Butler et al., 2013; Lisman, O’Connor, Deuster, & Knapik, 2013; O’Connor, Deuster, Davis, Pappas, & Knapik, 2011), or reported an injury prediction cut-off score of 17 (Peate, Bates, Lunda, Francis, & Bellamy, 2007).

Within a population of NCAA college athletes, Clifton, Grooms, and Onate (2015) found that OHS score was positively correlated with FMS score using a Spearman’s rho correlation statistic (ρ = 0.5, p < 0.001). Additionally, those subjects who scored a one on the OHS were 3.56 times more likely to score twelve or below (95% CI: p = 0.018) on the FMS (Clifton et al., 2015). According to these authors’ data, the OHS may be of use as a potential stand-alone movement screen.
Movement screen raters observe participants’ ability to meet the following criteria while performing the OHS (Cook, Burton, & Hoogenboom, 2006a):

1. upper torso parallel with tibia or toward vertical,
2. femur below horizontal,
3. knees aligned over feet,
4. dowel aligned over feet,
5. elbows straight, and
6. heels down.

Raters observe each subject and record a score between zero and three: three is designated when a subject performs the movement and meets all criteria; two is designated when a subject performs the movement with one compensation; one is designated when a subject performs the movement with multiple compensations; and zero is designated if the subject experiences any pain when performing the movement (Cook, Burton, & Hoogenboom, 2006a). Follow up with a medical professional is recommended when a subject receives a score of zero.

This particular exercise is often chosen within screens to highlight aberrant movement patterns due to the proposed strength, stability, mobility, coordination, and balance demands (Cook, 2010a). For example, the lower extremity joint mobility requirements to receive a three on the OHS component of the FMS are high (Butler et al., 2010) and correspond to above average passive joint ROM values (hip flexion – 121.1±2.0°; knee flexion – 130.7±3.8°; ankle dorsiflexion – 31.4±1.8°) as set forth in the Merck Physical Therapy Manual (hip flexion – 0-125°; knee flexion – 0-130°; ankle dorsiflexion – 0-20° [Moroz, 2013]). Furthermore, according to Cook, minor ankle DF or thoracic extension limitations are likely to result in an OHS score of two, and a score of one is due to these limitations as well as lack of hip flexion (Cook, 2006a). It is important
to note that these claims are based on clinical experience, not peer-reviewed scientific research.

**Movement Screen Reliability**

Determining the reliability of any analytic tool is critically important in scientific research (Stahly, Lohr, & Jones, 1950). Researchers have examined the reproducibility of certain movement screens’ results by assessing inter-rater and intra-rater reliability (Venturini, Ituassu, Teixeira, & Deus, 2006). With one exception, which will be discussed below (Shultz et al., 2013), the majority of reported FMS reliability values are within the good to excellent range. Inter-rater intraclass correlation coefficient (ICC) values of the FMS range between 0.38 and 0.91 (Elias, 2014; Minick et al., 2010; Schneiders, Davidsson, Hörman, & Sullivan, 2011; Onate et al., 2012; Schneiders et al., 2011; Shultz et al., 2013; Smith et al., 2013; Teyhen et al., 2012). Intra-rater ICC values of the FMS range between 0.6 and 0.92 (Gribble, Brilge, Pietrosimone, Pfile, & Webster, 2013; Onate et al., 2012; Shultz et al., 2013; Smith, Chimera, Wright, & Warren, 2013; Teyhen et al., 2012). Details regarding such data are included in Table 2, adapted from “The Functional Movement Screen: A Review” (Beardsley & Contreras, 2014).
Table 2

*Recent Reliability of FMS*

<table>
<thead>
<tr>
<th>Study</th>
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<th>Statistics</th>
<th>Intra-rater</th>
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<td>ICC</td>
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<tr>
<td>Schneiders et al., 2011</td>
<td>0.97</td>
<td>K_w</td>
<td>NA</td>
<td>NA</td>
</tr>
<tr>
<td>Shultz et al., 2013</td>
<td>0.38</td>
<td>K alpha</td>
<td>0.6</td>
<td>ICC</td>
</tr>
<tr>
<td>Smith et al., 2013</td>
<td>0.87 – 0.89</td>
<td>ICC</td>
<td>0.81 – 0.91</td>
<td>ICC</td>
</tr>
<tr>
<td>Teyhen et al., 2012</td>
<td>0.76</td>
<td>ICC</td>
<td>0.74</td>
<td>ICC</td>
</tr>
</tbody>
</table>

In a few of the studies cited in Table 2, component tests of the FMS were individually assessed for reliability. The OHS component test specifically has demonstrated moderate to excellent reliability. Inter-rater *ICC* values ranging between 0.68 – 1.00 (Schneiders et al., 2011; Teyhen et al., 2012) and weighted kappa (*k_w*) values of 0.64 – 1.00 (Minick et al., 2010; Onate et al., 2012) have been recorded for the OHS. Additionally, an intra-rater *ICC* value of 0.73 (Frohm, Heijne, Kowalski, Svensson, & Myklebust, 2012) and *k_w* values of 0.69 to 0.76 (Onate et al., 2012; Teyhen et al., 2012) have been reported for the OHS. Details regarding such data are included in Table 3 below.

Table 3

*Recent Reliability of the OHS*

<table>
<thead>
<tr>
<th>Study</th>
<th>Inter-rater</th>
<th>Statistics</th>
<th>Intra-rater</th>
<th>Statistics</th>
</tr>
</thead>
<tbody>
<tr>
<td>Frohm et al., 2012</td>
<td>N/A</td>
<td>N/A</td>
<td>0.73</td>
<td><em>ICC</em></td>
</tr>
<tr>
<td>Minick et al., 2010</td>
<td>0.64 – 1.00</td>
<td><em>K_w</em></td>
<td>N/A</td>
<td>N/A</td>
</tr>
<tr>
<td>Onate et al., 2012</td>
<td>1.0</td>
<td><em>K_w</em></td>
<td>0.69</td>
<td><em>K_w</em></td>
</tr>
<tr>
<td>Schneiders et al., 2011</td>
<td>1.0</td>
<td><em>ICC</em></td>
<td>N/A</td>
<td>N/A</td>
</tr>
<tr>
<td>Teyhen et al., 2012</td>
<td>0.68</td>
<td><em>ICC</em></td>
<td>0.76</td>
<td><em>K_w</em></td>
</tr>
</tbody>
</table>
In the majority of movement screen reliability studies, the raters share similar backgrounds with regards to education, profession, certification, and/or experience; however, a heterogeneous group of raters (one student, one physical therapist, two athletic trainers, and two strength and conditioning coaches) returned poor inter-rater reliability values—between 0.177 and 0.38 (Shultz et al., 2013). This sample of raters was intentionally chosen to assess inter-rater reliability across a varied group of raters.

A broad professional utilization of movement screens exists, and the varying levels of qualification and experience of those professionals both administering movement screens and prescribing corrective exercise should be noted. As this study utilized a diverse sample of raters, researchers and practitioners should be aware of the limitations of the reported movement screen reliability values with regards to heterogeneous groups of raters.

**Movement Screen Validity**

Both the FMS and NASM movement screens claim to identify both performance potential and injury risk factors by evaluating fundamental movement patterns. Observed aberrant movement patterns are anecdotally believed to be the result of mobility restrictions, strength deficiencies, and asymmetries (Cook, 2010a; Clark, 2004). These claims are based on professional clinical experience rather than peer reviewed, scientific research data. Since practical application often precedes scientific analysis of diagnostic tests, anecdotal evidence is often the only evidence available to clinicians and researchers. As a result, anecdotal evidence has helped frame numerous scientific investigations, but it is important to remember that anecdotal evidence is the lowest level of evidence. As such, researchers have begun to investigate the validity of the FMS and, specifically, the OHS component test.
Normative data

Given that significant performance differences exist between elite and non-elite athletes—such as maximal power output, strength, speed, agility, anaerobic threshold, and VO2max (Lorenz, Reiman, Lehecka, & Naylor, 2013)—movement screens, which claim to predict performance, should be able to detect differences between such groups. However, normative data on the FMS did not discriminate between various populations of physically active adults despite significant differences in performance capacity. For example, the mean score of a group of young, recreationally active adults (15.7+/1.9) was not significantly different than the average score of a population of elite male Gaelic field sport athletes (15.56+/1.46) or a group of recreational running athletes (15.4+/2.4) within similar age ranges (Fox et al., 2014; Loudon et al., 2014; Schneiders et al., 2011). Practitioners using the FMS could be led to assume that a variety of individuals share similar performance capacities and/or deficits, regardless of level of proficiency. As it currently stands, movement screen results may incorrectly identify recreational exercisers as elite athletes or vice versa. Thus, the FMS’s ability to identify performance potential is questionable.

Performance

Despite claiming an association between movement screen score and performance potential, researchers have reported weak correlations. Okada et al. (2011) investigated correlations between FMS score to validated performance tests such as backward overhead medicine ball throw (Stockbrugger & Haennel, 2001), t-run agility (Sporis, Jukic, Milanovic, & Vucetic, 2010), single leg squat (DiMattia, Livengood, Uhl, Mattacola, & Malone, 2005) and core stability (Nesser, Huxel, Tincher, & Okada, 2008; Tse, McManus,
& Masters, 2005) in recreationally-active adults. Moderate correlations were reported between FMS score and performance tests (correlation coefficient $[r] = -0.518$ to $0.415$). The OHS movement screen component score was weakly correlated with backward overhead medicine ball throw ($r = -0.229$), t-run agility ($r = 0.108$), and single leg squat ($r = -0.225$) performance tests. Despite significant correlations between core stability and performance tests, FMS scores were poorly correlated with core stability, measured by time to fatigue in trunk flexion and extension tests. Okada et al. (2011) concluded that performance of the FMS requires minimal core stability, which is contradictory to the anecdotal claims made by the creators of the FMS. Furthermore, movement screen component tests are novel tasks whose performance may be dependent upon coordination and motor control, rather than athletic ability and core stability.

In a sample of NCAA Division 1 golfers, Parchman and McBride (2011) assessed the correlation of lower extremity maximal strength (one repetition maximum back squat) and FMS score to various measures of performance (vertical jump, 10- and 20-meter sprint, agility t-test, and golf swing club speed). Strong correlations between performance tests and lower extremity maximal strength were reported:

1. Vertical jump height – $r = 0.869$
2. Sprint time
   a. 10m – $r = -0.812$
   b. 20-m – $r = -0.872$
3. Agility T-test – $r = -0.758$
4. Club head velocity – $r = 0.805$

However, FMS scores were poorly correlated to those same measures of performance:

1. Vertical jump height – $r = 0.249$
2. Sprint time
Lockie et al. (2015b) also reported poor to moderate correlations between measures of athletic performance and overall FMS and component scores. Specifically, OHS score exhibited poor to moderate correlations with:

1. Jump distance
   a. bilateral vertical jump – $r = 0.428$
   b. vertical jump left – $r = -0.12$
   c. vertical jump right – $r = -0.102$
   d. bilateral standing long jump – $r = 0.457$
   e. standing long jump left – $r = 0.287$
   f. standing long jump right – $r = 0.104$
   g. lateral jump left – $r = 0.41$
   h. lateral jump right – $r = 0.113$

2. Sprint time
   a. 0-5m – $r = -0.124$
   b. 0-10m – $r = -0.152$
   c. 0-20m – $r = -0.115$

3. Agility
   a. 505 left – $r = -0.017$
   b. 505 right – $r = -0.181$
   c. T-test left – $r = -0.276$
   d. T-test right – $r = -0.246$

This led the authors to conclude that individual movement dysfunctions cannot be reliably identified using the FMS and that strength and conditioning professionals would be better served using a lower extremity maximal strength test to assess subjects’ performance rather
than the FMS. These results demonstrate that the FMS is not a strong indicator of general athletic or skill-specific performance.

Additionally, athletic performance and injury often involves movement at high velocity, with high ground reaction forces, some degree of physiological fatigue, and/or external loading, whereas movement screen component tests are performed slowly and with no external load. Frost et al. (2015) demonstrated high variability of whole body functional movement patterns (lift from the ground to waist height, bodyweight squat, lunge, cable press with the right arm, and cable pull with the right arm) in response to increased velocity and load demands. This suggests that movement screens performed slowly and with no external load are potentially not indicative of movement patterns as task demands increase. Physical capacity tests such as upper- and lower-extremity maximal strength, vertical/horizontal jump, sprint, and agility are performed under conditions as would be found in athletic performance environments. Therefore, these tests may be more valuable and accurate assessments of subjects’ performance movement patterns than movement screens.

**Gender.** Performance capacity and injury risk varies between men and women. Researchers believe that these differences may be due to movement pattern and muscle activation differences between genders when performing sport specific tasks such as running/cutting (Hanson, Padua, Blackburn, Prentice, & Hirth, 2008; Malinzak, Colby, Kirkendall, Yu, & Garrett, 2001), jumping (Padua et al., 2009), and squatting (Mauntel, Post, Padua, & Bell, 2015). Proposed causes of increased risk of injury in males vs. females in the above listed activities include greater hip adduction angle, knee valgus angle, and ankle DF angle (Malinzak et al., 2001; Mauntel et al., 2015; Padua et al.,
2009), as well as greater quadriceps to hamstring activation ratios (Hanson et al., 2008; Malinzak et al., 2001). Movement screen scores are based on the presence or absence of these movement patterns.

Many of the studies evaluating movement screens, however, have utilized either male only (Fox, O’Malley, & Blake, 2014; Frohm et al., 2012; Frost, Tyson, Beach, Callaghan, & McGill, 2012) or mixed gender samples (Butler, Plisky, Southers, Scoma, & Kiesel, 2010; Gribble, Prigle, Pietrosimone, Pfile, & Webster, 2013; Klusemann, Fay, Pyne, & Drinkwater, 2011). Other studies have not specified gender in the sample demographics (Butler et al., 2013; Lisman, O’Connor, Deuster, & Knapik, 2013). The author is aware of two researchers who have investigated the relationship between FMS score and gender. Schneiders et al. (2011) reported insignificant differences in FMS score ($p = 0.329$) between genders in a population of young, active adults, whereas Udris (2013) positively identified significant differences in FMS scores between genders ($p = 0.001$) in a population of collegiate cheerleaders.

As such, recent research has been conducted to independently evaluate the relationship between performance potential and injury risk with FMS score in samples of women only. Lockie et al. (2015a) investigated the correlations between overall and component FMS scores with flexibility, linear speed, change-of-direction speed, and leg power, in nine female athletes. Subjects’ flexibility, assessed by bilateral and unilateral sit-and-reach, was well correlated with overall FMS score ($r = 0.698$), left active straight leg raise ($r = 0.725$), and left in-line lunge ($r = 0.704$). However, linear speed ($r = -0.227$ to $-0.050$), agility ($r = -0.274$ to $0.555$), and jumping ($r = -0.542$ to $0.359$) exhibited poor-to-moderate correlations with FMS overall score. While the FMS may serve as a good
indicator of lower extremity flexibility in female athletes, it is not an effective indicator for many other measures of performance, as listed above, within both mixed, male-only, and female-only sample populations (Lockie et al., 2015a).

**Injury risk factors**

According to multiple authors, movement screens may be of value for their ability to predict future injury (Butler et al., 2013; Chorba et al., 2010; Kiesel, Plisky, & Voight, 2007; Lisman et al., 2013; O’Connor et al., 2011; Peate et al., 2007). The primary factors believed to increase risk of injury include (a) mobility restrictions, (b) strength deficiencies, and (c) asymmetries (Clark, 2004; Cook, 2010a).

**Mobility restrictions.** Muscle flexibility is a potential risk factor for physical activity injuries. Witvrouw, Danneels, Asselman, D’Have, and Cambier (2003) examined the incidence of lower extremity injury in professional soccer players and its relationship to muscle flexibility. The athletes who sustained musculoskeletal injuries to the hamstrings (N = 31; p = 0.02) and quadriceps (N = 13; p = 0.05) exhibited significantly lower ROM in hip and knee flexion before their injury than those subjects who remained uninjured throughout the competitive season.

The significance of hamstring flexibility on injury risk in military trainees was examined by Hartig and Henderson (1999). At the beginning of a 13-week basic training course, trainees were assigned to either a control (N = 148) or an intervention company (N = 150). Both companies performed the basic training fitness routine, which included hamstring stretching once daily in the morning before physical training. The intervention company included three additional daily hamstring stretching sessions before lunch, dinner, and bedtime. The researchers reported significantly fewer lower extremity overuse
injuries and increased hamstring flexibility (25 injuries, 16.7% incidence rate, +7° passive knee extension) compared to the standard basic training (43 injuries, 29.1% incidence rate, +3° passive knee extension). The difference in injuries ($p = 0.02$) and hamstring flexibility improvement ($p < 0.001$) between the two companies were both significant. A hamstring stretching program was an important factor in reducing lower extremity overuse injuries in army recruits. This research provides insight not only into lower extremity injury risk factors but also potential interventions to reduce risk of injury.

Research on the relationship between ROM and overall/component movement screen scores is limited. There is evidence to suggest that FMS score is correlated to measures of lower body flexibility. As mentioned in the previous section, adult female team sport athletes’ sit-and-reach performance was well correlated with overall score ($r = 0.698$), active straight leg raise (left – $r = 0.725$; right – $r = 0.598$) and left leg in-line lunge ($r = 0.704$) component tests of the FMS (Lockie et al., 2015a). Additionally, male junior basketball players’ (ages 14-17) sit and reach test was moderately correlated with the active straight leg raise ($r = 0.50$) component test of the FMS (Klusemann, Fay, Pyne, & Drinkwater, 2011). However, the other component tests in both of the aforementioned research studies were either poorly correlated with measures of flexibility (OHS [$r = 0.183-0.274$], right hurdle step [$r = 0.335-0.383$], right in-line lunge [$r = 0.413-0.456$], right straight leg raise [$r = 0.52-0.598$], trunk stability push-up [$r = 0.116-0.231$], rotary stability [$r = 0.275-0.456$]) (Lockie et al., 2015a) or were not directly reported (Klusemann, Fay, Pyne, & Drinkwater, 2011).

Research on the relationship between ROM and overall and component movement screen scores is limited. With regards to the relationship between overall or component
movement screen scores and various measures of flexibility, correlation does not imply causation. In other words, identifying statistically significant correlations is very different than, and does not directly support, the claim that mobility restrictions directly influence movement screen scores. Corrective exercise intervention strategies, which are included in movement screen procedures to rectify observed aberrant movement patterns, are not substantiated in the research literature. In fact, corrective exercises designed to improve ROM may not necessarily affect dynamic movements such as those seen in movement screen assessments. Moreside and McGill (2013) found that utilized hip ROM in dynamic movements (active standing hip extension, lunge, standing twist/reach, and riding an elliptical trainer) was unchanged, despite significant improvement in subjects’ passive hip range of motion with stretching and core endurance training. Additional investigation is needed to clearly identify the nature of the relationship between overall and component movement screen scores with mobility restrictions.

Mobility restrictions may also be a contributing factor to certain chronic pain conditions. Decreased range of motion is related specifically to the prevalence of patellofemoral pain syndrome (PFPS). Piva, Goodnite, and Childs (2005) compared lower extremity soft tissue length between 30 patients with PFPS and 30 gender- and age-matched controls. Significantly decreased range of motion of the quadriceps \( p < 0.001 \), hamstrings \( p < 0.001 \), gastrocnemius \( p < 0.001 \), and soleus \( p < 0.001 \) was reported in the patients with PFPS compared to the controls.

The system of assigning subjects a score between zero and three for each component test which are added together to give a composite score, may be overcomplicating the process of identifying subjects at greater risk of injury. Kodesh,
Shargal, Kislev-Cohen, Funk, Dorfman and colleagues (2015) identified no significant differences in total FMS score between groups of injured (16, inter-quartile range; 12.75-18) and non-injured (16, inter-quartile range; 13.25-17) female soldiers undergoing a combat fitness course. However, more zero scores, which are given when a subject experiences pain while performing the FMS, were found in the injured than the non-injured group (51.35 % vs. 30.5%; \( p = 0.03 \)). The researchers suggest that although total FMS score is not a significant predictor of injury, a score of zero on any component test may serve as an early warning for increased risk of injury.

Bushman, Grier, Canham-Chervak, Anderson, North, and Jones (2015) also reported a significant association between an increased risk of injury and a score of zero on FMS component tests—including OHS \(( p < 0.01 )\), hurdle step \(( p < 0.01 )\), inline lunge \(( p < 0.01 )\), trunk stability push-up \(( p < 0.01 )\), and rotary stability \(( p = 0.03 )\)—despite poor injury prediction ability of the total FMS score. Whereas simply screening for pain when performing specific movements is an effective method to evaluate injury risk based on the results of the two aforementioned research studies, low composite FMS scores may mistakenly direct prevention and treatment efforts toward individuals who are not actually at greater risk for injury. Therefore, the researchers advise caution when implementing the FMS as a screening tool for injury risk.

**Strength deficiencies.** Strength deficiencies have been linked to a number of non-contact lower extremity injuries and chronic pain conditions. PFPS, for example, is associated with hip abduction strength deficiencies in women, ranging from 14% (Souza & Powers, 2009) to 40% (Moradi, Akbari, Ansari, Emrani, & Mohammadi, 2014) as compared to asymptomatic control subjects. Interestingly, male subjects with
patellofemoral pain syndrome displayed no significant differences in hip strength \((p > 0.05)\), but a 17\% decrease in peak isometric force of the knee extensors (Bolglia, Earl-Boehm, Emery, Hamstra-Wright, & Ferber, 2015). Although gender strength discrepancies exist, they are not accounted for when interpreting the generalized results of movement screens.

Injury to the anterior cruciate ligament (ACL), which is a very serious and costly injury (Griffin et al., 2000), often occurs in non-contact situations in which dynamic movements exceed the capacity of the lower extremity to safely dissipate the associated forces and torques. Specifically, knee valgus and internal rotation moments strain the ACL (Shin, Chaudhari, & Andriacchi, 2011), potentially resulting in injury. Concentric hip abduction \((r^2 = 0.13, p < 0.05)\), knee extension \((r^2 = 0.18, p < 0.05)\), and knee flexion \((r^2 = 0.14, p < 0.001)\) peak torques—measured isokinetically at 60\°/second—have been reported as significant predictors of knee valgus when performing a single leg squat in a population of adults evenly distributed between genders (Claiborne, Armstrong, Gandhi, & Pincivero, 2006). In both the FMS and NASM movement screen assessment procedures, medial and lateral knee displacement are two of the aberrant movement patterns that raters are trained to identify.

According to the FMS/NASM models, these deficiencies would then be addressed with corrective exercise to strengthen the presumably weak hip abductors and thigh musculature (Clark, 2004; Cook, 2010a). However, when observing subjects perform bilateral bodyweight squats, Padua, Bell, and Clark (2012) reported significantly increased activation amplitude in the hip adductors with no statistically significant difference in activation amplitude in either the gluteus medius or maximus when comparing subjects
with and without knee valgus. These findings suggest that knee valgus, one of the observable aberrant movement patterns when performing the OHS, may also be caused by a variation in abduction and adduction activation amplitudes. This potential cause of aberrant movement patterns is not addressed by current corrective exercise interventions.

**Asymmetries.** In Cook’s (2010a) most recent publication detailing the FMS, he advises identifying and managing asymmetries using the FMS because of their relation to increased risk of injury. There is evidence to support the relationship between asymmetry with lower extremity injury in athletic populations. Baumhauer, Alosa, Renstrom, Trevino, and Beynnon (1995) examined asymmetry related ankle injury risk factors within a sample of 145 collegiate athletes. In comparing athletes who experienced inversion ankle sprains with uninjured athletes, the researchers identified significantly greater eversion-to-inversion strength ratios (injured – 1.0; uninjured – 0.8; \( p < 0.04 \)) and subtalar eversion ROM (injured – 8.7\(^\circ\)±2.7\(^\circ\); uninjured – 7.22\(^\circ\)±2.6\(^\circ\); \( p = 0.04 \)). Within-subject analysis of the athletes that sustained an ankle injury identified significantly greater plantar flexion torque (injured – 72.2±23.3 ft-lbs; uninjured – 69.33±19.26 ft-lbs; \( p = 0.03 \)), subtalar inversion ROM (injured – 20.3\(^\circ\)±4.1\(^\circ\); uninjured – 19\(^\circ\)±3.4\(^\circ\); \( p =0.03 \)), dorsiflexion-to-plantarflexion strength ratios (injured – 0.37; uninjured – 0.35; \( p = 0.03 \)), and anatomic eversion-to-inversion ratio (injured – 0.48; uninjured – 0.42; \( p = 0.03 \)) in the injured ankle as compared to the contralateral uninjured ankle.

Ankle injuries can lead to chronic ankle instability (CAI), which often results in reinjury and reduced functional capacity (Anandacoomarasamy & Barnsley, 2005). CAI can be assessed with a number of assessment tools, one of which is the Foot and Ankle...
Disability Index (FADI). The FADI reliably detects functional limitations in patients with CAI and is able to distinguish between healthy subjects and those with CAI (Hale & Hertel, 2005). Movement screen scores, which are based on observable aberrant movement patterns, are also used to identify movement deficiencies (e.g. ankle DF ROM), which may contribute to conditions such as CAI. Choi and Shin (2015) assessed the ability of the lower extremity FMS (OHS, hurdle step, and in-line lunge) scores to distinguish between subjects with and without unilateral CAI. Hurdle step \( p < 0.05 \) and in-line lunge \( p < 0.05 \) were significantly different between the two groups. However, the OHS \( p > 0.05 \) was not. Although the unilateral component tests of the lower extremity FMS are able to effectively distinguish subjects with and without unilateral CAI, the bilateral OHS component test does not. This is notable, considering Cook (2010a) claims that the OHS is representative of overall FMS score and that scores below three are likely the result of minor ankle DF limitations (Cook, 2006a).

Knapik, Bauman, Jones, Harris, and Vaughan (1991) identified statistically significant differences between the right and left sides in hip extension flexibility (chi square, 11.2; \( p < 0.001 \)), knee flexion strength measured at 180°/sec (chi square, 7.9; \( p = 0.04 \)), and the ratio between knee flexion and knee extension strength also measured at 180°/sec (chi square, 9.0; \( p = 0.03 \)) in a population of female collegiate athletes who sustained one or more injuries over a one year period (Knapik, Bauman, Jones, Harris, & Vaughn, 1991). Of the 55 total injuries reported, 44 affected the lower extremity and 11 affected the upper extremity. Further statistical analysis revealed that more injuries occurred if the right leg exceeded the left leg by 15% or more in hip extension flexibility (chi square, 10.71; \( p < 0.001 \)) or in knee flexion strength (chi square, 9.5; \( p = 0.005 \)).
More recently Nadler, Malanga, DePrince, Stitik, and Feinberg (2000) reported significant differences in maximum hip extension strength ($p = 0.02$) using a hand-held dynamometer between female collegiate athletes with and without self-reported lower extremity injury within the previous year. This was associated with a bilateral asymmetry of 10.9% greater left maximum hip extension strength. Furthermore, those subjects who reported low back pain during the pre-participation screening physicals exhibited 15% greater left maximum hip extension strength. Neither of the two research studies presented above included descriptive statistics as to the leg dominance of their subjects. As such, it is difficult to consolidate the discrepancy between side of asymmetry and its relation to injury. However, asymmetry is clearly a significant factor with regards to injury.

Of the seven component FMS tests, five are performed separately on the right and left side (hurdle step, in-line lunge, active straight leg raise, shoulder mobility, and rotary stability). In assessing collegiate athletes, Warren, Smith, and Chimera (2015) found no statistically significant associations between asymmetry in any of the five unilateral component tests listed above and non-contact injuries sustained over the course of the competitive season (hurdle step [$p = 0.58$], in-line lunge [$p = 0.09$], active straight leg raise [$p = 0.43$], shoulder mobility [$p = 0.74$], rotary stability [$p = 0.46$]). Within this population, the five unilateral FMS component tests were not valid predictors of injury risk based on asymmetry.

*Previous injury*

Furthermore, previous injury has been reported as a statistically significant predictor of future injury (Brockett, Morgan, & Proske, 2004; Dvorak et al., 2000; Ryan, DeBurca, & Mc Creesh, 2014; Venturelli et al., 2011). For example, in a sample of amateur
soccer athletes, players who had sustained two or more injuries within the previous 12 months were 32% more likely to incur an injury over the following two seasons than those who had no previous injuries (Chalmers, Samaranayaka, & McNoe, 2013).

Movement screens, which are designed to observe movement patterns that may result in future injury, (Cook, 2010a) are unable to differentiate between previously injured and uninjured subjects. Statistical analysis of normative movement screen data in college athletes (Warren, Smith, & Chimera, 2015), recreational runners (Loudon et al., 2014), and active young adults (Schneiders et al., 2011) showed no significant differences between those with and without current/previous injury. Additionally, Chorba et al. (2010) recorded similar average movement screen scores when including (14.3+/−1.77) and excluding (14.0+/−1.76) those subjects with a previously reconstructed ACL in a sample of female collegiate athletes. Given that previous injury is a statistically significant predictor of future injury risk and current movement screen evaluations cannot distinguish between previously injured and uninjured subjects, their ability to predict future injury is questionable.

Predict injury risk

Another area of concern is the costly nature of injury. This factor has led to the development of movement screens for the purposes of identifying risk of injury such that it could be prevented. As a result, researchers have investigated the ability of movement screen score/performance to predict future sport and exercise injuries. A systematic review and meta-analysis was conducted by Dorrel et al. (2015) to report the ability of FMS score to predict future injury. The researchers included seven articles, which assessed the predictive validity of the FMS. The statistics reported in this review
included specificity, sensitivity, and area under the curve (AUC). Specificity is the ability of a test to accurately classify those subjects who score above the cut score and do not sustain injury. Average specificity amongst the studies included in this meta-analysis was good (0.85; 95% CI, 0.77-0.91). However, average sensitivity, which is the ability of a test to accurately classify those study subjects who scored on or below the cut score and sustain injury, was poor (0.24; 95% CI, 0.15-0.36). This data suggests that the capacity of the FMS to positively identify those at greater risk for injury is poor. The high specificity and low sensitivity suggests that the FMS may be more effective at clearing subjects than identifying those with movement patterns which are associated with increased risk of injury. Furthermore, AUC, which is the ability of the test to accurately discriminate between those at risk and not at risk of injury, was determined to be 0.58 (95% CI, 0.42-0.77). The authors note that this discriminative capacity is only slightly better than chance (Dorrel, Long, Shaffer, & Myer, 2015). Clinicians using the FMS should be aware of the implications of this data as it illustrates significant limitations of movement screens’ predictive capacity.

Whereas researchers have investigated the predictive validity of overall movement screen score, the association between specific strength deficiencies, mobility restrictions, and asymmetries to individual component test scores has not been thoroughly evaluated. The only research found by the author in this regard was conducted by Maybry (2008), which investigated the ability of the OHS score to identify subjects’ passive and active ankle DF ROM. These parameters were measured in a seated position by goniometer. High and low ankle DF ROM was distinguished using a cut off score of 10°. Maybry noted, “a high sensitivity rate
would show that the movement screens were able to identify those with low flexibility” (2008, p. 7). Out of 29 participants whose ankle DF ROM was less than 10°, 22 (76%) received a score of one or two. However, seven subjects (24%) received a score of three, which incorrectly identified them as having above average ankle DF ROM. Maybry also noted “[a] specificity of 100% would show that movement screens recognize all people with good flexibility based on their test score” (2008, p. 7). Of the 31 participants whose ankle DF ROM was greater than 10°, 18 (58%) were given a score of three. Thirteen subjects (42%) received a score of one or two, which incorrectly identified them as having below average ankle DF ROM. In this study, sensitivity and specificity values indicated that OHS scores incorrectly identified a portion of subjects’ ankle DF. Less experienced exercise professionals who utilize the OHS score as the primary method of screening for mobility restrictions, including ankle DF, may unnecessarily prescribe corrective exercise treatments and/or medical follow-ups to clients.

**Improvement in movement screen score performance**

Longitudinal corrective exercise intervention studies have demonstrated the ability to positively influence movement screen scores (Cowen, 2010; Frost et al., 2012; Kiesel et al., 2011). A valid movement screen should reflect the ability for corrective exercise interventions to positively influence movement screen scores following initial assessment (Beardsley & Contreras, 2014). This is of particular value to clinicians whose goal, through the use of movement screens, is to identify and rectify aberrant movement patterns to reduce risk of injury and/or increase performance potential.

Over the course of six weeks, Cowen (2010) reported significant FMS score improvements (pre-FMS score = 13.3±2.3; post-FMS score = 16.5±2.2; \( p = 0.000 \)) in a
population of firefighters using on-site yoga classes as the corrective exercise intervention. Of the 108 participants, 88 had no prior experience with yoga and only 77 participants completed the follow-up testing. The author concluded that yoga has the ability to improve overall FMS scores in a population of firefighters; however, in this study there was no control group and the average number of yoga classes attended by the subjects over the six-week period was four. The possibility of additional factors contributing to the significant improvements in follow-up testing performance should be considered when interpreting the results of this study.

Kiesel et al. (2011) reported improvements in FMS score within a population of professional football players. The athletes were required to attend four weekly sessions, which included stretching, trigger point treatment, and corrective exercises, for seven weeks. At the end of the intervention, FMS scores improved significantly for linemen (pre = 11.8±1.8; post = 14.8±2.4; \( p < 0.01 \)) and non-lineman (pre = 13.3±1.9; post = 16.3±2.4; \( p < 0.01 \)). As with the previous study by Cowen (2010), Kiesel et al. (2011) did not include a control group to measure the intervention group’s screen score improvements against. This limits the validity of the researchers’ results.

General off-season training or familiarization with the tested movements might also contribute to the observed movement screen performance improvements (Hopkins, Schabort, & Hawley, 2001). Sprague et al. (2014) recorded pre- and post-season FMS scores in a population of NCAA women’s volleyball, and men’s and women’s soccer athletes. The unique aspect of this study is that the authors did not intervene with corrective exercise or stretching protocols. Although overall FMS score was not significantly different (\( p = 0.158 \)), both the OHS (\( p = 0.001 \)) and in-line lunge (\( p < 0.001 \)) scores were
significantly increased while the active straight leg raise \( (p = 0.013) \) and rotary stability \( (p = 0.011) \) scores were significantly decreased. Additionally, fewer players received a score of one \( (X^2 = 26.148; p < 0.001) \) and less asymmetries were recorded \( (X^2 = 4.258; p = 0.039) \) at the end of the season. In this population, fundamental movement patterns, as displayed in FMS component test scores, vary over the course of a competitive season and factors other than corrective exercise are likely contributing to the observed changes in component screen scores. The extent to which these factors also contributed to the reported improvements in FMS score in the previously discussed studies is unknown.

According to this researcher’s knowledge, Frost et al. (2012) conducted the only movement screen based corrective exercise intervention study to include a control group. Inconsistent results were reported following a 12-week corrective exercise intervention, which included two experimental groups and one control group. The first experimental group’s corrective exercise intervention emphasized mobility and neuromuscular control training. The second experimental group’s corrective exercise intervention emphasized maximizing performance and fitness outcomes at the expense of individual-specific movement quality feedback. In response to the corrective exercise intervention, no significant improvements were reported in total FMS score \( (p > 0.176) \). However, out of 60 subjects, 26 participants improved their score, 17 decreased, and 17 remained the same. Within the control group of 20 subjects, eight improved and nine decreased their scores. Only three control subjects’ scores remained the same. The authors conclude that group mean scores are not necessarily representative of a participant’s individual overall FMS score (Frost et al., 2012). The results of both Frost et al. (2012) and Sprague et al. (2014) show significant variability of movement screen scores without specific corrective exercise
interventions, which suggests that movement screen scores are not in all instances representative of a subject’s absolute physical capacity. Rather, it is reflective of one’s performance at a given point in time and may be subject to change based on various factors. This may be said for all movements, not just those specific to movement screens.

**Ankle DF & the Effect on OHS Performance**

*Assessment*

Certain aberrant movement patterns are used to identify ankle mobility restrictions when performing the OHS screen. Raters observe subjects from the anterior, posterior, and lateral positions. External rotation of the foot, heel lift, or excessive forward lean are identified as indicators of potential ankle DF ROM deficiencies within the NASM corrective exercise screen OHS solutions table (Clark, 2004). Furthermore, Cook claims an OHS score of two is likely the result of minor ankle DF or thoracic extension limitations and a score of one is due to gross limitations with the motions just mentioned as well as hip flexion (Cook, 2006a). These claims are based on clinical experience, not peer-reviewed scientific research.

Ankle DF ROM is typically measured either passively in a non-weight bearing position or in a weight-bearing lunge (WBL) (Bennell, Talbot, Wajswelner, Techovanich, Kelly, & Hall, 1998; Dill, Begalle, Frank, Zinder, & Padua, 2014; Konor, Morton, Eckerson, & Grindstaff, 2012). To measure ankle DF ROM passively, the clinician moves the foot into maximal ankle DF and records the angle between the foot and shank segments (see Figure 1).
To measure ankle DF ROM in a WBL, the subject assumes a kneeling lunge and pushes the front knee forward as far as possible while keeping the front heel down. The clinician then records the angle between the foot and shank segments (see Figure 2). A goniometer is typically used to measure ankle DF passively, whereas a goniometer, inclinometer, or three-dimensional motion analysis may be used to measure ankle DF in a WBL.
Reliability

Although both methods are reliable means of assessing ankle DF ROM (Bennell et al., 1998; Konor et al., 2012; Venturini, Ituassu, Teixeira, & Deus, 2006), the WBL has been shown to be more reliable (ICC=0.93-0.96) than passive assessments (ICC=0.32-0.72) for ankle DF ROM (Venturini et al., 2006). As the applied torque is greater than in passive measurement methods, the WBL may provide a more accurate representation of available ankle DF ROM during weight-bearing activities (Bennell et al., 1998). Clinicians should be aware of the limitations of passive ankle DF measurements when interpreting the results of previous research utilizing these methods. Additionally, the increased torque in a WBL may be similar to the torque experienced at the ankle when performing closed-chain movements such as the OHS. If the OHS is indeed an accurate predictor of ankle DF ROM, the WBL and OHS ankle DF angles should be similar. This correlation has yet to be investigated.
Validity

The ability of a score or observed aberrant movement patterns when performing the OHS component of movement screens to predict ankle DF ROM has not been validated. There is, however, scientific evidence to support ankle DF ROM as an influential factor in performance of squatting movement patterns. Dill et al. (2014) categorized physically active young adults into two groups based on ankle DF ROM (limited ankle DF – passive ≤ 5°, WBL ≤ 44.01°; normal ankle DF – passive ≥ 15°, WBL ≥ 44.02°) and reported lower extremity kinematics when performing the OHS. No significant differences in lower extremity kinematic joint variables were observed between the groups when categorized using the passive ankle DF assessment. However, when categorizing subjects into limited and normal ankle DF ROM groups using the WBL, the limited ankle DF ROM group displayed significantly lower peak knee flexion (mean difference, 15.26°; \( p = 0.001 \)), knee flexion displacement (mean difference, 14.94°; \( p = 0.001 \)), and ankle DF displacement (mean difference, 7.89°; \( p < 0.001 \)) when performing the OHS (Dill et al., 2014). Again, the greater torques while assessing ankle DF ROM in a WBL may more accurately relate to movement screens such as the OHS.

Macrum et al. (2012) also demonstrated the influence of ankle DF ROM on lower extremity kinematics when performing the OHS by placing a 12° wedge under each subjects’ forefoot, effectively limiting ankle plantarflexion ROM. This allowed the researchers to observe acute changes in squatting patterns between two conditions; with and without intentionally restricted ankle DF. Over seven trials, the forefoot wedge resulted in significantly decreased peak knee flexion (\( p < 0.001 \)) and knee flexion excursion (\( p < 0.001 \)) with significantly increased peak ankle DF (\( p = 0.006 \)), ankle DF excursion (\( p < 0.001 \))
peak knee valgus angle \((p = 0.02)\), and medial knee displacement \((p < 0.001)\) as compared to the no wedge condition (Macrum, Bell, Boling, Lewek, & Padua, 2012). Both knee valgus angle and medial knee displacement are identifiable aberrant movement patterns which influence a subject’s OHS score.

Kasuyama et al. (2009) also identified ankle DF ROM as an intrinsic factor associated with the ability to assume a deep squatting posture. Subjects were asked to squat as deeply as possible with the heels down until the thigh and calf were in contact with each other and maintain this position for at least five seconds. From this performance, the researchers separated subjects into two groups; those who were able to attain this position (possible squatting) and those who did not (impossible squatting). Lower extremity joint ROM was determined using a number of clinical assessment tests including straight-leg raise for hip flexion, heel-buttock distance for knee flexion, modified Thomas test for hip and pelvis flexibility, finger-floor distance for trunk flexion, and WBL for ankle DF ROM. In this population, ankle DF ROM was a statistically significant \((p < 0.001)\) discriminator between the possible and impossible squatting groups (Kasuyama, Sakamoto, & Nakazawa, 2009). All of the above researchers’ results lend support to the significant influence of ankle DF ROM to squatting performance. A common limitation amongst these studies is the lack of a direct comparison between ankle DF ROM to OHS score. This relation is suggested but not yet substantiated.

Butler et al. (2010) recorded lower extremity kinematics when performing the OHS using motion analysis and reported the results as the averages within each group of movement screen scores according to the FMS criteria. Recorded average peak utilized ankle DF joint angles were \(24.5 \pm 2.3^\circ\) (SEM) in those subjects scoring a one, \(27.9 \pm 2.6^\circ\)
(SEM) in those subjects scoring a two, and $31.4 \pm 1.8^\circ$ (SEM) in those subjects scoring a three. From a score of one to two, an increase in utilized peak ankle DF of $3.4^\circ$ (13.8%) corresponds with an increase of $26.3^\circ$ (31%) in utilized peak knee flexion and an increase of $28.7^\circ$ (32.3%) in utilized peak hip flexion. Although this relationship does not imply causation, it lends support to the previous researchers’ findings that ankle DF ROM may be an influential factor in lower extremity joint kinematics when performing the OHS.

Moseley, Crosbie, and Adams (2003) identified significantly altered motor control strategies between two groups of subjects (flexible and inflexible ankle DF) when performing a stair descent. The group of subjects with inflexible ankles lifted heels earlier (at 57% stance phase) than those subjects with flexible ankles (who lifted at 71% stance phase). Additionally, the inflexible ankle group shifted their center of pressure more anteriorly. Considering motor control strategies differ between flexible and inflexible ankles (Moseley et al., 2003), and lower extremity kinematic differences exist when performing the OHS between higher and lower ankle DF (Butler et al., 2010), it is possible that individual motor control strategies, and the associated observable aberrant movement patterns when performing movement screens, may be affected by or the result of strength deficiencies and mobility restrictions.

**Motor Learning and Neuromuscular Control**

Performance of physical tasks is governed by characteristics such as mobility, stability, strength, and endurance as well as neuromuscular factors such as motor control and learning. Although numerous intervention studies have demonstrated positive effects of multifaceted (strength and neuromuscular control) training programs on improving jump-landing mechanics, such as ground reaction forces, hip abduction angle, hip/knee
flexion angles, and knee/ankle separation distance (Herman et al., 2009; Noyes et al., 2005), from these results it is impossible to determine which individual components are effectively contributing to altered movement patterns. However, Onate et al. (2001) demonstrated that a neuromuscular control training intervention providing only performance feedback is effective in improving jump landing mechanics and reducing ground reaction forces (Onate, Guskiewicz, & Sullivan, 2001). From these results, we know that neuromuscular control can be a limiting factor in jump landing mechanics.

Although the effect of feedback has not been accounted for in movement screen testing criteria nor the interpretation of results, Frost et al. (2013) reported a significant positive effect on screen score by informing subjects of the grading criteria by which their performance would be evaluated. The average composite movement screen score increased from 14.1±1.8 to 16.7±1.9 and the OHS component score increased from 1.4±0.7 to 2.0±0.6 following an explanation of the scoring criteria. Based on these results, it can be inferred that movement screen performance can be influenced by neuromuscular control limitations and that observed movement patterns may not necessarily be the result of mobility restrictions, strength deficiencies, and/or asymmetries. Therefore, current testing procedures may not provide an accurate assessment of the variables movement screens claim to identify and further investigation conducted to illustrate the effect of slight alterations of movement screen testing procedures.

Practice is another factor that may influence movement screen performance as a function of neuromuscular control. Hopkins et al. (2001) identified a significant effect of practice when multiple trials are used to measure outcomes in physical performance tests. Subjects’ performance varied when tests were repeated. The average coefficient of
variation decreased significantly from 1.2% between the first and second trials, to 0.2% between the second and third. This suggests that initial trials may not be representative of a subject’s true performance capacity and that repeated exposure is likely to result in more accurate outcomes. This has not been accounted for within the context of movement screens testing procedures, nor investigated. If a subject were to improve their movement screen performance with practice, as has been demonstrated in other physical performance tests, the limitations in those specific situations would not necessarily be related to mobility restrictions, strength deficiencies, and/or asymmetries.

The question remains as to whether evaluating learned or habitual movement behavior is of greater importance in predicting performance potential and injury risk. Current movement screen design tests habitual movement behavior. The accepted opinion concerning this topic is not objectively substantiated by research data. Rather, it is based on the opinion of individual researchers. Frost et al. (2012) concluded that habitual movement behavior is more important to evaluate than learned movement behavior, as these patterns are representative of what would be performed in the environments where injury is most likely to occur. It may be beneficial for testing procedures to include cuing and feedback, considering their usage is widely accepted and practiced within the fields of coaching and motor development. Assessment of both habitual and learned behavior may best serve the patient and practitioner in developing the most effective training plan to resolve movement dysfunction.
**Practical Impressions of Movement Screens**

Movement screens display both strengths and weaknesses in their ability to assess performance potential and injury risk. The FMS specifically is a reliable assessment tool, as reported by its good inter-rater and intra-rater reliability values. The OHS is a common component test amongst a number of movement screens, likely due to the interplay between stability and mobility demands. Ankle DF ROM is a contributing factor to OHS movement patterns. However, Maybry’s reported sensitivity and specificity values correspond to non-weight bearing passive and active ankle DF ROM, not utilized ankle DF when performing the OHS. Valuable information would be obtained by the statistical comparison between subjects’ utilized ankle DF ROM and OHS component screen score.

Movement screens are not good performance assessment tools and researchers have suggested that other performance screens would better serve strength and conditioning professionals. Although movement screen scores correlate with certain measures of flexibility, their overall ability to predict injury, based on meta-analysis review, is only slightly better than chance. However, it is important to note that movement screens are typically performed in clinical settings, which are very different than those evident in sport and exercise environments. It is possible that movement screens could be more effective in predicting performance potential and injury risk if limitations such as speed, load, and state of physical preparation (warm-up) were accounted for by inclusion in the testing procedures. Given the positive effects of warm-up, which will be detailed in the following section, and their widespread professional utilization, this omission from movement screen testing protocols is counterintuitive.
Warm-up

General warm-up

The purpose of a warm-up before sport or exercise is to gradually prepare one’s body for the specific physical activity task-demands to follow. Warming-up induces a number of physiological processes, which positively affect performance and reduce risk of injury. For example, there is an increase in core temperature in response to warm-up, which causes an increase in blood flow to active muscle tissue through vasodilation (Shrier, 2008). Additionally, a rise in muscle temperature reduces risk of injury by improving tissue compliance such that both the required force and length of stretch to tear a muscle is increased significantly (Noonan, Best, Seaber, & Garrett, 1993). According to a review by Shellock and Prentice (1985), previous studies indicate that increased nerve conduction velocity due to elevated temperatures positively affects reaction time, contraction speed, and motor coordination. Warm-up can also increase joint ROM by decreasing passive resistance of muscle tissue, which is of benefit to those activities with substantial flexibility demands (Bandy, Irion, & Briggler, 1998; Beedle & Mann, 2007; Behm & Chaouachi, 2011; Johnson et al., 2007; Kubo, Kanehisa, Kawakami, & Fukunaga, 2001; O’Sullivan, Murray, & Sainsbury, 2009).

Despite the aforementioned benefits, movement screens are conducted without a warm-up. Scientific research studies have not yet investigated the effect of warm-ups on movement screen score or performance. If inclusion of a warm-up were to affect movement screen score, the testing procedures might be considered invalid and the resultant data would be misrepresentative of the subject’s movement capacity.
Dynamic Warm-up

While warm-ups have in the past consisted primarily of submaximal cardiorespiratory exercise and/or static stretching, dynamic warm-up (DWU) is increasingly utilized as a pre-activity warm-up due to the positive effects on both performance and injury risk as reported in the research literature. Although many DWU protocols have been adopted by sport and exercise professionals, most include the following components: (a) gross-motor movements – such as lunging, twisting, reaching, pushing, and pulling; (b) dynamic stretching – which is defined as the rhythmic oscillation of a limb or joint through its full range of motion; (c) and functional, sport-specific movements – such as skipping, bounding, and sprinting at increasing intensities (Bishop & Middleton, 2013, Faigenbaum et al., 2005; Fletcher & Jones, 2004; Herman & Smith, 2008; McMillian et al., 2006). Rehearsal of movement patterns similar to the sports-specific movements utilized during physical activity likely influences the efficacy of one’s neuromuscular control. It should also be noted that the effect of warm-up is volume dependent. Research study warm-up sessions range in duration from 5 to 15 minutes, with individual components quantified either by duration or sets and repetitions. The goal is to appropriately prepare subjects for the physical activity task demands to follow without causing excessive fatigue (Behm & Chaouachi, 2011).

DWU effect on performance

The positive effect of DWU on performance has led to increased utilization by coaches, athletes, and healthcare professionals. In a systematic review with meta-analysis into the effects of warming-up on physical performance, 79% of the studies analyzed demonstrated a positive effect on variables ranging from sport specific skills, such as
jumping, throwing, kicking, and agility, to actual in-game competitive performance outcomes. Of these studies showing a positive effect on performance measures and variables, the range of improvement varied between 1 to 20% (Fradkin, Zazryn, & Smoliga, 2010).

Lower limb extension power is positively affected by dynamic stretching. Following a brief dynamic stretching intervention (butt-kick exercise for three sets of 30 seconds), Manoel et al. (2008) reported statistically significant improvements in isokinetic unilateral knee extension power at both 60º per second (°⋅s⁻¹), (8.9%; p < 0.05) and 180°⋅s⁻¹ (6.3%; p < 0.05). Yamaguchi and Ishii (2005) also reported significant improvements in bilateral leg extension power (10.1%; p < 0.01) following dynamic stretching of the lower limb musculature (plantar flexors, hip extensors, hamstrings, hip flexors, quadriceps femoris) for 30 seconds per stretch per leg. Simultaneous improvements in vertical jump performance (4.9%; p < 0.05) and electromyographic (EMG) activity of the m. vastus medialis (14.4%; p > 0.05) were reported in response to dynamic stretching of the plantar flexor, hip extensors, hamstrings, hip flexors, and quadriceps femoris (Hough, Ross, & Howatson; 2009). Although the elevated EMG activity in response to the dynamic stretching was not significant, Hough et al. (2009) suggest that the increased motor unit activation may have facilitated more powerful muscular contractions, which would account for the improvements in vertical jump performance. These improvements demonstrate the potential ability of a DWU to increase neurological drive (Hough, Ross, and Howatson, 2009).

In contrast, Beedle et al. (2008) found no significant improvement in upper or lower body maximal strength, as measured by bench and leg press, following dynamic stretching.
The dynamic stretching intervention was similar to the previously mentioned researchers’ protocols, consisting of one upper body (diagonal plane arm swings) and one lower body (sagittal plane leg swings) movement performed for three sets of 30 seconds. Although the samples were similar (recreationally active young adults with weight training experience), the difference in results between these research studies may be accounted for by the assessed movements. The positive results from Hough et al. (2009), Manoel et al. (2008), and Yamaguchi and Ishii (2005) involved tests of lower extremity power with submaximal loads. However, Beedle et al. (2008) assessed maximal strength with only two warm-up sets for the bench and leg press following the dynamic stretching. A more robust DWU may be required to elicit significant improvements in maximal strength.

DWU used in the context of sport and recreational exercise is typically more comprehensive than in the above studies. This type of DWU has been shown to be effective at improving performance of whole body functional measures of agility and power. McMillian, Moore, Hatler, and Taylor (2006) assessed subjects’ performance with and without a DWU, which consisted of calisthenics (bend and reach, rear lunge and reach, diagonal lunge and reach, turn and reach, squat, jump, prone row, push-up, and windmill) and movement drills (verticals, laterals, crossovers, skip, and shuttle sprint) and lasted ten minutes. Agility T-drill time decreased significantly when comparing subjects’ performance with a DWU (9.56±0.79 seconds; \( p < 0.01 \)) than without (9.77±0.82 s; \( p > 0.05 \)). Medicine ball throw distance increased significantly following the DWU (9.79±3.0 meters; \( p < 0.01 \)) than without (9.47±2.89 m; \( p > 0.05 \)). Lastly, five-step jump distance was significantly greater following the DWU (10.06±1.23 m; \( p < 0.01 \)) than without (9.51±1.14; \( p > 0.05 \)).
Using the DWU validated in the study by McMillian et al. (2006), Herman and Smith (2008) evaluated its effect on various performance variables in a sample of male NCAA Division 1 wrestlers over the course of four weeks. This data was then compared to the effect of a static stretching warm-up. After the four week DWU intervention, the researchers reported improvements in peak torque of the quadriceps (11%; \(p < 0.05\)), broad jump distance (4%; \(p < 0.05\)), medicine ball underhand throw distance (4%; \(p < 0.05\)), sit-ups in two minutes (11%; \(p < 0.05\)), push-ups in two minutes (3%; \(p < 0.05\)), 300-yard shuttle run (2%; \(p < 0.05\)), and 600-meter run (2.4%; \(p < 0.05\)). The static stretching warm-up did not significantly improve any of the aforementioned performance variables. These two studies illustrate both acute and long-term benefits associated with inclusion of a DWU in both competitive and recreational physical activity.

In a population of male rugby union players, Fletcher and Jones (2004) recorded significant decreases in 20-meter sprint times following an ambulatory DWU (\(p < 0.05\)). This included lower body dynamic stretches (high knees, hip rolls, running cycles, and straight leg kicking) at a jogging pace. However, dynamic stretches performed in a stationary position did not significantly decrease sprint time (\(p > 0.05\)). The researchers hypothesized that in addition to the enhanced receptor and transmission sensitivity and increased speed of neural impulses, rehearsal of movements in the DWU that closely resemble the task of sprinting may positively affect motor control and coordination. This hypothesis may apply to movement screen performance by including movements in a DWU, which specifically mimic the mobility, stability, and positional demands of movement screen component tests. This would illustrate the potential contribution of
motor control and coordination in addition to performance measures as discussed in this section.

Although the effect of a DWU has yet to be investigated as it relates to movement screens, if there were to be an acute, positive effect on complex, multi-joint movements such that it would significantly impact screen score/performance, the poor correlations between movement screen scores and performance as outlined in the section on movement screen validity may be a result of inappropriate physical preparation. It is possible that inclusion of a DWU may result in a more valid representation of subjects’ movement capacity. Additionally, the proposed corrective exercises based on movement screen performance without a DWU may be unnecessary. This would suggest that the information obtained by clinicians who use movement screens may not be valid in all instances.

**DWU effect on ROM**

The effect of a comprehensive DWU on ROM has not been clearly evaluated. The majority of DWU research revolves around its effect on performance variables, as described above. However, dynamic stretching, which is a common component of DWU protocols, has been widely researched and shown to significantly improve joint ROM (Bandy, Irion, & Briggler, 1998; Beedle & Mann, 2007; Behm & Chaouachi, 2011; Samukawa, Hattori, Sugama, & Takeda, 2011).

The effect of dynamic stretching on joint ROM is time dependent. With longer durations (>90 seconds), similar improvements occur between static and dynamic stretching in lower extremity joint ROM (Beedle & Mann, 2007). However, with shorter durations (<30 seconds), dynamic stretching has a considerably smaller effect on lower extremity joint ROM than static stretching of a similar duration (Bandy et al., 1998). The
effect of a comprehensive DWU (as previously described) on joint ROM is warranted. Despite the claim that mobility is a limiting factor in movement screen performance, subjects are assessed without a warm-up. Should there be a significant effect of DWU on movement screen performance, simultaneous assessment of ROM would be necessary to confirm that the improvements in movement screen performance were in fact the result of increased ROM.

**DWU effect on ankle DF ROM.** There is a significant amount of research demonstrating a positive effect of static stretching on ankle DF (Johnson et al., 2007; Radford, Burns, Buchbinder, Landorf, & Cook, 2006). However, there are considerably fewer studies specifically investigating the effect of a DWU on ankle DF. Samukawa et al. (2011) reported statistically significant increases \( (p < 0.0001) \) in ankle DF ROM following dynamic stretching of male subjects’ plantar flexors for five sets of 30 seconds (Samukawa, Hattori, Sugama, & Takeda, 2011). Given that ankle DF impacts OHS performance, a DWU (which positively affects ankle DF) should have a similarly positive effect on subjects’ OHS score.

**Conclusion**

Although widely used as a joint mobility assessment tool, data to support the validity of the OHS score is inconclusive and contradictory. One study alone has provided kinematic data of subjects’ OHS screen performance (Butler et al., 2010). Furthermore, Maybry (2008) reported only moderate sensitivity and specificity of the OHS screen score to accurately identify ankle DF ROM. A comparison to validate the relationship between the OHS score and ankle DF ROM is warranted. Additionally, the positive effect of a DWU on physical activity performance variables and ROM is amply supported within the
current research literature. Movement screen testing, however, occurs in a non-warmed up state, despite claiming an association between screen scores, performance potential, and risk of injury (Clark, 2004; Cook et al., 2006a; Cook et al., 2010a). Given the benefits of a DWU to optimize performance and increase ROM, it is important to determine the effect of warm-ups on movement screens. Knowing that DWU influences both muscular physiology and neurology, improvements in movement screen score following a DWU would suggest that additional factors, besides those accounted for in the corrective exercise algorithms, may contribute to its performance.
CHAPTER 3

METHODS

Participants

Thirty-three university students (21 males and 12 females) were recruited to participate in the investigation. Subjects were required to be physically active for a minimum of 120 minutes per week at a moderate intensity. Participants were between the ages of 18- to 40-years old to ensure complete musculoskeletal development and to avoid age-related degeneration (Borstad, 2006). See Table 4 for more details on participants. Volunteers currently injured or recovering from an injury that would prevent them from performing bodyweight bilateral squats without pain were excluded from the study. Institutional review board approval was provided prior to recruitment. All participants consented and passed the Par-Q health questionnaire.

Table 4
Population Demographics and Measurements

<table>
<thead>
<tr>
<th></th>
<th>N = 33</th>
<th>Age (years)</th>
<th>Height (cm)</th>
<th>Weight (kg)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Male</td>
<td>21</td>
<td>25±3.8</td>
<td>173±23.4</td>
<td>84.1±24.3</td>
</tr>
<tr>
<td>Female</td>
<td>12</td>
<td>23.5±4.9</td>
<td>161.9±8.0</td>
<td>58.2±7.4</td>
</tr>
</tbody>
</table>

(Mean ± Standard Deviation)

Procedures

Testing procedures were explained to participants in written email communication and demonstrated by video prior to testing. Testing took place over the course of two sessions, wherein each subject completed both the experimental and control conditions. The order of the testing sessions was randomized by a coin toss. Participants wore their own non-reflective sneakers, spandex shorts, and tight-fitting shirt to the testing sessions.
The subjects’ height in centimeters and weight in kilograms were recorded using a stadiometer (Seca wall-mounted stadiometer, model number: 216) and scale (Health-o-Meter digital scale, model number: 845KL).

Reflective markers were placed according to the Helen Hayes Marker Set at the following locations:

1. three head markers (top, front, and back);
2. left and right acromioclavicular joints;
3. inferior angle of the right scapula;
4. left and right lateral epicondyles;
5. left and right ulnar joints;
6. left and right anterior superior iliac spine;
7. sacrum;
8. left and right lateral thighs;
9. left and right medial and lateral femoral condyles;
10. left and right lateral shanks;
11. left and right medial and lateral malleoli;
12. left and right heels; and
13. left and right second metatarsals.

Marker locations were identified and labeled using a black marker in the event that they were to fall off during the DWU treatment.

Upon placement of the 25 reflective markers, participants were guided through the OHS movement screen procedures. Two practice sets of five repetitions were performed prior to the recorded test to control for the effect of practice and motor learning (Frost et al., 2013; Hopkins et al., 2001). General OHS instructions were given before the first practice set. Each subject assumed the starting position by placing his or her feet shoulder width apart. The subject held a dowel of negligible weight and adjusted his or her hands
so that the elbows were at a 90° angle when the dowel is held just above the crown of the head. The dowel was then pressed overhead with the shoulders flexed and abducted, and the elbows extended. The subject was then instructed to descend slowly into a squat position, hold for one second, return to the starting position, and repeat for a total of five repetitions. See Figures 3 and 4 for reflective marker placement and OHS demonstration.

Figure 3
*OHS Demonstration (Anterior)*
Before the second practice set, subjects were given the grading criteria by which their OHS performance would be scored, which included the following:

1. upper torso is parallel with tibia or toward vertical,
2. femur below horizontal,
3. knees aligned over feet,
4. dowel aligned over feet,
5. elbows straight, and
6. heels down.

On the third set, subjects’ performance was digitally recorded as detailed in the instrumentation section. The researcher recorded a score between 0 and 3 according to the following guidelines utilized by Lockie et al. (2015b):

Scoring criteria for a ‘3’. Performed without compensation.

Scoring criteria for a ‘2’. Performed with a single compensation.
Scoring criteria for a ‘1’. Performed with more than one compensation.

Scoring criteria for a ‘0’. Performed with pain.

Reported OHS score was based on the repetition that successfully met the greatest number of the above grading criteria.

**DWU**

The DWU was composed of movements that positively affect performance and increase joint ROM, as demonstrated in previous research (Bandy, Irion, & Briggler, 1998; Beedle & Mann, 2007; Behm & Chaouachi, 2011; Bishop & Middleton, 2013; Faigenbaum et al., 2005; Herman & Smith, 2008; McMillian, Moore, Hatler, & Tyler, 2006; Samukawa, Hattori, Sugama, & Takeda, 2011). The DWU took approximately 10 minutes to complete and involved a series of ambulatory dynamic movements for 15 yards each:

1. high knee skips with contralateral shoulder flexion and extension;
2. reverse high knee skips with contralateral shoulder flexion and extension;
3. forward lunge with trunk rotation;
4. reverse lunge with trunk rotation;
5. carioca;
6. left leg lateral lunge;
7. right leg lateral lunge;
8. lateral shuttle run;
9. walking straight leg kicks;
10. walking knee to chest;
11. walking quadricep stretch;
12. walking hip cradle; and
13. forward and reverse shuttle runs (instructed to perform at 70, 80, then 90% intensity).
Following the DWU, participants were re-scored in the OHS according to the procedures outlined above. When performing the control trial, participants rested for 10 minutes (the time it would have taken to perform the DWU) following the initial OHS performance and were then re-scored in the OHS according to the procedures outlined above.

**Instrumentation**

The Motion Analysis system was used to record subjects’ utilized ankle DF ROM. Motion capture was conducted using 12 visible infrared cameras interfaced with the Real Time Motion Capture System (Eagle 1M and Raptor cameras, Motion Analysis Corporation, Santa Rosa, CA). Strobe control and data sampling rate were set at 120 Hz. Two Basler high-speed video cameras (model number: a602fc-2) were used to record digital video performance set at 250 frames per second. One was placed in the frontal plane, at a height of 107 cm and 6.1 m from the subject. The second was placed in the sagittal plane, at a height of 107 cm and 4.6 m from the subject. See Figure 5 for lab setup.
Post Processing

Cortex software was used to process kinematic Motion Analysis data. Marker trajectories were smoothed using a 5 Hz Butterworth filter (Butler et al., 2010). Initial calculation of utilized ankle joint angles, using toe to virtual ankle joint center to virtual knee joint center landmarks, returned unexpectedly low values. Researchers concluded that an offset angle, heel to toe to virtual ankle joint center, needed to be included in the calculation of utilized ankle joint angles to correspond with normative ankle DF ROM (Moroz, 2013). Reported utilized ankle DF was the lowest value between the right and left ankles for the repetition, which garnered the OHS score.

Intra-rater reliability for the researcher was calculated by comparing subjects’ real-time OHS score with subsequent video analysis of the same OHS trial. Video analysis has been reported as a viable means of assessing reliability. Schultz et al. (2013) obtained excellent intra-rater (0.91) reliability values when evaluating the FMS first in real time then
with subsequent video analysis. The real-time OHS scores were used in the statistical analyses.

Inter-rater reliability was calculated by comparing the researcher’s real-time ratings with the ratings from the video footage of the second rater. Both raters were certified and experienced fitness professionals pursuing graduate degrees in biomechanics. Both raters gained experience in administering the OHS movement screen through the piloting process. Raters graded subjects’ OHS independently and did not confer with regards to score given.

**Statistical Analysis**

Statistical analysis was completed using SPSS software, version 23.1. Independent variables include experimental condition (experimental or control) and time (pre or post). Dependent variables include: (a) OHS screen score and (b) utilized ankle DF. Utilized ankle DF values were reported as group means ± standard deviation according to OHS score. Statistical significance was set at $p < 0.05$.

Data analysis was completed with the following:

1. **ICC** – for inter-rater and intra-rater reliability
2. Paired t-tests – to establish homogeneity between DWU and CON pre utilized ankle DF values
3. Wilcoxon signed rank test – to establish homogeneity in pre OHS score between DWU and CON conditions
4. One-way ANOVA – to determine statistical difference between mean utilized ankle DF of each group of scores
5. Chi squared contingency table – to evaluate the effect of DWU on OHS score
6. ANOVA with repeated measures – to evaluate the effects of and interactions between treatments and time.
7. A combining means and other t-distributed or normally distributed statistics calculator (*Combining Means*, 2016) – to determine minimum detectable change.
CHAPTER 4

RESULTS

Reliability

Inter-rater reliability in all conditions and at all time points was very good ($ICC = 0.87$). Intra-rater reliability in all conditions and at all times was excellent ($ICC = 0.98$).

Homogeneity between Experimental Conditions

A paired t-test was used to assess homogeneity in pre utilized ankle DF between the DWU and CON conditions. There were no significant differences found in pre utilized ankle DF between the DWU and CON groups, ($t[32] = .14, p = .89$). The Wilcoxon signed rank test was used to assess homogeneity in pre OHS Score between the DWU and CON conditions. There were no significant differences found in Pre OHS Score between the DWU and CON groups, ($z = -1.89, p = 0.06$).

Differences in Utilized Ankle DF between OHS Score Groups

**DWU**

The pre OHS score distribution of the DWU condition with corresponding ankle DF values is detailed in Table 5 below.

<table>
<thead>
<tr>
<th>DWU Pre OHS Score</th>
<th>Number of Subjects</th>
<th>Pre Utilized Ankle DF</th>
</tr>
</thead>
<tbody>
<tr>
<td>3</td>
<td>11</td>
<td>25.6±6.9°</td>
</tr>
<tr>
<td>2</td>
<td>8</td>
<td>20.5±7.4°</td>
</tr>
<tr>
<td>1</td>
<td>14</td>
<td>17.0±6.9°</td>
</tr>
</tbody>
</table>

*(Mean ± Standard Deviation)*
Results of the One-Way ANOVA identified a significant difference in pre utilized ankle DF in the DWU condition between OHS score groups ($F[2, 30] = 4.89, p = 0.02$). Results of the Tukey post-hoc analysis are presented in Table 6 below.

Table 6

<table>
<thead>
<tr>
<th>$D W U$ Pre OHS</th>
<th>$D W U$ Pre OHS</th>
<th>$p$-value</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>2</td>
<td>0.48</td>
</tr>
<tr>
<td></td>
<td>3</td>
<td>0.01*</td>
</tr>
<tr>
<td>2</td>
<td>1</td>
<td>0.48</td>
</tr>
<tr>
<td></td>
<td>3</td>
<td>0.27</td>
</tr>
<tr>
<td>3</td>
<td>1</td>
<td>0.01*</td>
</tr>
<tr>
<td></td>
<td>2</td>
<td>0.27</td>
</tr>
</tbody>
</table>

*Significant at $p < 0.05$

$C O N$

The pre OHS score distribution of the CON condition with corresponding ankle DF values is detailed in Table 7 below.

Table 7

<table>
<thead>
<tr>
<th>$C O N$ Pre OHS Score</th>
<th>Number of Subjects</th>
<th>Utilized Ankle DF</th>
</tr>
</thead>
<tbody>
<tr>
<td>3</td>
<td>14</td>
<td>24.8±6.1°</td>
</tr>
<tr>
<td>2</td>
<td>7</td>
<td>18.5±6.4°</td>
</tr>
<tr>
<td>1</td>
<td>12</td>
<td>16.9±6.6°</td>
</tr>
</tbody>
</table>

(Mean ± Standard Deviation)
Results of the One-Way ANOVA identified a significant difference in pre utilized ankle DF in the CON condition between OHS score groups \( F[2, 30] = 5.5, p = 0.01 \). Results of the Tukey post-hoc analysis are presented in Table 8 below.

Table 8

\textit{CON – Between Scores One Way ANOVA – Utilized Ankle DF}

<table>
<thead>
<tr>
<th>CON Pre OHS</th>
<th>CON Pre OHS</th>
<th>Sig.</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>2</td>
<td>0.85</td>
</tr>
<tr>
<td>1</td>
<td>3</td>
<td>0.01*</td>
</tr>
<tr>
<td>2</td>
<td>1</td>
<td>0.85</td>
</tr>
<tr>
<td>2</td>
<td>3</td>
<td>0.1</td>
</tr>
<tr>
<td>3</td>
<td>1</td>
<td>0.01*</td>
</tr>
<tr>
<td>3</td>
<td>2</td>
<td>0.1</td>
</tr>
</tbody>
</table>

*Significant at \( p < 0.05 \)

\textbf{Pre OHS Score Frequency Distribution}

Subjects’ pre OHS score frequency distribution differed between DWU and CON trials. The CON trial displayed fewer scores of ones and twos, with a greater number of subjects receiving a score of three. These differences, however, were not statistically significant \( z = -1.89, p = 0.06 \). See Figure 6 below for more details.
Effect of DWU on OHS Score

There is a significant relationship between DWU and improved OHS score, ($X^2 [1, N = 41] = 11.4, p = 0.001$). Those subjects that scored a three at the pre time points were excluded. Within the DWU condition 10 subjects improved and 12 showed no improvement in their OHS scores. Within the CON condition, all 19 subjects showed no improvement in their OHS scores. See Figure 7.
Effect of DWU on Utilized Ankle DF

To determine the effect of the intervention (DWU/CON) on utilized ankle DF, a 2x2 repeated measures ANOVA was conducted. Analysis of variance showed no main effects of treatment ($F[1, 32] = 0.03, p = 0.86$) or time ($F[1, 32] = 0.13, p = 0.73$) on utilized ankle DF. When including only the ten subjects whose OHS score improved following the DWU, analysis of variance showed no main effect of time on utilized ankle DF ($F[1, 9] = 0.14, p = 0.72$).
Minimum Detectable Change

Using the *Combining Means and Other t-Distributed or Normally Distributed Statistics Calculator* (Sportscience), the DWU condition demonstrated a 100% trivial effect on utilized ankle DF at the 3/-3° threshold value. The CON condition displayed a 100% trivial effect on utilized ankle DF at the 3/-3° threshold value. See Table 9.

Table 9
*Minimum Detectable Change for All Subjects*

<table>
<thead>
<tr>
<th>Condition</th>
<th>Threshold (°)</th>
<th>Beneficial (%)</th>
<th>Trivial (%)</th>
<th>Harmful (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>DWU</td>
<td>3/-3</td>
<td>0</td>
<td>100</td>
<td>0</td>
</tr>
<tr>
<td>CON</td>
<td>3/-3</td>
<td>0</td>
<td>100</td>
<td>0</td>
</tr>
</tbody>
</table>

When including only those subjects whose OHS Scores improved, the DWU condition displayed a 99.4% trivial effect on utilized ankle DF at the 3/-3° threshold value. Those same subjects’ CON condition showed a 100% trivial effect on utilized ankle DF at the 3/-3° threshold value. See Table 10.

Table 10
*Minimum Detectable Change for Subjects Who Improved*

<table>
<thead>
<tr>
<th>Condition</th>
<th>Threshold (°)</th>
<th>Beneficial (%)</th>
<th>Trivial (%)</th>
<th>Harmful (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>DWU</td>
<td>3/-3</td>
<td>0.6</td>
<td>99.4</td>
<td>0</td>
</tr>
<tr>
<td>CON</td>
<td>3/-3</td>
<td>0</td>
<td>100</td>
<td>0</td>
</tr>
</tbody>
</table>
CHAPTER 5
DISCUSSION

According to the researcher’s knowledge, this is the first investigation into the effect of a DWU on OHS movement screen performance. Many of the statistical results reported within this thesis are novel in that they expand upon previous researchers’ results by including additional details, offering revised interpretations, and controlling for previous study design limitations. These will be discussed in detail in the following sections.

Reliability

The OHS reliability values obtained in the present investigation ranged from very good to excellent. Both intra-rater and inter-rater reliability values are consistent with the results of other researchers’ reported OHS reliability values (Frohm et al., 2012; Minick et al., 2010; Onate et al., 2012; Schneiders et al., 2011; Teyhen et al., 2012). The OHS is a reliable assessment test, both as a component of movement screens, such as the FMS, and on its own.

Previous researchers’ OHS reliability values were evenly distributed between intraclass correlation coefficient (ICC) and weighted kappa (k_w). However, the majority of overall movement screen reliability values were reported using the ICC statistical model. As such, the reliability statistics used in the present investigation were chosen to correspond with the majority of overall movement screen reliability ICC values.

The nature of this study dictated that both the intra-rater and inter-rater OHS scores be assigned by observing subjects’ performance with the recorded 2-D video. In designating OHS score this way, the raters were allowed to observe each subject’s
performance in slow motion. However, this is not the prescribed method for assigning movement screen scores. As such, it is a study design limitation. However, Shultz et al. (2013) reported excellent intra-rater reliability values ($ICC = 0.91$) when evaluating the FMS in real time followed by video analysis. Given the results of Shultz et al. (2013), we believe that this method of reporting reliability data did not affect the results. Furthermore, this method of observation allows for a more thorough understanding of a subject’s movement patterns. Thus, this method could be used effectively in movement screen rating procedures.

**Differences in Utilized Ankle DF between OHS Score Groups**

According to the author’s knowledge, Butler’s research (2010) is the only study to assess lower extremity joint kinematics of the OHS in relation to movement screen scores. Although Butler et al. (2010) found no significant differences between groups’ respective utilized ankle DF ($p = 0.1$), this investigation identified significant differences (DWU – $p = 0.02$; CON – $p = 0.01$). Specifically, these differences were reported between the highest and lowest scoring groups (DWU – $p = 0.01$; CON – $p = 0.01$). Both the results of Butler et al. (2010) and the present investigation suggest that, despite general use of the OHS movement screen in assessing ankle DF, within this population, OHS score is not a valid discriminator of utilized ankle DF.

Ankle DF values reported in Butler’s research (2010) were approximately 6 to 7° greater in all groups than the present investigation’s results. A direct comparison of the methods utilized to assess ankle DF was not possible as this was not explicitly detailed in Butler’s investigation. However, similar between group differences of 3-4° were reported in both samples. See Table 11 below. The discrepancies between the results of the present
investigation and Butler et al. (2010) may be due to sample demographics. Butler’s sample consisted of nine males and 18 females. The present investigation’s sample included 21 males and 12 female participants. Given that Udris (2013) reported significant differences in FMS score between genders in a population of collegiate cheerleaders, the gender distribution variance may have influenced the results. To account for these potentially influential gender-related factors, researchers may select samples limited to either male-only, female-only, or report statistical results for each gender separately.

Table 11

<table>
<thead>
<tr>
<th></th>
<th>1s</th>
<th>2s</th>
<th>3s</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Butler (2010)</strong></td>
<td>24.5±2.3° (SEM)</td>
<td>27.9±2.6° (SEM)</td>
<td>31.4±1.8° (SEM)</td>
</tr>
<tr>
<td>N</td>
<td>9</td>
<td>9</td>
<td>10</td>
</tr>
<tr>
<td><strong>Foster DWU Pre</strong></td>
<td>17.0±6.9° (SD)</td>
<td>20.5±7.4° (SD)</td>
<td>25.6±6.9° (SD)</td>
</tr>
<tr>
<td>N</td>
<td>14</td>
<td>8</td>
<td>11</td>
</tr>
<tr>
<td><strong>Foster CON Pre</strong></td>
<td>16.9±6.6° (SD)</td>
<td>18.5±6.4° (SD)</td>
<td>24.8±6.1° (SD)</td>
</tr>
<tr>
<td>N</td>
<td>12</td>
<td>7</td>
<td>14</td>
</tr>
</tbody>
</table>

Additionally, the reported standard deviation in this investigation ranged from 6.1° to 7.4°, which would effectively place outliers’ utilized ankle DF within the mean utilized ankle DF of the OHS score above or below. For example, a number of subjects who received a score of one displayed considerably higher utilized ankle DF, which was nearer the mean for subjects scoring a three on the OHS (see Table 12). The inverse phenomenon was also observed with a number of subjects who scored a three in the OHS, yet their utilized ankle DF was nearer the mean of an OHS score of one.
Table 12
Utilized Ankle DF Outliers

<table>
<thead>
<tr>
<th>OHS Score</th>
<th>Ankle DF</th>
<th>Diff from Mean</th>
<th>Condition</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>23.5</td>
<td>+6.5</td>
<td>DWU Pre</td>
</tr>
<tr>
<td>1</td>
<td>26.3</td>
<td>+9.3</td>
<td>DWU Post</td>
</tr>
<tr>
<td>1</td>
<td>23.9</td>
<td>+7</td>
<td>CON Pre</td>
</tr>
<tr>
<td>1</td>
<td>23.8</td>
<td>+6.9</td>
<td>CON Pre</td>
</tr>
<tr>
<td>1</td>
<td>27.5</td>
<td>+10.6</td>
<td>CON Pre</td>
</tr>
<tr>
<td>1</td>
<td>26.2</td>
<td>+9.3</td>
<td>CON Post</td>
</tr>
<tr>
<td>1</td>
<td>26.7</td>
<td>+9.8</td>
<td>CON Post</td>
</tr>
<tr>
<td>3</td>
<td>18.9</td>
<td>-6.7</td>
<td>DWU Pre</td>
</tr>
<tr>
<td>3</td>
<td>16.9</td>
<td>-8.7</td>
<td>DWU Pre</td>
</tr>
<tr>
<td>3</td>
<td>17.5</td>
<td>-8.1</td>
<td>DWU Pre</td>
</tr>
<tr>
<td>3</td>
<td>19.5</td>
<td>-6.1</td>
<td>DWU Post</td>
</tr>
<tr>
<td>3</td>
<td>15.8</td>
<td>-9.8</td>
<td>DWU Post</td>
</tr>
<tr>
<td>3</td>
<td>17.4</td>
<td>-8.2</td>
<td>DWU Post</td>
</tr>
<tr>
<td>3</td>
<td>16.6</td>
<td>-9</td>
<td>DWU Post</td>
</tr>
<tr>
<td>3</td>
<td>15.6</td>
<td>-10</td>
<td>DWU Post</td>
</tr>
<tr>
<td>3</td>
<td>14.3</td>
<td>-11.3</td>
<td>DWU Post</td>
</tr>
<tr>
<td>3</td>
<td>12</td>
<td>-13.6</td>
<td>DWU Post</td>
</tr>
<tr>
<td>3</td>
<td>17.8</td>
<td>-7</td>
<td>CON Pre</td>
</tr>
<tr>
<td>3</td>
<td>18.7</td>
<td>-6.1</td>
<td>CON Pre</td>
</tr>
<tr>
<td>3</td>
<td>12.9</td>
<td>-11.9</td>
<td>CON Pre</td>
</tr>
<tr>
<td>3</td>
<td>19.8</td>
<td>-5</td>
<td>CON Post</td>
</tr>
<tr>
<td>3</td>
<td>18.3</td>
<td>-6.5</td>
<td>CON Post</td>
</tr>
<tr>
<td>3</td>
<td>17.8</td>
<td>-7</td>
<td>CON Post</td>
</tr>
<tr>
<td>3</td>
<td>13.1</td>
<td>-11.7</td>
<td>CON Post</td>
</tr>
</tbody>
</table>

Although there is a trend between higher OHS score and greater utilized ankle DF, the inconsistency illustrated in the data above suggests that mean ankle DF values are not representative of all subjects within a given group score. These data suggest that a subject’s chosen OHS motor control strategy may influence utilized ankle DF and/or a subject’s utilized ankle DF may influence their OHS motor control strategy. The relationship between OHS score and the requisite utilized ankle DF is not as straightforward as movement screens’ interpretation analysis suggests.
Pre OHS Score Frequency Distribution

Despite randomization of testing sessions, practice repetitions, and knowledge of grading criteria, subjects’ OHS Score frequency distribution differed between the DWU and CON trials. Frost et al. (2012) conducted one of the few research studies examining an intervention effect on movement screen performance with a control group. In that study, no comparison was made of the distribution of FMS scores between the intervention and control groups. However, similar to the results of the present investigation, no statistically significant changes were reported between the control group’s test and retest mean scores. Frost et al. (2012) noted that group mean scores were not representative of individuals’ scores, which did vary significantly on subsequent testing sessions. Within the control group of 20 subjects, eight subjects’ overall movement screen score improved, nine subjects decreased, while only three remained the same.

Both our results and Frost’s demonstrate a relative inconsistency in movement screen performance on separate testing occasions. The reliability of both movement screens’ component tests and rating system is of critical importance. If a portion of subjects’ movement screen performance is inconsistent across multiple testing sessions, the validity of the test may be questionable. Currently, there is no accounting for the variety of motor control strategies used to accomplish movement screen testing requirements. Further scientific investigation may improve the understanding of how these factors influence movement screen performance. This may, in turn, influence the capacity in which movement screens are utilized.
Effect of DWU on OHS Score

In the present investigation, the DWU condition resulted in a significantly greater proportion of subjects whose OHS Score improved versus the CON condition. These results support our hypothesis that, in some subjects, OHS Score will improve following a DWU. In this sample, DWU has the capacity to acutely improve functional movement patterns. Current movement screen administration assesses subjects’ performance in a non-warmed up state. This is counterintuitive given the positive benefits associated with warm-ups in general and DWU specifically. It is possible that the poor correlations between performance and injury risk may be related to inappropriate physical preparation preceding movement screen testing. Clinicians should be aware that a DWU may be an effective first step in correcting aberrant movement patterns before prescribing corrective exercise.

This study takes into account previous researchers’ study design limitations. The study by Frost et al. (2013) investigating the effect of subjects’ knowledge of grading criteria on movement screen performance did not include a separate control group/trial. Although the reported improvements are likely the result of the experimental intervention, this cannot be verified given the omission of a control group’s results. Potential variables which may have influenced post-test performance might include the effect of practice and learning. The present investigation attempted to control for these variables by inclusion of practice sets, knowledge of grading criteria, and video demonstration. Additionally, Frost (2013) reported a fractional, numerical improvement in mean OHS score. However, OHS scores are ordinal variables, not numerical. As such, the present investigation indicated the effect of DWU as a function of the proportion of subjects whose OHS score improved,
rather than overall mean change. As a result, the researcher is unaware of comparable statistical results.

Effect of DWU on Utilized Ankle DF

Despite the increased proportion of subjects with improved OHS scores in the DWU group, there were no significant main effects of time or treatment, nor interactions between time and treatment, on utilized ankle DF. Furthermore, data indicates that there is a 100% trivial chance of this DWU having an effect great enough to increase utilized ankle DF three degrees, which is the minimum between group (OHS Score) difference in the DWU condition. Therefore, a significant proportion of the subjects’ altered movement patterns following the DWU may not have been the result of changes in utilized ankle DF.

While ankle DF significantly affects OHS, altered OHS movement patterns are not necessarily the result of increased ankle DF. While this investigation does not take into account the complex interaction and contribution of all lower extremity joints and musculature, it does clearly refute the assumption that, in subjects whose OHS movement patterns are compromised, ankle DF needs to be increased to improve OHS score/performance.

The inverse is also likely true as Moreside and McGill (2013) reported insignificant changes in functional movement patterns despite improvements in subjects’ hip mobility. These two sets of results support the concept that changes in functional movement patterns and improvements in mobility are not necessarily related. Other variables may be responsible for the observed changes in OHS performance following the DWU. The interplay between factors affecting an individual’s movement patterns is likely more
complicated than a movement screen’s assessment and correction procedures, potentially including factors such as motor learning and control.

**Limitations/Delineations**

A number of limitations must be considered when interpreting the results reported in this study.

*Activity leading up to testing*

Although inclusion criteria established all subjects as generally physically active, this study did not track acute physical activity in the hours and days leading up to testing. Subjects may have experienced significant muscle soreness, stiffness, and/or general fatigue from previous physical activity, or a lack thereof, when performing the testing procedures. Future studies may benefit by advising participants of a specified amount of physical activity to perform in the days leading up to the test, to assure less variation in results.

*Fatigue/Soreness as a result of DWU*

The DWU that subjects completed was intentionally challenging so as to prepare the body to perform optimally in a short amount of time. Despite the minimum physical activity requirements that subjects were expected to meet, there were noticeable physiological differences in their responses to the DWU. As such, a subject’s fatigue following the DWU may have affected their OHS re-test, which was performed immediately after completing the DWU and reapplication of any dropped motion analysis reflective markers. This may have affected certain subjects’ physical performance in the same vein as the previous limitation.
Time between testing sessions

The majority of subjects were able to select two testing sessions with a minimum of seven days between appointments. However, personal scheduling issues led some subjects’ secondary testing session to be slightly more or less than one week apart. The shortest period between testing sessions was four days and the longest period was ten days.

Motivation

A number of studies also indicate that motivation in exercising or during physical activities can have significant impact on a subject’s efforts and outcomes (Roberts, 1992). Additionally, different types of motivation (e.g. intrinsic versus extrinsic factors) may spur different results for a number of demographics (Kilpatrick, Hebert, & Bartholomew, 2005). As such, motivation may be a key factor influencing the effectiveness of physical movements in laboratory settings. While the researcher made efforts to relay the purpose and workings of the study in similar fashion across the board, one cannot account for the individual motivations that this sample may have brought with them. It is the researcher’s observation that motivation levels varied significantly between subjects, which may have contributed to performance outcomes. Additionally, having subjects serve as their own control, which required two 60-minute visits, may have detrimentally affected motivation levels on the second testing session. Establishing separate subjects for the experimental and control groups may have mitigated this factor.

Performance may be optimized with an incentive, such as a reward for those subjects who receive the highest score or improve following the treatment. Additionally, inclusion of a qualitative motivation screening questionnaire may facilitate the selection of
those subjects who are as invested in their own performance as are the researchers in the methodological validity of their investigation.

Subjects’ footwear

A number of recent studies have indicated that footwear can have a significant influence on ankle movement during exercise (Baltich, Emery, Stefanyshyn, & Nigg, 2015; Beck, Sukalo, & Weeks, 2013). While participants were required to wear the same shoes on both testing sessions, in one instance, a subject accidentally reported to the second testing session with different footwear than the first. This, however, did not affect the initial OHS score between the DWU and control trials. Additionally, the exact specifications of shoe were not considered. Given that an elevated forefoot significantly affected subjects’ OHS movement patterns (Dill et al., 2014), it is plausible that a heel lift would also impact OHS performance. However, the athletic shoes worn by the subjects in this investigation did not have a uniform heel height. Therefore, researchers may be best served to prescribe a certain type(s) of footwear to all subjects in order to gain the same benefits from this influential element across the entire sample. As this may be difficult to accomplish, researchers might instead require all subjects to perform the testing procedures barefoot.

Sample characteristics

This sample was comprised primarily of young adult university students, whom are not necessarily representative of the wide range of persons who are evaluated using this movement screen testing procedure. More diverse and/or targeted samples may expand the applicability of the results of this study to a broader range of individuals.
Additionally, one-third of subjects (those with a pre-test score of “3”) were eliminated from the statistical analysis of the DWU effect on OHS Score. This reduced the sample size within the experimental condition by 11 subjects, which may have weakened the statistical power of the present investigation. To account for this, future research into the effect of a DWU or other intervention on movement screens might exclude subjects scoring a three.

Non-certified raters

Although both raters are educated (BS Kinesiology and MS in progress), certified (NASM/NSCA and ACSM certified personal trainers), and experienced fitness professionals (competitive athletic and strength/conditioning coaches), neither are FMS certified. To account for this, raters reviewed testing procedures and practiced throughout pilot trials.

Future Research

Considering that the OHS movement screen is used to assess ankle, hip, and thoracic strength deficiencies and/or mobility restrictions (Clark et al., 2004; Cook, 2010a), future efforts should be made to investigate other proposed causes of observed aberrant movement patterns when performing the OHS movement screen. Researchers should also take into account the numerous external variables that could significantly influence the measurements of these movements, as detailed in the literature review and the limitations sections of the present investigation. Furthermore, the OHS is only one component test of many within movement screens that are widely utilized without scientific validation. Proper assessment of each component test’s validity, across generalizable samples and with
external factorial influences considered, is warranted to obtain a better understanding of the efficacy of these testing instruments.

The reliability statistics used in this study were gathered via ICC, which was the most frequently utilized method of reported reliability in other recent investigations of movement screens. Additional studies providing data solely for the OHS are necessary in order to further support its reliability. Considering the majority of reliability statistics for movement screens utilize ICC, OHS score should be measured similarly for continuity purposes.

This study did not include statistical comparisons between subjects’ utilized and available ankle DF. The correlation between these variables and OHS Score would be expansive with regards to previous research reporting average utilized joint kinematics of the OHS (Butler et al., 2010) and the sensitivity/specificity of a subject’s OHS score to predict their passive ankle DF ROM (Maybry, 2008). This may provide a more in depth understanding of the OHS movement screen’s ability to assess ankle DF ROM.

**Practical Implications**

The subjective discussion as to the uses of movement screens to assess habitual versus learned movement patterns has yet to be quantified with objective research data. Assessment of habitual movement patterns is believed to be more important (Frost et al., 2012) considering those are most likely to occur when in sport and exercise environments. This is based on expert opinion, which is the lowest level of evidence, and unsubstantiated by scientific research data.

However, due to the significant effect of DWU on OHS score in the present investigation, “habitual” patterns observed during a non-warmed up state, as dictated by
current movement screen testing procedures, may not be representative of all subjects’ absolute performance in sport and exercise environments, which would include a warm-up. Practitioners should be aware that a DWU, as well as knowledge of the grading criteria (Frost et al., 2013), can acutely alter subjects’ movement screen score. Additionally, practitioners should be aware that movement patterns may be altered when transitioning from a low demand, clinical setting to a high-demand, sport or exercise environment (Frost et al., 2015). This warrants a similar investigation into the effect of cuing on movement screen performance, considering its ability to significantly affect sport movement patterns (Onate et al., 2001) and widespread use within the fields of coaching and motor learning.

As demonstrated by the limitations of the research studies conducted to date, movement screens may not accurately assess their intended measures. Still, knowing what movement screens do not test does not give insight into what is being evaluated. To date, the factors, which contribute to movement screen performance, including the OHS component test, have not been clearly illustrated. The administration procedures and resultant corrective exercise prescriptions are supported only anecdotally. Considering the widespread use of movement screens and the conflicting research data in support of their validity, efforts should be made to verify these assessment tools.

Conclusion

The aim of this study has been to investigate the theoretical basis and administrative procedures of movement screens. There is potential value in the simplicity and accessibility of movement screens to obtain a general impression of subjects’ movement quality, which is likely why their usage is so widespread. However, the cause-and-effect
algorithms proposed to explain aberrant movement patterns are neither clear nor well understood scientifically.

A significant proportion of subjects’ OHS score improved following the DWU. Despite the claimed associations between OHS score and ankle DF ROM (Clark, 2004; Cook, 2010a), the improvements following the DWU were not the result of increased utilized ankle DF. Although the results presented in this study do not offer a definitive answer to the exact variables that are being assessed when performing the OHS movement screen, the acute changes in screen score, in response to interventions such as those seen in the research literature outlined above, suggest that a multitude of factors contribute to one’s movement patterns and score. Given that the present investigation implemented controls to account for the effects of practice (Hopkins et al., 2001) and knowledge of grading criteria (Frost et al., 2015), we can conclude that the observed improvements were due to physiological and/or neuromuscular factors associated with DWU.

Current testing procedures do not take into account the effects of warm-up, feedback, cuing, and/or motor control. Until the above factors are taken into account, practitioners should be aware of these as limitations when interpreting the results of movement screen assessment. Aberrant movement patterns or low scores might be considered as “red flags,” which could be further evaluated by a qualified movement professional with validated and specific assessment tools. This two-step approach may provide a more accurate representation of a subject’s movement capacity than movement screen testing alone.
REFERENCES


Appendix A

ParQ+

CSEP approved Sept 12 2011 version

PAR-Q+

The Physical Activity Readiness Questionnaire for Everyone

Regular physical activity is fun and healthy, and more people should become more physically active every day of the week. Being more physically active is very safe for MOST people. This questionnaire will tell you whether it is necessary for you to seek further advice from your doctor OR a qualified exercise professional before becoming more physically active.

SECTION 1 - GENERAL HEALTH

Please read the 7 questions below carefully and answer each one honestly: check YES or NO.

<table>
<thead>
<tr>
<th></th>
<th>YES</th>
<th>NO</th>
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<td>7.</td>
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If you answered NO to all of the questions above, you are cleared for physical activity.

If you answered YES to one or more of the questions above, please GO TO SECTION 2.

Delay becoming more active if:

- You are not feeling well because of a temporary illness such as a cold or fever – wait until you feel better.
- You are pregnant – talk to your health care practitioner, your physician, a qualified exercise professional, and/or complete the PARmed-X for Pregnancy before becoming more physically active OR
- Your health changes – please answer the questions on Section 2 of this document and/or talk to your doctor or qualified exercise professional (CSEP-CEP or CSEP-CPT) before continuing with any physical activity programme.
### SECTION 2 - CHRONIC MEDICAL CONDITIONS

Please read the questions below carefully and answer each one honestly; check YES or NO.

<table>
<thead>
<tr>
<th>Yes</th>
<th>No</th>
<th>1. Do you have Arthritis, Osteoporosis, or Back Problems?</th>
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<td></td>
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<td>If yes, answer questions 1a-1c If no, go to question 2</td>
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<td></td>
<td></td>
<td>1a. Do you have difficulty controlling your condition with medications or other physician-prescribed therapies? (Answer NO if you are not currently taking medications or other treatments)</td>
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<td></td>
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<td>1b. Do you have joint problems causing pain, a recent fracture or fracture caused by osteoporosis or cancer, displaced vertebra (e.g., spondylolisthesis), and/or spondylolisthesis/pars defect (a crack in the bony ring on the back of the spinal column)?</td>
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<td>1c. Have you had steroid injections taken steroid tablets regularly for more than 3 months?</td>
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<td>2. Do you have Cancer of any kind?</td>
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<td>If yes, answer questions 2a-2b If no, go to question 3</td>
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<td>2a. Does your cancer diagnosis include any of the following types: lung/brethogenic, multiple myeloma (cancer of plasma cells), head, and neck?</td>
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<td>2b. Are you currently receiving cancer therapy (such as chemotherapy or radiotherapy)?</td>
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<td>3. Do you have Heart Disease or Cardiovascular Disease? This includes Coronary Artery Disease, High Blood Pressure, Heart Failure, Diagnosed Abnormality of Heart Rhythm</td>
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<td>If yes, answer questions 3a-3e If no, go to question 4</td>
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<td>3a. Do you have difficulty controlling your condition with medications or other physician-prescribed therapies? (Answer NO if you are not currently taking medications or other treatments)</td>
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<td>3b. Do you have an irregular heart beat that requires medical management? (e.g. atrial fibrillation, premature ventricular contraction)</td>
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<td>3c. Do you have chronic heart failure?</td>
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<td>3d. Do you have a resting blood pressure equal to or greater than 160/90 mmHg with or without medication? (Answer YES if you do not know your resting blood pressure)</td>
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<td>3e. Do you have diagnosed coronary artery (cardiovascular) disease and have not participated in regular physical activity in the last 2 months?</td>
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<td>4. Do you have any Metabolic Conditions? This includes Type 1 Diabetes, Type 2 Diabetes, Pre-Diabetes</td>
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<td>If yes, answer questions 4a-4c If no, go to question 5</td>
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<td>4a. Is your blood sugar often above 13.0 mmol/L? (Answer YES if you are not sure)</td>
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<td>4b. Do you have any signs or symptoms of diabetes complications such as heart or vascular disease and/or complications affecting your eyes, kidneys, and the sensation in your toes and feet?</td>
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<td>4c. Do you have other metabolic conditions (such as thyroid disorders, pregnancy-related diabetes, chronic kidney disease, liver problems)?</td>
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<td>5. Do you have any Mental Health Problems or Learning Difficulties? This includes Alzheimer’s Dementia, Depression, Anxiety Disorder, Eating Disorder, Psychotic Disorder, Intellectual Disability, Down Syndrome</td>
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<td>If yes, answer questions 5a-5b If no, go to question 6</td>
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<td>5a. Do you have difficulty controlling your condition with medications or other physician-prescribed therapies? (Answer NO if you are not currently taking medications or other treatments)</td>
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<td>5b. Do you also have back problems affecting nerves or muscles?</td>
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<td>Question</td>
<td>YES</td>
<td>NO</td>
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<td><strong>6. Do you have a Respiratory Disease?</strong></td>
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<tr>
<td>This includes Chronic Obstructive Pulmonary Disease, Asthma, Pulmonary</td>
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<tr>
<td>High Blood Pressure</td>
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<td>6a. Do you have difficulty controlling your condition with</td>
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<td>medications or other physician-prescribed therapies?</td>
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<tr>
<td>(Answer NO if you are not currently taking medications or other</td>
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<td>treatments)</td>
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<td>6b. Has your doctor ever said your blood oxygen level is low at rest</td>
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<tr>
<td>or during exercise and/or that you require supplemental oxygen therapy?</td>
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<td>6c. If asthmatic, do you currently have symptoms of chest tightness,</td>
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<tr>
<td>wheezing, laboured breathing, consistent cough (more than 2 days/week),</td>
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<td>or have you used your rescue medication more than twice in the last</td>
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<td>week?</td>
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<td>6d. Has your doctor ever said you have high blood pressure in the</td>
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<td>blood vessels of your lungs?</td>
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<tr>
<td>**7. Do you have a Spinal Cord Injury? This Includes Tetraplegia and</td>
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<tr>
<td>Paraplegia</td>
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<td>7a. Do you have difficulty controlling your condition with medications</td>
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<td>or other physician-prescribed therapies?</td>
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<td>(Answer NO if you are not currently taking medications or other</td>
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<td>treatments)</td>
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<td>7b. Do you commonly exhibit low resting blood pressure significant</td>
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<td>enough to cause dizziness, light-headedness, and/or fainting?</td>
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<td>7c. Has your physician indicated that you exhibit sudden bouts of high</td>
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<td>blood pressure (known as Autonomic Dysreflexia)?</td>
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<td><strong>8. Have you had a Stroke?</strong> This Includes Transient Ischemic Attack</td>
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<td>(TIA) or Cerebrovascular Event</td>
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<td>8a. Do you have difficulty controlling your condition with medications</td>
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<td>or other physician-prescribed therapies?</td>
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<td>(Answer NO if you are not currently taking medications or other</td>
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<td>treatments)</td>
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<td>8b. Do you have any impairment in walking or mobility?</td>
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<td>8c. Have you experienced a stroke or impairment in nerves or muscles in</td>
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<td>the past 6 months?</td>
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<td>**9. Do you have any other medical condition not listed above or do you</td>
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<td>live with two chronic conditions?</td>
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<td>9a. Have you experienced a blackout, fainted, or lost consciousness as</td>
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<td>a result of a head injury within the last 12 months OR have you had a</td>
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<td>diagnosed concussion within the last 12 months?</td>
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<td>9b. Do you have a medical condition that is not listed (such as</td>
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<td>epilepsy, neurological conditions, kidney problems)?</td>
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<tr>
<td>9c. Do you currently live with two chronic conditions?</td>
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</tbody>
</table>

Please proceed to Page 4 for recommendations for your current medical condition and sign this document.
PAR-Q+

If you answered NO to all of the follow-up questions about your medical condition, you are ready to become more physically active:

- It is advised that you consult a qualified exercise professional (e.g., a CSEP-CEP or CSEP-CPT) to help you develop a safe and effective physical activity plan to meet your health needs.
- You are encouraged to start slowly and build up gradually – 20-60 min. of low- to moderate-intensity exercise, 3-5 days per week including aerobic and muscle strengthening exercises.
- As you progress, you should aim to accumulate 150 minutes or more of moderate-intensity physical activity per week.
- If you are over the age of 45 yrs. and NOT accustomed to regular vigorous physical activity, please consult a qualified exercise professional (CSEP-CEP) before engaging in maximal effort exercise.

If you answered YES to one or more of the follow-up questions about your medical condition:

- You should seek further information from a licensed health care professional before becoming more physically active or engaging in a fitness appraisal and/or visit a or qualified exercise professional (CSEP-CEP) for further information.

Delay becoming more active if:

- You are not feeling well because of a temporary illness such as a cold or fever – wait until you feel better.
- You are pregnant – talk to your health care practitioner, your physician, a qualified exercise professional, and/or complete the PARmed-X for Pregnancy before becoming more physically active OR
- Your health changes – please talk to your doctor or qualified exercise professional (CSEP-CEP) before continuing with any physical activity programme.

SECTION 3 - DECLARATION

- You are encouraged to photocopy the PAR-Q+. You must use the entire questionnaire and NO changes are permitted.
- The Canadian Society for Exercise Physiology, the PAR-Q+ Collaboration, and their agents assume no liability for persons who undertake physical activity. If in doubt after completing the questionnaire, consult your doctor prior to physical activity.
- If you are less than the legal age required for consent or require the assent of a care provider, your parent, guardian or care provider must also sign this form.

Please read and sign the declaration below:

I, the undersigned, have read, understood to my full satisfaction and completed this questionnaire. I acknowledge that this physical activity clearance is valid for a maximum of 12 months from the date it is completed and becomes invalid if my condition changes. I also acknowledge that a Trustee (such as my employer, community/fitness centre, health care provider, or other designate) may retain a copy of this form for their records. In these instances, the Trustee will be required to adhere to local, national, and international guidelines regarding the storage of personal health information ensuring that they maintain the privacy of the information and do not misuse or wrongfully disclose such information.

NAME __________________________________________________________________________________________________________________________________________

DATE ______________________________________________________________________________________________________________________________

SIGNATURE ____________________________________________________________________________ WITNESS ____________________________________________________________________________

SIGNATURE OF PARENT/GUARDIAN/CARE PROVIDER _____________________________________________________________________________________________

For more information, please contact:
Canadian Society for Exercise Physiology
www.csep.ca

KEY REFERENCES

The PAR-Q+ was created using the evidence-based AGREE process (1) by the PAR-Q+Collaboration chaired by Dr. Darren E. R. Watherton with Dr. Norman Gledhill, Dr. Veronica Jenni, and Dr. Donald C. McKenzie (2). Production of this document has been made possible through financial contributions from the Public Health Agency of Canada and the BC Ministry of Health Services. The views expressed herein do not necessarily represent the views of the Public Health Agency of Canada or BC Ministry of Health Services.

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Appendix B

Adult Consent Form

California State University, Northridge
CONSENT TO ACT AS A HUMAN RESEARCH PARTICIPANT

The Effect of a High Intensity, Dynamic Warm Up on Lower Extremity Joint Mobility & Motor Control

You are being asked to participate in a research study. “The Effect of a High Intensity, Dynamic Warm Up on Lower Extremity Joint Mobility & Motor Control”, a study conducted by Joshua Foster, as part of the requirements for the M.S. degree in Kinesiology with a Concentration in Biomechanics. Participation in this study is completely voluntary. Please read the information below and ask questions about anything that you do not understand before deciding if you want to participate. A researcher listed below will be available to answer your questions.

RESEARCH TEAM

Researcher:
Joshua Foster
Department of Kinesiology
18111 Nordhoff St.
Northridge, CA 91330
818-256-9671
joshloaded@gmail.com

Faculty Advisor:
Shane Stecyk
Department of Kinesiology
18111 Nordhoff St.
Northridge, CA 91330-8287
818-677-4738
Shane.Stecyk@csun.edu

PURPOSE OF STUDY
The purpose of this research study is to assess the validity of current movement screen results and diagnoses.

SUBJECTS
Inclusion Requirements
18 years or older and able to perform a bodyweight squat without pain.

Exclusion Requirements
Currently injured or recovering from an injury within the past 3 months. Previous experience with the Overhead Squat assessment test.
Knowledge of the Overhead Squat assessment test grading criterium.

**Time Commitment**
This study will involve approximately 75 minutes of your time over 2 testing sessions to occur during the spring 2015 semester.

**PROCEDURES**
If you agree to participate you will:
1. Hear an explanation of the research study and procedures, then sign the adult consent form and complete the ParQ+ health screening questionnaire (10 min).
2. Be required to wear non-reflective sneakers, spandex shorts, and a tight fitting shirt to the testing session.
3. Have your height and weight recorded using a scale and stadiometer (5 min).
4. Have reflective markers attached via adhesive tape to various locations. Marker sites will be shaved as needed using a new disposable razor (10 min).
5. Perform a weight bearing lunge to record passive ankle dorsiflexion range of motion using the Cortex motion analysis system (10 min).
6. Complete 5 Overhead Squats followed by 5 Single Leg Squats (10 min).
7. Perform a guided dynamic warm up (10 min).
8. Repeat assessment of passive ankle dorsiflexion range of motion (10 min).
9. Complete another 5 Overhead Squats followed by 5 Single Leg Squats (10 min).

No compensation will be provided. No deception will be used.

**RISKS AND DISCOMFORTS**
The possible risks and/or discomforts associated with the procedures described in this study include:
1. muscle fatigue and/or soreness
2. muscle cramping
3. dehydration
4. skin irritation
5. injuries due to falls
6. In the rarest of instances, death.

This study involves no more than minimal risk. There are no known harms or discomforts associated with this study beyond those encountered in normal daily life. Should the participant feel pain or discomfort at any point during the study procedures, you are allowed to withdraw without consequence. You will be allowed time to rest and drink water as needed. The researcher will be supervising throughout the entire study. In case of injury, CSUN students will be referred to the Klotz Student Health Center. Non-CSUN students will be referred to their personal physician. In case of emergency, the researcher will activate EMS.

**BENEFITS**
Subject Benefits
You may not directly benefit from participation in this study.
**Benefits to Others or Society**
Results of this study may enhance the administration and validity of movement screens involving the Overhead Squat.

**ALTERNATIVES TO PARTICIPATION**
The only alternative to participation in this study is not to participate.

**COMPENSATION, COSTS AND REIMBURSEMENT**
**Compensation for Participation**
You will not be paid for your participation in this research study.

**Costs**
You will be responsible for the cost of transportation and parking.

**Reimbursement** [Optional]
You will not be reimbursed for any out of pocket expenses, such as parking or transportation fees.

**WITHDRAWAL OR TERMINATION FROM THE STUDY AND CONSEQUENCES**
You are free to withdraw from this study at any time. **If you decide to withdraw from this study you should notify the research team immediately.** The research team may also end your participation in this study if you do not follow instructions, miss scheduled visits, or if your safety and welfare are at risk.

**CONFIDENTIALITY**
**Subject Identifiable Data**
During data collection you will be identified by a code. A list linking de-identified data to identified data will be stored on the researcher’s password protected laptop. Identifiable data will be stored in Dr. Stecyk’s office, RE 283, in a locked file cabinet. De-identified data will be stored on the Biomechanics lab computer in RE 174. All identifiable and de-identifiable data will be destroyed immediately following publication or after five years (whichever comes first).

**Data Storage**
Identifiable data will be stored in Dr. Stecyk’s office, RE 283, in a locked file cabinet. De-identified data will be stored on the Biomechanics lab computer in RE 174.

**Data Access**
The researcher and faculty advisor named on the first page of this form will have access to your study records. Research assistants will have access to de-identifiable data. Any information derived from this research project that personally identifies you will not be voluntarily released or disclosed without your separate consent, except as specifically required by law. Publications and/or presentations that result from this study will not include identifiable information about you.

**Data Retention**
The researchers intend to keep the research data until the date of publication or after 5 years (whichever comes first).

**IF YOU HAVE QUESTIONS**
If you have any comments, concerns, or questions regarding the conduct of this research please contact the research team listed on the first page of this form.

If you have concerns or complaints about the research study, research team, or questions about your rights as a research participant, please contact Research and Sponsored Projects, 18111 Nordhoff Street, California State University, Northridge, Northridge, CA 91330-8232, or phone 818-677-2901.

**VOLUNTARY PARTICIPATION STATEMENT**
You should not sign this form unless you have read it and been given a copy of it to keep. **Participation in this study is voluntary.** You may refuse to answer any question or discontinue your involvement at any time without penalty or loss of benefits to which you might otherwise be entitled. Your decision will not affect your relationship with California State University, Northridge. Your signature below indicates that you have read the information in this consent form and have had a chance to ask any questions that you have about the study.

**I agree to participate in the study.**
___ I agree to be video recorded
___ I do not wish to be video recorded

___________________________________________________ __________________
Participant Signature Date

___________________________________________________ __________________
Printed Name of Participant

___________________________________________________ __________________
Researcher Signature Date

___________________________________________________ __________________
Printed Name of Researcher
Appendix C

Recruitment Letter

Purpose
- Record the effect of a dynamic warm up on lower extremity joint mobility and performance of both bodyweight Overhead and Single Leg Squats.
- Assess the motor control contribution to Overhead and Single Leg Squat performance.

Requirements
- Healthy, Adult (18+ years old).
- Must be able to perform a bodyweight squat.
- Not currently injured.
- No currently recovering from injury within the past 3 months.
- One 75 minute lab visit on campus at Cal State University, Northridge.
- Bring tight fitting athletic clothes, shoes, and water.

Contact Information
- Joshua Foster, Lead Researcher
- 818-256-9671
- joshloaded@gmail.com
Appendix D

Recruitment Script for Oral Presentation to KIN Classes

Hello, my name is Joshua Foster. I am a graduate student in the Kinesiology department with a concentration in Biomechanics at Cal State University, Northridge. The program requires that each student complete a thesis project. I will be assessing the contribution of motor control as a limiting factor in the Overhead and Single Leg Squat movement screens and the effect of a dynamic warm up on both passive and active joint range of motion measurements.

I am looking to recruit volunteers to participate in my study. To be eligible you must be at least 18 years old, able to perform a bodyweight squat without pain, not currently suffering or recovering from a physical injury (within the past 3 months), no prior experience with the Overhead and Single Leg Squat movement screens or their grading criteria. All assessment will occur within one 75 minute data collection session. No additional visits will be required.

There will be no compensation from participation in this study. Participants will not have any direct benefits from participating in this study. The results of this study may enhance the administration and validity of movement screens involving the Overhead and Single Leg Squats. Additionally, a greater understanding of the effect of dynamic warm up on joint flexibility may be gained.

Questions?

I’ve prepared a Sign-Up Sheet for interested parties to share their contact information with me, which I will leave here with your instructor. I will respond to those interested by email to give more detailed information about the project, procedures, and scheduling a lab visit to participate.
Appendix 5

Email Recruitment Letter

Thank you for agreeing to participate in my research project! I’ve prepared a list of available appointments at the following link. Pick 2 dates separated by approximately one week. Let’s try to cluster appointments back to back on the same days to maximize efficiency!

http://www.agreeAdate.com/9483694960CCB07A0518D6D8725E3E8ECA0E

The lab is at CSUN, Redwood Hall room 174. It’s at the north east corner of the building. You can find street parking on Zelzah near Plummer. Here’s a link to the campus map:

http://www.csun.edu/csun-maps

You'll need athletic shoes to perform a moderate 10 minute dynamic warm up. Please be prepared to wear the same shoes in the second testing session (I will remind you). You'll need tight fitting shorts & shirt (something that will not move when arms are overhead and squatting). Men have been doing the procedures without a shirt. Women have been doing the procedures with a sports bra (if you’re comfortable). We'll have tight shorts for you to wear if needed. The reason for this is because we’ll be attaching adhesive reflective markers at 30 anatomical locations to record your movements with a 3D motion analysis system. This is the same technique used to create CGI models based off of human movements.

You'll be tested for ankle range of motion in a kneeling lunge. Then perform 5 bodyweight squats and 5 single leg squats. Then either 10 min of dynamic warm up (experimental) or rest (control). Retest range of motion, 5 more bodyweight squats, 5 more single leg squats. DONE. Please plan for the testing to take 75 minutes. Here is a video to demonstrate the components of the testing procedure.

https://www.youtube.com/watch?v=4_zduvzf-fw

Questions?