

FUNCTIONAL MOVEMENT SCREENING AND BALANCE UNDER TORSO-
LOADED AND UNLOADED CONDITIONS

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This dissertation is dedicated to my father.

“Figure it out.”

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ABSTRACT

Impairments in balance and functional movement lead to greater risk of musculoskeletal injury (MSKI). The Functional Movement Screen™ (FMS) has been used to predict MSKI, but little is known regarding the extent to which the FMS can accurately predict deficiencies in balance in non-military and military populations.

In Study 1, 34 physically-active adults performed the FMS and composite reach distance (CR) and overall stability indices (OSI) were measured using the Y Balance and Biodex balance tests, respectively. Results indicated that (a) higher overall FMS scores were associated with better CR and OSI; (b) participants with FMS composite scores ≥ 15 exhibited better CR compared to those with composite scores ≤ 14 ; and (c) scores of 2 on the deep squat and 3 on the trunk stability push-up predicted better CR. Higher shoulder mobility scores (2, 3) and a rotary stability score of 3 also predicted better OSI.

In Study 2, 30 adults with fitness profiles typical of military recruits were tested to identify predictors of loaded CR (LCR) and loaded OSI (LOSI) from unloaded (FMS) and torso-loaded FMS (24.2 kg) (mFMS) item scores. Data analyses revealed that FMS composite scores exhibited the strongest relationship with LCR and participants with higher FMS composite scores (≥ 15) displayed higher LCR values compared to those with lower composite scores (≤ 14). With respect to FMS subscores, an in-line lunge score of 1 predicted a shorter LCR and a shoulder mobility score of 3 predicted better LOSI. Loaded shoulder mobility and trunk stability push-up scores of 3 predicted better and worse LOSI, respectively.

In summary, results from this dissertation project provide support for using the traditional and loaded FMS to assess unloaded and loaded dynamic balance in active adults and military recruits. From a practical standpoint, attainment of suboptimal scores on the FMS may be a possible indication to conduct further testing to determine if balance-specific interventions are needed. Future research in this area should also explore the use of a wider range of scores when employing the FMS to improve the sensitivity of this assessment, especially when incorporating external loads to screen for movement deficiencies.

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CHAPTER I

DISSERTATION INTRODUCTION

Musculoskeletal injuries (MSKI) are one of the most prevalent injuries in active adults, athletes, and military personnel (Cohen et al., 2010; Feuerstein, Berkowitz, & Peck Jr, 1997; Jones, Canham-Chervak, Canada, Mitchener, & Moore, 2010; Lincoln, Smith, Amoroso, & Bell, 2002; Songer & LaPorte, 2000). For the general population, MSKI can result in significant treatment costs, more missed work days compared to those lost to illness, and may limit the ability to perform activities of daily living and adhere to a physical activity regiment (Hootman et al., 2002; US Department of Health and Human Services, 1996). Among recruits and military infantry and personnel, the high incidence of MSKI is a major causal factor for disability discharge and medical evacuations (Almeida, Maxwell-Williams, Shaffer, & Brodine, 1999; Jones, Bovee, & Knapik, 1992; Jones, Bovee, Harris, & Cowan, 1993a; Jones et al, 1993b). The presence of MSKI in warfighters and recruits can also lead to significant loss of duty days, extensive treatment costs, and a decline in combat readiness (Jones & Hansen, 1996; Kaufman, Brodine, & Shaffer, 2000; Knapik, Ang, Reynolds, & Jones, 1993; Tomlinson, Lednar, & Jackson, 1987).

The Functional Movement Screen™ (FMS) is a practical screening tool that was developed to identify individuals with altered movement patterns and deficits in stability, mobility, and balance (Cook, Burton, & Hoogenboom, 2006a; Cook, Burton, &

Hoogenboom, 2006b; Teyhen et al., 2014), all of which may increase the risk of MSKI. The FMS includes seven functional movements: (1) deep squat, (2) hurdle step, (3) in-line lunge, (4) shoulder mobility, (5) active straight leg raise, (6) trunk stability push-up, and (7) rotary stability test (Cook et al., 2006a; Cook et al., 2006b; Cook, 2011).

Implementation of the FMS prior to the start of seasonal competition or military training has been shown to successfully predict individuals who are at high risk for experiencing MSKI. Prospective studies in which the FMS was administered before the start of a competitive athletic season have demonstrated that professional American football players who scored a 14 or lower (out of a possible 21 points) were approximately 12 times more likely to experience an MSKI compared to players scoring 15 or higher (Kiesel, Plisky, & Voight, 2007). In a similar fashion, Marine officer candidates who scored 14 or lower on pre-basic training FMS testing were 1.7 to 1.9 times more likely to be injured compared to officer candidates who displayed scores of at least 15 (Lisman, O'Connor, Deuster, & Knapik, 2013; O'Connor, Deuster, Davis, Pappas, & Knapik, 2011).

A performance variable that the FMS is intended to assess is functional balance measured during hurdle step and in-line lunge movements (Cook et al., 2006a; Cook et al., 2006b). In several studies, poor balance ability evaluated using a variety of balance tests have successfully predicted MSKI. Studies employing a single-leg balance test, a more static version of the hurdle step movement found in the FMS, have reported that athletes with poor balance ability displayed a 2- to 10-fold greater risk of experiencing ankle sprains (McGuine, Greene, Best, & Levenson, 2000; Trojian & McKeag, 2006;

Watson, 1999). Additionally, high school and collegiate athletes with poor performance on the Star Excursion Balance Test were 2.5 to 6.5 times more likely to incur an MSKI compared to athletes who exhibited adequate balance (Butler, Lehr, Fink, Kiesel, & Plisky, 2013; Plisky, Rauh, Kaminski, & Underwood, 2006).

Research documenting the association between balance ability and MSKI in non-athletic and military populations is sparse. The majority of balance research involving MSKI in military personnel has utilized static balance assessments, which may not be particularly appropriate for active-duty soldiers, given the movement tasks (e.g., marching, stair climbing, quick turns, breaching of urban locations) which are typically performed by military personnel (Schiffman, Bensel, Hasselquist, Norton & Piscetelle, 2004). Nonetheless, the inverse relationship observed between balance ability and MSKI risk in athletes has led investigators to hypothesize that a similar link may also exist among military personnel, as well as the general population (Butler et al., 2013; Plisky et al., 2006; Schiffman et al., 2004). Moreover, an additional key consideration relative to military populations is the potential influence of load carriage on balance. In this regard, data indicating that military loading tactics result in decreased static balance control and postural sway in active duty infantrymen and Army ROTC recruits (May, Tomporowski, & Farrara, 2009) suggests that the addition of load carriage during movement-based military tasks may impose a substantial challenge to the balance ability of military personnel, which may increase the risk of MSKI.

Purpose of the Dissertation

While the FMS appears to successfully predict MSKI risk and has been shown to be reliable between and within raters (Gribble, Brigle, Pietrosimone, Pfile, & Webster, 2013; Minick et al., 2010; Teyhen et al., 2012), the construct validity of the FMS has not been quantified. Because movements of the FMS are intended to assess balance, and balance ability has been previously linked to MSKI risk, research is needed to determine if the FMS can be used to predict balance in healthy general populations and military recruits. In addition, armed forces personnel who are required to wear external loads during military maneuvers may experience additional challenges with respect to balance. If FMS tests can accurately predict balance deficiency, and components of the FMS that have the greatest relationship with loaded and unloaded balance can be identified, practitioners may be able to target individuals who are at risk for MSKI and gauge the impact of corrective exercise programs to reduce MSKI risk by monitoring changes in FMS composite and item scores. Therefore, the purpose of the first study of this 2-part dissertation project was to evaluate whether FMS composite scores and subscores can be used to predict balance ability in physically-active males and females. The purpose of the second study of this dissertation was to determine if a torso-loaded FMS assessment can be used to predict loaded balance ability more accurately compared to using the traditional FMS screening tool.

CHAPTER II

REVIEW OF LITERATURE

The prevalence of physical disability in the United States Armed Forces has substantially increased over the past decade (Songer & LePorte, 2000). Of all physical disability cases observed in the U.S. Army between 1989 and 1996, musculoskeletal injuries such as knee injuries, lumbo-sacral strains, and intervertebral disc syndrome, are the most common causes of disability discharge (Feuerstein et al., 1997; Lincoln et al., 2002; Songer & LaPorte, 2000). Non-battle-related MSKI are experienced by 34% of deployed soldiers and comprise the majority of treatment visits among military personnel operating in combat settings (Cohen et al., 2010; Jones et al., 2010; Truax, Chandnani, Chacko, & Gonzalez, 1997; Wasserman et al., 1997). During recent efforts in ‘Operation Iraqi Freedom’ and ‘Operation Enduring Freedom’, non-battle MSKI were responsible for 24% of medical evacuations and 14% were due to battle-related injuries (Cohen et al., 2010; Jones et al., 2010).

The high rate of MSKI among current U.S. military forces directly impacts the availability of personnel and monetary resources, training time, and combat readiness (Kaufman et al., 2000). The occurrence of MSKI is particularly relevant for members of infantry and specialized units that must work as a team (Knapik et al., 1993). A major concern regarding MSKI is the cumulative work time, or duty time, lost following an injury. Medical surveillance data from several cohorts of Army infantrymen and recruits

have shown that injuries sustained during training resulted in 40 to 120 days/100 soldiers/month of limited duty (Jones & Hansen, 1996; Kaufman et al., 2000; Knapik et al., 1993; Tomlinson et al., 1987). However, the proportion of limited duty days attributable to MKSI is unknown. While recent epidemiological data are unavailable, earlier findings suggest that MSKI are likely responsible for a large percentage of limited duty days, as they contribute to 51% of disability discharges cases in the U.S. Army (Feuerstein et al., 1997). In addition to the impact of MSKI on personnel availability, the financial burden of MSKI in military populations is quite extensive. Along these lines, Jones and Hansen (1996) estimated that U.S. Army disability cases in 1993 alone resulted in \$485 million in lifetime medical costs.

Former U.S. Army Surgeon General James Peake referred to non-battle related injuries as a “hidden epidemic” in modern warfare (World Health Organization, 2006). Considering the substantial financial burden, loss of duty days, and comments from Surgeon General Peake, it appears that non-battle-related MSKI are an ongoing issue and efforts by the military medical corps to prevent MKSI are a high priority. Consequently, interest in preventing injuries in soldiers continues to grow and emphasizes the need for additional research in this area.

Common MSKI in Military Recruits and Infantrymen

MSKI appear to be the predominant injury type in active-duty infantrymen and recruits who attend boot camp or undergo similar training (Bush, Brodine, & Shaffer, 2000). It should be noted that a cumulative analysis of MSKI in various military occupations can be misleading, as staff, leadership, communication specialists, and

mechanics are often included in injury analysis and are typically not required to perform high volumes of physical training (Feuerstein et al., 1997). Therefore, it is important to quantify the extent to which MSKI occur in active-duty infantrymen and recruits who frequently perform training and operations featuring large physiological demands.

The incidence of MSKI in military recruits is particularly high (Almeida et al., 1999; Jones et al., 1992; Jones et al., 1993a; Jones et al., 1993b). In one study involving Army basic training, muscle strains, ankle sprains, and overuse knee injuries were the most-reported MSKI (Jones et al., 1993b). Similarly, the most common MSKI in Marine recruits were ankle sprains, iliotibial band syndrome, stress fractures, tendinitis in the patella tendon, and shin splints (Almeida et al., 1999). Because the military has limited access to recruits prior to basic training, they typically train on their own and may not be engaged in structured exercise programs. Consequently, when basic training commences, they are often unprepared for the high volume of running, loaded marching, and other strenuous physical training activities required during boot camp (Kaufman et al., 2000).

Unlike newly-recruited soldiers, active duty infantrymen have fulfilled physical performance requirements and should exhibit higher levels of physical fitness and combat readiness. Similar to the incidence of injuries in recruits, MSKI is the most-often reported injury in active duty warfighters (Feuerstein et al., 1997; Knapik et al., 1993). Among infantrymen, general musculoskeletal pain, strains, sprains, and low-back pain are the four most prevalent MSKI (Feuerstein et al., 1997; Knapik et al., 1993). When categorized by body location, most MSKI involve the feet, ankles, and knees (Feuerstein et al., 1997; Knapik et al., 1993). More recent findings have indicated that 47% of all

injury hospitalizations in a sample of active duty infantrymen were due to lower-limb joint derangement (Jones et al., 2006). In both recruits and active duty warfighters, MSKI experienced during training generally occur in the lower extremities, at or below the knee (Almeida, Williams, Shaffer, Luz, & Badong, 1997; Almeida et al., 1999; Knapik et al., 1993; Riddell, 1989; Jones et al., 1993b). Soldiers who progress from training to deployment also incur MSKI in the lower extremities (Jones et al., 2010). While some discrepancy exists concerning which musculoskeletal injuries are most prevalent, it is clear that foot, knee, and ankle injuries should be the target of MSKI prevention efforts among recruits and active duty soldiers (Almeida et al., 1999; Jones et al., 1993b; Riddell, 1989; Shaffer, Brodine, Almeida, Williams, & Ronaghy, 1999).

Risk Factors for MSKI

Several risk factors for MSKI have been identified in military soldiers; but factors associated with the highest MSKI risk may be dependent upon the training requirements and/or duties assigned to military personnel (Kaufman et al., 2000). The scope of this review is focused on military recruits and active-duty soldiers, who are at a high injury risk due to the physical nature of their respective occupation and training status. Specific risk factors for MSKI are classified based on their potential for modification to affect overall risk. Variables such as sex and height are intrinsic risk factors for MSKI and are unalterable at a single point in time. Extrinsic factors such as terrain, training volume, equipment, and load carriage mass can be potentially modified to reduce the risk of MSKI. Considering all risk factors identified in the literature, low physical fitness and past physical activity, sex, and biomechanical characteristics are most strongly associated

with high risk of MSKI in military recruits and infantrymen (Almeida et al., 1999; Cowan et al., 1996; Jones et al., 1993a; Jones et al., 1993b; Knapik et al., 1993; Reynolds et al., 1993; Shaffer et al., 1999).

Intrinsic Risk Factors

Sex is an intrinsic risk factor for overall injury and particularly for MSKI. Female military personnel appear to be at greater risk for MSKI compared to males (Jones, 1983; Jones et al., 1993a), but the explanation for this observation remains unclear. Anatomical characteristics and body stature are two factors which may be related to the increased risk of MSKI associated with female sex. In one study of Army recruits, shorter women exhibited a greater risk of MSKI than taller women and men (Jones et al., 1993a) and female soldiers are more likely to experience stress fractures (Pope, 1999). It has been hypothesized that when marching in formation, shorter females may take longer strides to keep pace with taller soldiers (Jones et al., 1993a; Orr, Pope, Johnston & Coyle, 2011) and the resultant exaggeration in stride length and subsequent alterations in gait mechanics sustained over long distances may heighten the risk for MSKI in female soldiers. Women also typically exhibit larger Q angles (the angle between the line from the anterior superior iliac spine to the center of patella and the line from the center of the tibial tubercle to the center of the patella) than men (Haycock & Gillette, 1976), but the connection between this measurement of the angle between the quadriceps muscles and the patella tendon and knee injury has not been firmly established and has been studied primarily in female athletes (Haycock & Gillette, 1976; Myer, Ford, & Hewett, 2005).

However, in a sample of male Army infantry personnel, those with Q angles greater than 15 degrees demonstrated an increased risk of stress fractures (Cowan et al., 1996).

A large body of evidence reveals a significant association between physical fitness/activity parameters and MSKI risk in recruits and infantrymen. Sedentary lifestyle and low physical activity levels obtained through self-reported recalls of physical activity levels just prior to the start of formal military training have been tied to a higher injury risk (Almeida et al., 1999; Jones et al., 1993a; Jones et al., 1993b). For instance, in a sample of U.S. Marine recruits, low self-reported pre-training running experience was related to a greater incidence of lower-limb stress fractures (Shaffer et al., 1999). Shaffer and colleagues (1999) also noted that a lower relative risk of injury during basic training was associated with greater running experience prior to military training. In addition, when categorized into quartiles, soldiers with the slowest mile run times were found to display the highest risk for injury (Jones et al., 1993a). This latter finding is of particular importance, as evidence linking cardiorespiratory fitness and risk of MSKI is the most robust among all observed risk factors (Jones & Knapik, 1999). Taken together, these findings suggest that recruits with low pre-training physical activity and aerobic fitness levels who are suddenly exposed to a high degree of sustained physical stress (i.e., running, long-distance marching) during basic training may incur a greater likelihood risk of MSKI (Jones et al., 1993a).

Prior research has indicated that a bimodal association exists between body mass index (BMI) and risk of physical injury. In a sample of U.S. Army recruits, men with the highest and lowest BMI measurements displayed a greater risk of injury compared to

recruits with BMI values considered “normal” (Jones et al., 1993a). When this sample was split into quartiles, men in quartiles representing the highest and lowest BMI values were 2.8 and 2.3 times more likely to be injured during basic training compared to the two middle quartiles, respectively (Jones et al., 1993a). Conversely, Jones et al. (1993b) reported no association between BMI and lower-extremity injuries in a sample of male Army trainees categorized into BMI quartiles. While the presence of an association between BMI and MSKI in males is unclear, the relationship between these two variables has not been documented in female Army recruits (Jones et al., 1993a; Jones et al., 1993b). Considering the lack of clarity regarding BMI and injury risk, body composition measurements which can assess relative body fat may be a more sensitive predictor of injury in military populations. However, such measurements are not generally practical, as they would require extensive time and more specialized resources.

The relationship between flexibility and injury in military populations is similar to that reported for BMI. Using a toe-touch test to assess lower back and hamstring flexibility, a bimodal relationship was found between flexibility and injury risk (Jones et al., 1993a), such that soldiers with limited flexibility are at increased risk for MSKI. However, no studies have identified lower and upper thresholds for flexibility to determine the optimal level of flexibility for injury prevention.

Unlike fitness parameters like cardiorespiratory function, body composition, and flexibility, muscular endurance does not appear to contribute to MSKI risk. Limited research has shown that when a sample of Army recruits in basic training was separated into quartiles, no significant difference in injury incidence was found between recruits in

the lowest and highest quartiles for the number of push-ups and sit-ups performed (Jones et al., 1993a). In view of the fact that the majority of injuries in military populations are found in the lower extremities, typical field tests of muscular fitness, such as push-ups and sit-ups, which evaluate trunk and upper-body muscle strength, may be generally insensitive to the majority of injuries experienced in soldiers.

Extrinsic Risk Factors

Extrinsic risk factors are variables that can be modified to lower the risk of MSKI under certain conditions. It is important to recognize that extrinsic risk factors may only be modifiable during activities completed in controlled training environments. Hence, active duty soldiers in combat situations will likely have little control over the mass of their external load which needs to be supported and carried, the physical requirements required to complete the assigned military operation, and the terrain which needs to be traversed. Often, these external conditions can have a negative impact on the mobility of military units (Orr et al., 2011). While light infantry units can move faster and cover greater distances (Lind, 2004), the majority of soldiers, and especially those operating in controlled training environments and deployed settings, continue to operate under standardized conditions that cannot be manipulated easily.

During basic training, overall injury rates are highest during periods featuring large training volumes (Almeida et al., 1999). Support for this assertion comes from data showing that U.S. Army recruits placed in units that run the greatest cumulative distances exhibit the highest risk for overall injury and MSKI (Jones & Knapik, 1999). It is important to note that these statistics are appropriate only for military recruits who

recently transitioned from self-selected training to formal basic training within their military units. As mentioned previously, these recruits may have also experienced dramatic increases in overall physical requirements during basic training. Considering the proposed link among MSKI, pre-training fitness, and training volume, it is possible that an elevated risk of MKSI during basic training may reflect the impact of both normal amounts of running, walking, and marching mileage and a sudden overload of physiological stress imposed on top of prior training volume.

Footwear can also influence the risk of MSKI. Footwear worn by military personnel must meet specific requirements that are vital for protecting the feet and ankles from physical damage and environmental conditions (Kaufman et al., 2000). Additionally, military boots must provide sufficient ankle support to minimize ankle injuries. As a consequence of highly protective and durable footwear, typical military boots have relatively little shock absorption properties compared to commercial boots (Williams, Brodine, Shaffer, Hagy, Kaufman, 1997). Military personnel wearing boots with low shock absorption capabilities may be more likely to experience MSKI, as the repetitive forces from running, marching, and other military tasks are not attenuated by the boot and are more readily transferred to the soft tissue and bones of the lower limbs. This risk may be heightened by performing repetitive physical activities over extended time periods during military training and active duty operations.

Load Carriage and MSKI

Historically, warfighters have traveled long distances in formation to fulfill operational duties while carrying weapons, equipment, and supplies necessary for soldier

survival and battle readiness (Orr et al., 2011). The external loads supported and carried by soldiers have progressively increased from around 15 kg before 1800, to 26 to 68 kg in recent overseas deployments in Afghanistan, depending on mission operation and the type of forces being deployed (Knapik, 1989; Dean, 2008). In the U.S. Army, loads are categorized as fighting loads, approach march loads, and emergency approach march loads (Foot Marches, 1958). In 2003, average loads for operations in Afghanistan were 29 kg for fighting loads, 46 kg for approach march loads, and 60 kg for emergency approach loads (Dean, 2008). Loaded marches are a staple in nearly all military training camps. In Army recruit training, 12-mile marches with a 35-lb rucksack must be completed within four hours to satisfy physical requirements (Basic standards of the airborne, 2011). In general, soldiers must carry external loads during most operations while being able to adequately function from tactical, survival, and mission perspectives (“Foot marches,” 1990).

While load carriage is a necessary component of military maneuvers, it can result in several negative outcomes with respect to soldier mobility, injury, and overall effectiveness of warfare. The support and transport of loads by military personnel can impose significant stress on skeletal muscles, connective tissues, and the skeleton (Harman, Han, & Frykman, 2001; Polcyn, Bense, Harman & Obusek, 2001). Reports of MSKI during heavy-loaded marches date back to 400 BC, when Greek soldiers experienced stress fractures and soft tissue damage that were life-threatening and left them unable to maintain pace with their traveling units (Lee, 2007). Despite advances in medical care and load carriage equipment such as the Modular Lightweight Load-

Carrying Equipment (MOLLE) pack, injuries during load carriage remain a significant problem for today's military personnel. Of U.S. Army soldiers who experienced MSKI, 80% were unable to continue to perform tasks with load carriage and 73% could not carry a rucksack (Jennings, Yoder, Heiner, Loan, & Bingham, 2008). From a group standpoint, the operational capability, battle readiness, and mission success of an entire military unit could be compromised if the ability to carry required loads is hindered due to MSKI (Orr et al., 2011).

Of all injuries sustained during loaded marches, the most-reported injury is foot blisters (Bush et al., 2000; Knapik, Reynolds & Harman, 2004c). The majority of the remaining injuries are musculoskeletal in nature and are located in the neck and shoulders, back, and lower limbs (Knapik et al., 2004c; Orr, Johnston, Coyle, & Pope, 2015). Knee pain has been identified as a common MSKI during load carriage in some studies (Dalen, Nilsson, & Thorstensson, 1978), but data confirming this assertion is equivocal. Dalen et al. (1978), for instance, reported a 15% incidence of knee pain during load carriage marching, but other studies have noted a 1% and 3% incidence of knee pain after a 20-km march and a 161-km march, respectively (Knapik, Reynolds, Staab, Vogel, & Jones, 1992; Reynolds, White, Knapik, Witt, & Amoroso, 1999). While speculative, it is possible that variation in physical training strategies, advancements in the ergonomic design of equipment, and the use of lighter materials may help to explain the lower incidence of knee pain in more recent investigations. While not quantified using specific criteria, researchers have noted that general knee pain may be caused by patellofemoral pain syndrome, patellar tendinitis, bursitis, and ligament strains (Knapik et al., 2004a).

Another commonly-reported MSKI occurring during load carriage is metatarsalgia, a non-specific overuse injury that typically results in pain and tenderness on the sole of the foot (Knapik et al., 2004a). Limited findings have shown that a dose-response relationship exists between load carriage task exposure and metatarsalgia (Knapik et al., 2004a). During load carriage tasks, the incidence of metatarsalgia has been reported to be 20% after seven months of training, 9% after five days of training, and 3% after a single load carriage bout of 20 km (Knapik et al., 1992; Reynolds et al., 1999; Sutton, 1976). It has been suggested that the association between load carriage task exposure and metatarsalgia may be strengthened by biomechanical deviations from normal walking behavior related to load carriage and fatigue. During load carriage, the foot may rotate around the distal metatarsal bones and increase mechanical stress (Kinoshita, 1985). Consequently, the onset of metatarsalgia during load carriage may contribute to stress fractures at the metatarsal bones caused by prolonged distances (300 miles) of loaded marching (Donald & Fitts, 1947).

While evidence supporting a link between load carriage and overall injury is robust, additional investigations are needed to study the isolated effects of load carriage on MSKI. With the exception of knee pain and metatarsalgia, the specific MSKI diagnosis in military recruits and infantrymen due to the unique effect of load carriage is sparse. This area of research has important practical implications, considering the high volume of load carriage task performance and high incidence of MSKI in soldiers.

Strategies for Minimizing MSKI in Military Personnel

In a recent paper, several prevention strategies to minimize physical training-related MSKI were reviewed (Bullock, Jones, Gilchrist, & Marshall, 2010). Research focusing on the prevention of overtraining to minimize MSKI has demonstrated a positive effect on MSKI risk. Reductions in running volume in Marine and Army recruits, for example, led to a decreased incidence of MSKI when compared to basic training incorporating more traditional amounts of running volume (Almeida et al., 1997; Jones, Cowan, & Knapik, 1994). Interestingly, in this study, 3-mile run times were found to be similar in units who trained at lower and traditional running volumes.

While Bullock et al. (2010) indicated that efforts to reduce overtraining appeared to be the most documented method of decreasing MSKI risk, the performance of multi-planar, neuromuscular, proprioceptive, and agility training has also been shown to significantly lessen MSKI. These training approaches typically utilize wobble boards, inflatable balls, and balance mats (Bullock et al., 2010) to improve stability, balance (Freeman, 1965; Tropp, Ekstrand, & Gillquist, 1983), and joint proprioception (Glencross & Thornton, 1981). Exercise programs that impose progressive challenges to balance and proprioceptive sensory input help to promote heightened mechanoreceptor activity in the joint capsule, ligaments, muscle, and skin (Bernier & Perrin, 1998). Improvements in balance and proprioception function have been shown to reduce ankle sprains, anterior cruciate ligament injuries, and MSKI (Bernier & Perrin, 1998; Ekstrand, Gillquist, & Liljedahl, 1983; Kaminski, Buckley, Powers, Hubbard, & Ortiz, 2003; Thacker et al., 1999). In addition, training programs featuring multiaxial exercises performed on

unstable surfaces can improve postural sway, reaction time, kinesthetic awareness, and control of the knee and ankle during standing, running, cutting, jumping, and landing in athletes (Bernier & Perrin, 1998; Ekstrand et al., 1983; Kaminski et al., 2003; Thacker et al., 1999).

Little research has been conducted to adopt neuromotor and balance training approaches for use by military personnel. However, it has been hypothesized that multi-planar, proprioceptive, and balance exercises reduce MSKI risk in the lower-extremity by promoting strength and stabilization of the trunk and postural muscles used during combat activities commonly performed in training and deployed settings (Bullock et al., 2010). In addition to other exercise program modifications, training programs which incorporate multi-axial calisthenic exercises have resulted in better core body stabilization, agility, and multi-planar movement skills in military recruits engaged in basic training (Knapik et al., 2004a; Knapik et al., 2004b; Knapik et al., 2003; Knapik, Bullock, Canada, Toney, & Wells, 2003; Trone, Hagan, & Shaffer, 1999). However, it is important to note that in addition to multi-planar calisthenic exercises, these training programs also addressed all components of fitness, employed gradual increases in exercise volume, precision of movement, greater variety of exercises, and decreased running mileage (Knapik et al., 2004a). Because reduced running mileage and more time spent on other training parameters have been shown to contribute to a lower rate of MSKI, the isolated effect of multi-planar, neuromotor exercise programs on MSKI is unclear in military populations (Bullock et al., 2010).

Functional Movement Screen™

In athletic and military populations, exercise assessment and training is typically focused on improving performance outcomes and evaluation of fundamental movement efficiency is often neglected. While this approach is designed to enhance performance, it does not address factors related to the risk of MSKI. Prominent researchers and practitioners from several fitness organizations (ACSM, NSCA, NASM, DoD) have described functional mobility, stability, and movement efficiency/quality as foundational variables underlying the development of athletic performance characteristics such as power, speed, agility, quickness, and endurance (Teyhen et al. 2014).

Description of the FMS

Deficiencies in functional movement have been associated with MSKI. Interestingly, a large proportion of individuals exhibit altered movement patterns, regardless of athletic ability (Kiesel et al., 2007; O'Connor et al., 2011; Plisky et al., 2006). Recently, investigators have begun using the Functional Movement Screen™ (FMS) to identify individuals with altered movement patterns. The FMS is a screening tool designed to identify movement deficiencies while performing functional movements that may contribute to MSKI (Cook, Burton, Hoogenboom, & Voight, 2014). The seven functional movements which comprise the FMS are (1) deep squat, (2) hurdle step, (3) in-line lunge, (4) shoulder mobility, (5) active straight leg raise, (6) trunk stability push-up, and (7) rotary stability test (Cook et al., 2006a; Cook et al., 2006b; Cook, 2011; Cook, Burton, Hoogenboom, & Voight, 2014). Based on a proprioceptive-based rationale, the FMS™ is intended to evaluate the stability, mobility, and symmetry of the body during

functional movement patterns (Cook et al., 2006a; Cook et al., 2006b; Cook, 2011). Individuals who perform poorly on FMS tests are likely to exhibit compensatory movement patterns that deviate from optimal movement mechanics that may increase the risk of MSKI (Cook et al., 2006a; Cook et al., 2006b; Cook, 2011; Kiesel et al., 2007; O'Connor et al., 2011; Plisky et al., 2006). Using data from the FMS, an evaluator can provide quantifiable information concerning the performance of basic locomotor, manipulative, and stabilization movements, as well as identify altered movement patterns (Cook et al., 2014).

FMS Scoring and Clearing Tests

During the FMS, each functional movement (FM) is performed three times, after which a score between 0 and 3 is assigned, based on a set of standardized visual criteria (Cook, 2011). A score of zero is recorded only if the performer experiences pain at any point during the FM. If an individual reports pain during any movement, the performer should be evaluated using the Selective Functional Movement Assessment (SFMA), rather than the FMS (Cook, 2011). If an individual cannot complete an FM, they receive a score of 1 and if an FM can be completed only with compensatory movement, a score of 2 is assigned. If an FM can be performed correctly without performing a compensatory movement, a score of 3 is assigned. After the shoulder mobility, stability push-up, and rotary stability movements have been completed, pain “clearing tests” are conducted to identify specific movement characteristics that may cause painful movement and injury. For example, if pain is experienced during the clearing test for the shoulder mobility movement, an individual may have a shoulder impingement or a lack of flexibility in the

shoulder girdle (Cook et al., 2006a; Cook et al., 2006b). If pain occurs while performing a specific clearance test, a score of zero should be given for the associated functional movement. After completion of the FMS, the score for each FM is added to provide a composite score out of a possible 21 total points. For tests that assess both sides of the body, the lowest score is recorded and used to calculate the composite score.

The FMS is ideal for practitioners, as it requires minimal equipment and time commitment from test administrators and those being assessed and can be used to screen large samples. The FMS is also easy to administer and has high scoring reliability (ICC = 0.906; kappa values = 0.80 to 1.00) when used by experienced and inexperienced evaluators (Leeder, Horsley, & Herrington, 2016; Minick et al., 2010). In this regard, moderate to good intra-rater and inter-rater reliability of FMS have been reported (intraclass correlation = 0.74 to 0.95) when testing athletic and active populations (Gribble et al., 2013; Minick et al., 2010) and active-duty service members (Teyhen et al., 2012).

Prediction of MSKI Using the Functional Movement Screen™

A review of the literature suggests that the FMS may be appropriate to predict and address improper body mechanics and MSKI in active populations. Based on a retrospective study of professional American football players (Kiesel et al., 2007), an FMS composite score of 14 or less indicates a significantly greater risk for MSKI. In this study, players with a score of 14 or less were nearly 12 times more likely to be injured throughout the course of a season. Additionally, players with asymmetrical scores between limbs/sides of the body were three times more likely to be injured. In contrast,

other investigations do not support the use of FMS composite scores to predict injury. In a sample of 18- to 24-year-old male competitive middle and long-distance runners, for instance, the mean FMS composite score assessed in the preseason was 14.1 ± 2.3 (Hotta et al., 2015). After completing a 6-month competitive season, findings indicated that the composite FMS score exhibited lower sensitivity and specificity for predicting running related MSKI when compared to summing functional movement scores for deep squat and active straight leg raises. Similarly, deep squat and trunk stability pushup scores were better predictors of non-contact injury compared to the composite FMS score in a sample of 135 professional soccer players (Rusling et al., 2015). These conflicting findings highlight the lack of clarity regarding the degree to which the FMS can accurately predict injury in active populations. A recent review of the efficacy of the FMS revealed moderate support for the effectiveness of predicting injury in team sport athletes using composite FMS scores (Kraus, Schutz, Taylor, & Doyscher, 2014).

Support for using the FMS to predict injury in military populations, while limited, is more consistent. In a sample of 874 Marine officer candidates, the average FMS composite score was 16.7 ± 1.7 (O'Connor et al., 2011) and approximately 11% of candidates scored a 14 or less (Lisman et al., 2013; O'Connor et al., 2011). In this group of officer candidates, those with FMS scores of 14 or less and slow 3-mile run times were 1.7 to 1.9 more likely to be injured than those with scores higher than 14 (O'Connor et al., 2011). These results are consistent with other research indicating that an FMS score of less than or equal to 14 may be a threshold for greater injury risk (Kiesel et al., 2007). The aforementioned duo of studies using the same cohort of Marine Officer Candidates

are the only investigations documenting the efficacy of the FMS in military populations. From an armed forces perspective, the ultimate goal is to predict MSKI by identifying functional movement deficiencies that predispose military personnel to high joint forces and dangerous loading patterns (Teyhen et al., 2014). If the FMS is a valid indicator of movement dysfunction, practitioners can use data from the FMS to develop and prescribe corrective exercise programs to address specific movement deficiencies of individual soldiers and reduce the incidence of MSKI. However, few reports are available regarding the proper interpretation and prescription of corrective exercise programs based on FMS data.

Balance Assessment Methods

In healthy populations, maintaining balance depends on visual cues, vestibular function, and somatosensory feedback from lower-limb structures (Nasher, 1997). As such, balance during dynamic movements requires greater somatosensory feedback and reactivity compared to static balance. Many researchers have investigated static balance, which may not strongly relate to functional activities requiring dynamic balance (Cachupe, Shifflett, Kahanov, & Wughalter, 2001). Therefore, balance assessment methods used in research must be chosen carefully based on the population being examined, physical ability, and the nature of the activity used to assess balance ability.

The Biodex Balance System (BBS) is a reliable tool for measuring dynamic balance and assessing proprioception by requiring mechanoreceptor feedback and subsequent reactivity to instability (Cachupe et al., 2001; Wilkerson & Nitz, 2010). The BBS uses a circular platform that, when disengaged from the base, reduces stability of the

platform to a specified difficulty level ranging from least stable (1) to most (8) stable. The BBS provides anterior-posterior, medial-lateral, and overall stability index scores, with overall stability index scores being the most reliable (Arnold & Schmitz, 1998). Balance trials on the BBS typically last 20 seconds, and two practice trials are recommended to obtain reliable measures (Cachupe et al., 2001).

The overall body of research using the BBS is quite broad, ranging from using the system for general balance assessment, balance training, and change in balance ability after intervention in athletic, elderly, clinical, and healthy populations (Akbari, Karimi, Farahini, & Faghihzadeh, 2006; DiStefano, Clark, & Padua, 2009; Gusi et al., 2012; Karimi, Ebrahimi, Kharizi, & Torkaman, 2011; Oh, Kim, Lee, & Lee, 2011). The BBS has been used to validate other balance and functional assessments, such as the timed-up-and-go test and the Star Excursion Balance Test (SEBT), (Akbari et al., 2006; Oh et al., 2011). While no gold standard for balance measurement currently exists, the BBS is arguably one of the most widely-accepted objective measurements of balance, proprioceptive function, and ankle stability, and has been used in general, athletic, and special populations (Akbari et al., 2006; Arnold & Schmitz, 1998; Cachupe et al., 2001; Testerman & Griend, 1999; Wilkerson & Nitz, 2010). In summary, the BBS provides a well-established and reliable assessment of balance for nearly all populations and can be used as a reference comparison for other balance and proprioception assessments.

The SEBT is an inexpensive, reliable, and relatively convenient method for quantifying functional balance ability in active and athletic populations (Attenborough et al., 2016; Cavanaugh, Quigley, Hodgson, Reid, & Behm, 2016). The SEBT requires a 1-

legged stance on a grid of eight lines. The participant is then asked to perform a maximal reach with the free leg in anterior, anteromedial, medial, posteromedial, posterior, posterolateral, lateral, and anterolateral directions. Reach distance is recorded and normalized based on individual leg length. Farther reach distances indicate better balance, lower-extremity coordination, flexibility, and strength (Plisky et al., 2006). Given the complexity of balance ability, the multifactorial nature of the SEBT makes it a valid tool for identifying of poor balance that may contribute to MSKI risk factors, such as ankle instability, in active and athletic populations (Akbari et al., 2006; Olmstead, Carcia, Hertel, & Shultz, 2002; Plisky et al., 2006).

Balance Deficiencies and Risk of MSKI

The performance of athletic tasks and the associated risk of MSKI is multifaceted. However, neuromuscular control and balance serve as a foundation for the performance of all skill-related movements (Teyhen et al., 2014). Moreover, balance, joint proprioception, and overall functional joint stability are key factors which contribute to the risk of MSKI of lower-limb joints (McGuine et al., 2000; Tropp et al., 1983; Wedderkopp, Kalltoft, Holm, & Froberg, 2003). Athletes that display poor performance and a high center of pressure displacement while performing single-leg balance tests display a 2- to 10-fold greater likelihood of experiencing an ankle sprain (McGuine et al., 2000; Trojian & McKeag, 2006; Watson, 1999). While the aforementioned studies identified a relationship between balance and injury, all balance assessments were static in nature. While important, these results are somewhat impractical because most injuries do not occur under static circumstances.

Theoretically, use of a dynamic balance test likely would appear to have greater construct validity compared to static tests and more accurately document the ability to stabilize posture in multiple planes of motion and compensate while performing specific movements that cause joint injury (Noronha, Franca, Haupenthal, & Nunes, 2013). Dynamic balance measures obtained using the SEBT in high-school basketball and collegiate football players prior to the start of a competitive season were highly correlated with the incidence of non-contact lower-extremity injury (Butler et al., 2013; Plisky et al., 2006). In these studies, athletes with poor balance test scores were 2.5 to 6.5 times more likely to experience MSKI (Butler et al., 2013; Plisky et al., 2006). Likewise, active, but non-athlete, university-aged students with poor dynamic balance exhibited a greater likelihood of having a lower-extremity injury (Noronha et al., 2013). In this investigation, students' anterior, postero-medial, and postero-lateral balance abilities were measured using the SEBT, after which the incidence of ankle sprains was tracked. Results from this investigation demonstrated that students with poor postero-lateral balance were 48% more likely to suffer an ankle sprain over the course of one year (Noronha et al., 2013). Several studies have also reported that the SEBT effectively identifies ankle instability in active and athletic populations (Olmstead et al., 2002; Plisky et al., 2006). In summary, it appears that the SEBT is a valid and efficient means of assessing balance ability, degree of ankle stability, and subsequent lower-limb MSKI risk.

While a paucity of information is available regarding the link between dynamic balance and MSKI in trained, active-duty military personnel, the relationship which exists between poor balance and risk for injury in athletic and active populations may

also be present for members of the military (Schiffman et al., 2004). This theory is supported by data from multi-axial, proprioceptive, and neuromotor training interventions in Army and Marine soldiers revealing that MSKI incidence was significantly decreased. It is possible that the hypothesized association between poor balance and risk of MSKI may be even stronger in military personnel due to load carriage requirements for soldiers. In a sample of enlisted Army soldiers, gradual increases in loads produced greater excursion of center of pressure, or postural sway, during a static balance test (Schiffman et al., 2004). Similar studies have also reported that military-style loading tactics decreased static balance control in Army ROTC recruits (May et al., 2009). As in studies investigating balance in other populations, balance tests in military populations are static assessments. However, it would seem more appropriate to evaluate dynamic balance when evaluating active-duty soldiers, given the importance of maintaining balance during marching and the performance of movements in urban scenarios such as stair climbing, quick turns, and entering through windows (Schiffman et al., 2004).

Association Between Balance and FMS Movements

To date, only one study has explored the relationship between FMS movements and balance (Hartigan, Lawrence, Bisson, Torgerson, & Knight, 2014). In this study, the authors quantified the association between the in-line lunge and power, speed, and balance. Balance was measured as center of pressure excursion in the medial-lateral direction while performing an in-line lunge. The best in-line lunge score out of three repetitions was used for analysis. Findings from this investigation revealed no relationship between balance during the in-line lunge and the in-line lunge composite

score. A major limitation noted in this study was that center of pressure excursion was only assessed during the in-line lunge rather than including balance data from the deep squat and hurdle step as part of the overall assessment of balance ability. Additionally, because center of pressure excursion was measured in the medial-lateral direction, analysis of excursion in all movement planes would have enabled the FMS to predict balance ability with greater sensitivity.

Conclusion

Lower-limb musculoskeletal injury are common occurrences in military personnel and account for significant medical treatment costs, loss of duty days, and personnel resources. Consequently, the ability to identify soldiers who are at risk for MSKI is critical for minimizing financial and personal losses and sustaining a strong military force. Soldiers with poor balance and mobility, two primary variables for athletic performance which are required during loaded marching and urban terrain tasks, may be at greater risk for sustaining ankle MSKI. The addition of torso load during military maneuvers may present additional challenges to maintaining balance ability during military maneuvers. The FMS was developed to assess balance, mobility, and bilateral strength by performing a series of functional movements and has been shown to accurately predict MSKI in athletic and military populations. While the FMS may be a viable and practical tool for predicting MSKI risk, the construct validity of the FMS has not been investigated. Due to the importance of balance during unloaded athletic movements and loaded military maneuvers, more research is needed to determine if FMS

composite and subscores can identify deficiencies in balance tasks performed under unloaded and loaded conditions.

CHAPTER III

FUNCTIONAL MOVEMENT SCREEN SCORES AND BALANCE

Introduction

While the performance of regular physical activity is associated with numerous health benefits (Physical Activity Guidelines Advisory Committee, 2008), the possibility of injury is an inherent risk of engaging in physical activity and exercise (Koplan, Siscovick, & Goldbaum, 1985; Pate et al., 1995; US Department of Health and Human Services, 1996). Musculoskeletal injuries (MSKI), particularly those occurring in the lower extremities, are prevalent among sedentary and active adults, military warfighters and recruits, and athletes of various disciplines and ability levels (Agel, Evans, Dick, Putukian, & Marshall, 2007a; Agel, Olson, Dick, & Arendt, 2007b; Almeida, Maxwell-Williams, Shaffer, & Brodine, 1999; Almeida, Maxwell-Williams, Shaffer, Luz, & Badong, 1997; Bennell & Crossley, 1996; Bush, Brodine, & Shaffer, 2000; Hootman et al., 2002; Kaufman, Brodine, & Shaffer, 2000; Jones, Bovee, Harris, & Cowan, 1993a; Jones et al., 1993b; US Department of Health and Human Services, 1996). Historically, musculoskeletal injuries (MSKI) are the major cause of work-related illnesses and missed work days among the lay public and military population of the United States (Almeida et al., 1997; Bernard & Fine, 1997; Feeney, North, Head, Canner, & Marmot, 1998; Hootman et al., 2002; Jones, Manikowski, Harris, Dziados, & Norton, 1988; Riihimaki, 1995; National Research Council, 2001). Sustaining an MSKI not only presents

challenges in maintaining daily physical function and covering treatment costs, but can also restrict participation in physical activity and sport pursuits and lead to extended periods of missed work days (Hootman et al., 2002).

Due to the high incidence and adverse outcomes of incurring muscle and skeletal injuries, injury prevention and the identification of persons at risk for MSKI are of great clinical importance. Over the past decade, researchers and practitioners have started to use the Functional Movement Screen™ (FMS), a comprehensive pre-participation screening tool, to identify persons at risk for MSKI. Developed to assess mobility, balance, and postural stability while performing seven functional movements involving the upper and lower body (Cook, Burton, & Hoogenboom, 2006a; Cook, Burton, & Hoogenboom, 2006b), the FMS has been shown to exhibit good reliability (Gribble, Brigle, Pietrosimone, Pfile, & Webster, 2013; Leeder, Horsley, & Herrington, 2013; Minick et al., 2010). FMS composite scores of 14 or less (out of 21 total points) have been associated with increased injury risk in athletic and military populations (Chorba, Chorba, Bouillon, Overmyer, & Landis, 2010; Kiesel, Plisky, & Voight, 2007; Lisman, O'Connor, Deuster, & Knapik, 2013; O'Connor, Deuster, Davis, Pappas, & Knapik, 2011; Zarei, Samani, & Reisi, 2015). Conversely, other investigators have reported the absence of a relationship or predictive value between injury occurrence and FMS composite scores, various FMS subscores, and combinations of FMS subscores (Dorel, Long, Shaffer, & Myer, 2015; Hotta et al., 2015; Moran, Schneiders, Mason, & Sullivan, 2017; Rusling et al., 2015; Wiese, Boone, Mattacola, McKeon, & Uhl, 2014).

While the risk for MSKI is multifactorial in nature, balance appears to be an important factor when considering lower-limb MSKI. Lower balance scores, as measured using a force plate, the Star Excursion Balance Test, the Y Balance Test, and single-leg balance tests, have been linked to increased MSKI in samples of athletes and non-athletes (Beynon, Murphy, & Alosa, 2002; Gribble, Hertel, & Plisky, 2012; McGuine, Greene, Best, & Levenson, 2000; Plisky, Rauh, Kaminski, & Underwood, 2006; Trojian & McKeag, 2006; Tropp, Ekstrand, & Gillquist, 1983; Willems et al., 2005). Because the amount of core stability needed to initiate compensatory postural adjustments to overcome changes in center of gravity can influence lower-extremity joint forces, the risk of lower-extremity injury may be highest in situations where balance is challenged (Brown, Haumann, & Potvin, 2003). The association between reduced balance ability and increased lower-extremity MSKI risk is also reflected by data showing a reduction in the incidence of injury and rate of injury reoccurrence following balance training or balance training implemented as part of a comprehensive training program (Caraffa, Cerulli, Progetti, Aisa, & Rizzo, 1996; Holme et al., 1999; Malliou, Gioftsidou, Pafis, Beneka, & Godolias, 2004; Tropp, Askling, & Gillquist, 1985; Verhagen et al., 2004).

Relatively little is known concerning the use of the FMS to predict balance. Although Hartigan et al. (2014) found no association between in-line lunge FMS sub-scores and balance measured by force plate during an in-line lunge movement, the remaining six movements of the FMS (deep squat, hurdle step, shoulder mobility, active straight-leg raise, trunk stability push-up, rotary stability) were not evaluated. In contrast, a lack of association between the FMS composite score and data from the Balance Error

Scoring System was observed for an adult sample with a broad age range (Perry & Koehle, 2013). Because the literature in this area is sparse, additional research is needed to quantify the construct validity of the FMS by documenting the relationship between overall and individual FMS scores and other additional balance assessment methods. Hence, the purpose of this study was to quantify the association between FMS composite scores and subscores and dynamic balance in healthy adults using the Biodex Balance System and the Y balance test.

Methods

Participants

Healthy males ($n = 22$) and females ($n = 12$) between the ages of 18 and 30 (mean age = 23.8 ± 3.1 years) were recruited to participate in the current investigation and completed an American College of Sports Medicine-American Heart Association health classification form and a Physical Activity Readiness Questionnaire (PAR-Q) to confirm their readiness to safely engage in this study. Mean height and weight for participants were 173.6 ± 7.4 cm and 79.4 ± 16.2 kg, respectively, and body fat percentage assessed via skinfolds was 16.4 ± 6.7 %. Using the International Physical Activity Questionnaires (IPAQ), 23 participants self-reported high physical activity levels and 11 participants reported moderate physical activity levels. To mitigate the influence of pre-existing injury on FMS and balance variables, individuals who had experienced a musculoskeletal injury or undergone lower-extremity surgery within a 12-month period were excluded from participation. Participants were asked to refrain from heavy exercise, alcohol consumption, and caffeine intake for 24 hours before all testing sessions and maintain

prescribed levels of medication use throughout the study. All testing procedures were approved by the university Institutional Review Board and written informed consent was obtained from all study participants.

Procedures

Body weight and height were measured twice using a digital scale (Tanita BF-522; Tanita Corporation, Tokyo, Japan) and a standard stadiometer, respectively, and averaged to derive mean body mass and height values. Triplicate measures of skinfold thickness at three body locations (men: chest, abdomen, thigh; female: tricep, suprailiac, thigh) were obtained in a serial fashion with a calibrated Lange skinfold caliper (Cambridge, MD, USA) and used to estimate body fat percentage (Pollock, Schmidt, & Jackson, 1980). If any two skinfold thicknesses at a given body site varied by more than 2 mm, an additional skinfold measurement was taken and the average of the two closest measures within a 2-mm range was used to estimate body fat percentage. To normalize Y Balance Test data, leg length was measured in the supine position from the anterior superior iliac spine to the center of the ipsilateral medial malleolus (Gribble & Hertel, 2003). Duplicate measures of anatomical leg length were also recorded and averaged to normalize maximal reach distances of the same leg.

Following anthropometric data collection, Functional Movement Screening™ (FMS) data were obtained. The seven assessments of the FMS involved performing the following body movements: (1) deep squat, (2) hurdle step, (3) in-line lunge, (4) shoulder mobility, (5) active straight leg raise, (6) trunk stability push-up, and (7) rotary stability (Cook et al., 2006a; Cook et al., 2006b). Each movement was performed two to three

times, depending upon the need to observe some movement patterns from different planes (Cook et al., 2006a; Cook et al., 2006b). The hurdle step, in-line lunge, shoulder mobility, active straight leg raise, and rotary stability movements were scored separately for each side of the body. After shoulder mobility, stability push-up, and rotary stability movements were completed, clearing exams intended to identify specific movement characteristics associated with painful movement or pre-existing injuries were completed. All FMS trials were scored by the same strength and conditioning specialist on a 0-to-3 ordinal scale, based on standardized FMS visual criteria (Cook et al., 2006a; Cook et al., 2006b). If a participant was unable to complete a body movement, a score of 1 was noted. Participants who were able to perform a movement, but displayed compensatory movement patterns, received a score of 2, and the correct performance of a movement without a compensatory movement pattern being displayed received a score of 3. The total score out of a possible 21 points (maximum score of 3 points per body movement) was calculated as the sum of scores for all seven movements. For bilateral assessments, the trial with the lowest score was used for statistical analysis (Cook et al., 2006a; Cook et al., 2006b). If any pain was reported during clearing exams for the shoulder mobility, stability push-up, and rotary stability movements, a score of zero was recorded.

After FMS testing, participants performed a Y balance test (YBT) and a balance test on a Biodex Balance System (BBS) in a counterbalanced order. In the YBT, participants assumed the YBT standardized starting position on a YBT kit, with the distal aspect of the first toe at the starting line. Participants stood on one leg and assessments performed for both legs and the starting stance leg were counterbalanced between

participants. Each participant was encouraged to extend the free leg as far as possible in anterior, posteromedial, and posterolateral directions. Maximal reach distance was recorded as the distance from the first toe of the stance leg (at the center of the grid) to the point at which the most distal part of the reaching foot was able to push the measurement block in the designated plane. These procedures were repeated three times for each leg. If a participant failed to maintain a single-leg stance, lifted or moved the stance foot, touched the reaching foot to the ground, or failed to return the reach foot to the starting position, the trial was repeated. To prevent a learning effect, each participant performed four separate YBT familiarization trials, with 3- to 5-minute rest periods separating each assessment (Robinson & Gribble, 2008). Following the familiarization trials, participants performed the YBT by completing three maximal anterior reach, posteromedial reach, and posterolateral reach attempts, with the greatest reach distances for each movement used for statistical analysis. A composite reach distance (CR) was calculated as the sum of the greatest reach distances in each direction for analysis of overall YBT performance (Plisky et al., 2006). The anterior, posteromedial, posterolateral, and composite reach distances were normalized by dividing each distance by leg length and multiplying the quotient by 100 (Gribble & Hertel, 2003).

Balance assessment was also conducted using the BBS. In this test, participants stood on a multiaxial platform with a 20° maximal platform tilt while looking at a monitor that illustrated the center of the platform using a cursor within a bullseye. All BBS tests were performed bilaterally with eyes open and the hands placed on the hips. Participants were asked to stand on the platform and assume a comfortable position. The

platform of the BBS consisted of a grid for standardizing foot placement. After a comfortable foot position was established and both feet were placed evenly on the platform, heel and toe coordinates were recorded and used in all subsequent BBS testing. After being instructed to keep the cursor on the monitor as close to the center of the bullseye as possible, participants completed three familiarization BBS trials, followed by a 3- to 5-minute rest period (Cachupe, Shifflett, Kahanov, & Wughalter, 2001; Pincivero, Lephart, & Henry, 1995). After the rest period, two sets of formal BBS trials were performed. Each set of BBS trials consisted of three, 20-second trials, during which bilateral balance was assessed at an instability level of 1 (with level 8 being most stable and level 1 being least stable). If balance was lost and the handrails were grabbed during BBS testing, the trial was repeated. For each set of balance trials, BBS software calculated the average overall stability index (OSI) using anterior-posterior and medial-lateral stability indices. Lower OSI scores reflected less deviation from the center of gravity, while better overall stability and higher OSI scores were indicative of greater deviation from the center of gravity and less overall stability.

Statistical Analysis

Pearson-product moment correlation analyses were used to quantify the relationship between FMS composite scores and the CR and OSI composite balance scores. FMS composite scores were then recoded into binary variables separated at a score equal to or less than 14, the composite score injury threshold adopted by previous researchers (Kiesel et al., 2007; Lisman et al., 2013; O'Connor et al., 2011; Zarei et al., 2015). Differences in composite balance scores (CR and OSI) between binary FMS

composite score variables of less than or equal to 14 and 15 or greater were determined at an $\alpha \leq .05$. Statistical analyses were performed using IBM SPSS software (SPSS

Statistics v20.0, IBM Corporation, Armonk, New York). Effect sizes were calculated as

$$d = \frac{Mean_1 - Mean_2}{\sqrt{\frac{Variance_1 + Variance_2}{2}}}$$

Determining an optimal model from FMS subscores to predict balance presents several challenges. The full model of the FMS consists of a relatively large number of predictors, all of which are ordinal data points. Traditional regression techniques, like dummy coding and linear fitting, may overestimate model fit or inappropriately scale the ordinal FMS items as continuous data (Gertheiss & Tutz, 2009). To address these limitations, a lasso penalized regression, which penalizes the coefficients of each predictor as a group rather than removing individual dummy variables from the model, was used to calculate group penalization parameters (Λ) for all FMS subscores to predict CR and OSI composite balance scores. For all predictors with recorded FMS scores ranging from 1 to 3, the score of 1 was designated as the reference category. All ordinal predictor coefficients were smoothed and statistical significance for each coefficient retained in the model was assessed using a bootstrap 95% confidence interval (CI). Lasso penalized regression analyses were conducted using ordPens (Gertheiss, 2015), gpreg (Breheny & Huang, 2015), boot (Canty & Ripley, 2017; Davidson & Hinkley, 1997), and base packages in R Version 3.4.2 (R Core Team, 2017).

Results

For both balance assessments, higher FMS composite scores were associated with better balance. FMS composite scores ($M = 15.85$, $SD = 2.48$) were positively related to

CR ($M = 95.61$, $SD = 7.10$, $r(32) = .60$, $p < .001$) and negatively related to OSI scores (with lower OSI scores indicating better balance) ($M = 9.17$, $SD = 3.00$, $r(32) = -.40$, $p = .018$). Fourteen participants scored 14 or less on the FMS and 20 participants scored 15 or higher. Mean CR scores were $91.4 \pm 6.0\%$ for members of the ≤ 14 group, and $98.5 \pm 6.4\%$ for members of the ≥ 15 group. Mean OSI scores were 10.0 ± 3.2 and 8.6 ± 2.8 for participants with FMS scores of ≤ 14 and ≥ 15 , respectively. Analysis of the difference in balance scores between the ≤ 14 and ≥ 15 groups revealed that participants in the low-scoring group exhibited significantly shorter CR values compared to those in the high-scoring group ($t(32) = -3.29$, $p = .003$, $d = 1.14$). However, OSI scores were not significantly different between low- and high-scoring FMS groups ($t(32) = 1.32$, $p = .199$, $d = 0.47$).

Findings from the penalized regression models, represented as unsmoothed and smoothed coefficients, as well as 95% confidence intervals, are shown in Table 1. Scores from two FMS items, active straight-leg raise and trunk stability push-up, were recoded into binary variables [(3) vs (2 or 1)] because a score of 1 was only achieved by 2 of the 34 participants. No participants were scored as 1 on the rotary stability item so it was also represented as a binary variable (3 vs 2). Hence, scores of 3 were compared to all lower scores for the active straight-leg raise and trunk stability push-up, and a score of 3 was compared to 2 for the rotary stability item.

When predicting the composite CR score, all FMS items were retained ($\Lambda = 0.16$) in the penalized regression model, but trunk stability push-up and deep squat were the only significant predictors, based on 95% confidence intervals. A score of 3 on the trunk

Table 1

Coefficients and 95% confidence intervals for retained FMS items predicting balance test performance.

| FMS Item | Subscore | Smoothed | | Unsmoothed | |
|--------------------------------------|----------|----------|-----------------|------------|-----------------|
| | | Coeff | 95% CI | Coeff | 95% CI |
| Composite Reach Distance (CR) | | | | | |
| Deep Squat | 2 | 8.28 | (0.001, 17.18)* | 8.46 | (-1.73, 17.05) |
| | 3 | 9.46 | (-1.77, 21.28) | 9.50 | (-3.02, 21.54) |
| Hurdle Step | 2 | -3.63 | (-12.06, 5.86) | -3.78 | (-13.21, 7.15) |
| | 3 | -7.94 | (-15.82, 1.55) | -8.22 | (-17.26, 2.59) |
| In-Line Lunge | 2 | 1.97 | (-7.02, 9.98) | 2.07 | (-8.26, 12.30) |
| | 3 | 8.91 | (-5.01, 19.26) | 9.23 | (-5.95, 22.27) |
| Shoulder Mobility | 2 | 5.65 | (-4.14, 12.73) | 5.75 | (-3.69, 12.37) |
| | 3 | 5.01 | (-3.23, 13.53) | 5.01 | (-3.14, 15.56) |
| Active Leg Raise | 3 | 5.99 | (-1.90, 14.36) | 6.17 | (-2.34, 14.72) |
| Stability Pushup | 3 | 6.68 | (1.40, 11.80)* | 6.77 | (1.24, 11.72)* |
| Rotary Stability | 3 | 0.97 | (-7.57, 10.83) | 0.91 | (-6.57, 10.54) |
| Overall Stability Index (OSI) | | | | | |
| Shoulder Mobility | 2 | -2.39 | (-4.72, -0.19)* | -2.42 | (-4.93, -0.50)* |
| | 3 | -4.66 | (-6.65, -2.57)* | -4.74 | (-6.41, -2.39)* |
| Rotary Stability | 3 | -1.93 | (-3.56, -0.31)* | -1.93 | (-3.66, -0.36)* |

Note. * $p \leq .05$. Confidence intervals for CR unsmoothed coefficients were based on 946 samples. Smoothed CR coefficient confidence intervals were based on 952 samples. Lower OSI scores represent better balance. For OSI confidence intervals, 979 and 976 samples were used for unsmoothed and smoothed data, respectively.

stability push-up item was predictive of greater CR compared to a reference category of all lower scores. For the deep squat, a score of 2 predicted greater CR. Relative to the prediction of OSI, only the shoulder mobility and rotary stability items were retained in the model OSI ($\Lambda = 0.45$). Scores of 2 and 3 on the shoulder mobility item were predictive of better (lower) OSI scores compared to the reference category of 1. A score of 3 on the rotary stability item was also predictive of better OSI compared to a score of 2.

Discussion

While many studies have documented the effectiveness of the FMS to predict MSKI risk, findings concerning the validity of this screening tool are equivocal (Chorba, Chorba et al., 2010; Dorrel et al., 2015; Hotta et al., 2015; Kiesel et al., 2007; Lisman et al., 2013; Moran et al., 2017; O'Connor et al., 2011; Rusling et al., 2015; Zarei et al., 2015). Consequently, researchers have gravitated toward study designs that evaluate relationships between the FMS and well-known MSKI risk factors like balance, aerobic fitness (Lisman et al., 2013), and body mass index (Heir & Eide, 1996; Jones, et al., 1993b; Perry & Koehle, 2013). Because poor dynamic balance is a well-established risk factor for injury across many populations (Beynon et al., 2002; Gribble et al., 2012; McGuine et al., 2000; Plisky et al., 2006; Trojian & McKeag, 2006; Tropp et al., 1983; Willems et al., 2005), recent studies in this area have focused on exploring the link between FMS scores and dynamic balance (Clifton, Harrison, Hertel, & Hart, 2013; de la Motte, Gribbin, Lisman, Beutler, & Deuster, 2016; Glass & Ross, 2015; Kelleher et al., 2017; Lockie et al., 2015; Teyhen et al., 2014). Based on the multifactorial nature of

MSKI risk and the comprehensiveness of the FMS as a screening assessment for potential injury risk, it seems reasonable to hypothesize that the FMS might be able to identify persons who display poor balance.

In the present investigation, higher FMS composite scores were related to longer composite reach distances on the YBT ($r = .60, p < .001$), and greater overall stability as measured using the Biodex Balance System ($r = -.40, p = .018$). These dual findings support data from studies reporting the presence of a mild to moderate positive relationship ($r = .35$ to $.49$) between FMS composite scores and YBT performance in samples of healthy adults and military recruits (de la Motte et al., 2016; Kelleher et al., 2017; Perry & Koehle, 2013; Teyhen et al., 2014). Conversely, other studies have found no significant association between composite scores and balance in the general public and recreationally active and team-sport athletic populations (Clifton et al., 2013; Lockie et al., 2015; Perry & Koehle, 2013). While the methodology for acquiring FMS data appears relatively consistent across studies, balance assessment techniques vary markedly. Studies which have documented significant relationships between the FMS composite scores and balance, for example, have employed dynamic balance tests like the YBT and Landing Error Scoring System (de la Motte et al., 2016; Kelleher et al., 2017; Teyhen et al. 2014). In contrast, static balance assessments, such as the Balance Error Scoring System and center of pressure mapping on a force plate, have been used in the majority of studies revealing no significant association between FMS composite scores and balance (Clifton et al., 2013; Perry & Koehle, 2013). Although performance on both balance tests were significantly correlated with FMS composite scores in the current

investigation, the absolute magnitude of the relationship was higher when FMS data were correlated with scores from the YBT ($r = .60$), a dynamic and functional evaluation of balance, as compared to values derived from Biodex testing ($r = -.40$) featuring minimal movement performed in a closed kinetic chain, bipedal stance. Interestingly, the absence of statistical significance between FMS composite scores and balance reported in some published studies has been tied to the use of static balance assessments, which lack the functional characteristics or movement components that FMS items were developed to evaluate (Glass & Ross, 2015).

Early investigations reported that athletes who achieved FMS composite scores of less than 14 were at significantly greater injury risk than those with scores exceeding 14 (Chorba et al., 2010; Kiesel et al., 2007). However, more recent studies have yielded a dichotomy of evidence supporting and refuting the use of the threshold score of 14 to predict injury risk in military personnel and athletes with various competitive backgrounds (Dorel et al., 2015; Hotta et al., 2015; Lisman et al., 2013; Moran et al., 2017; O'Connor et al., 2011; Rusling et al., 2015; Wiese et al., 2014; Zarei et al., 2015). Given that balance is related to injury risk, a desired quality for a threshold score is to identify poor balance in order for the FMS instrument to qualify as a comprehensive screening tool. In this regard, participants in the current investigation who achieved composite scores of 14 or less exhibited significantly shorter composite reach distances than those scoring greater than 14 ($t(32) = -3.29, p = .003, d = 1.14$). While the magnitude of difference in overall stability index (OSI) scores between participants scoring above and below the threshold composite score was indicative of an effect size of

moderate strength ($d = 0.47$), no statistical group difference was noted ($t(32) = 1.32, p = .20$). Although speculative, the lack of significance in dynamic stability between participants in the below- and above-threshold groups may have been a function of low statistical power resulting from the relatively small number of subjects in each threshold category.

When traditional regression techniques are used to analyze the predictive ability of individual FMS movements, ordinal FMS item scores are typically treated as interval data, which may result in an overestimation of the model fit (Gertheiss & Tutz, 2009). To overcome this potential drawback, we conducted two lasso penalized regressions to identify which FMS item scores predicted CR and OSI. Findings from these analyses demonstrated that individuals who scored lower than 3 on the trunk stability push-up displayed significantly shorter composite reach distances than those who scored a 3 on this body movement. Additionally, greater composite reach distance was predicted by deep squat scores of 2, but not 3. This latter finding was not surprising, considering the overlap in the movement abilities needed to perform well on the Y balance test and deep squat item. Although the deep squat is performed bilaterally and the Y balance test uses unilateral reaching movements, both of these tools assess functional mobility, strength, range-of-motion, and coordination at the hips, knees, and ankles (Cook et al., 2006b; Plisky et al., 2006). From both a statistical and theoretical viewpoint, the deep squat may be an important predictor of unilateral dynamic balance within the FMS construct. Smoothed coefficients and confidence intervals for the analysis predicting overall stability index also revealed that lower shoulder mobility and rotary stability scores (< 3)

predicted higher (or worse) overall stability index values. Viewed from a practical standpoint, this collective group of findings suggest that strength and conditioning coaches, tactical athlete coaches, occupational and physical therapists, and other practitioners who use the FMS to screen clients could potentially minimize MSKI risk in persons with poor balance by evaluating scores for the trunk stability push-up, deep squat rotary stability, and shoulder mobility items of the FMS battery.

To our knowledge, this is the first investigation to use penalized regression techniques to assess the ability of FMS items to predict dynamic balance performance. In earlier work, Glass & Ross (2015) employed lasso penalized regression techniques to predict static balance using center of pressure excursion measured from FMS items. In this study, only anterior-posterior center of pressure excursion was retained in any of the statistical models that were generated (Glass & Ross, 2015) and better deep squat item scores predicted worse balance in the sagittal plane. This result was unexpected, as the underlying theory of the FMS suggests that higher item scores should relate to enhanced movement stability and balance. The authors suggested that this finding may have been due to the lack of sensitivity of FMS item scoring or the use of static balance measures that do not exhibit an adequate degree of biomechanical specificity with respect to the dynamic nature of FMS test items (Glass & Ross, 2015). While the use of lasso penalized regression analyses addresses some of the challenges presented by analyzing FMS item scores, the limited range of scores for some FMS items suggests that the scoring criteria of the FMS may be insensitive to delineate small, but meaningful, differences in functional movement. This potential deficiency may also be exacerbated when assessing

smaller samples or samples consisting of persons with relatively homogenous movement item scores.

Future research should investigate the ability of the FMS to predict other MSKI risk factors. Collectively, studies of this kind would allow inferences regarding a specific risk factor to be made based on FMS item scores. Ultimately, this would enable practitioners to evaluate multiple risk factors using a single short and practical test, thereby reducing total testing time and the need for expensive and specialized equipment to assess several risk factors individually.

Findings from this investigation revealed that in healthy, active adults, the FMS composite score is positively associated with dynamic balance as measured using composite reach distances and overall stability indices. Although additional research in this area is warranted, an FMS composite cutoff score of ≤ 14 may be an appropriate threshold for identifying poor balance in an active population of younger men and women. The key finding emanating from this study was the identification of FMS item scores predicting balance performance. Male and female adults scoring poorly on deep squat, trunk stability push-up, shoulder mobility, and rotary stability items of the FMS may possess sub-optimal dynamic balance, thereby potentially increasing their risk of incurring an MSKI. Hence, practitioners using the FMS battery should be encouraged to consider poor scores on these specific movements as an indication to conduct additional balance testing to more thoroughly diagnose potential balance deficits. Additionally, future research should be aimed at quantifying the association and predictive ability of the FMS to predict other MKSI risk factors, in the hope that practitioners will eventually

be able to identify a multitude of injury risk factors using a practical and efficient FMS screening tool.

CHAPTER III REFERENCES

- Agel, J., Evans, T. A., Dick, R., Putukian, M., & Marshall, S. W. (2007). Descriptive epidemiology of collegiate men's soccer injuries: National Collegiate Athletic Association Injury Surveillance System, 1988-1989 through 2002-2003. *Journal of Athletic Training, 42*(2), 270.
- Agel, J., Olson, D. E., Dick, R., & Arendt, E. A. (2007). Descriptive epidemiology of collegiate women's basketball injuries: National Collegiate Athletic Association Injury Surveillance System, 1988-1989 through 2003-2004. *Journal of Athletic Training, 42*(2), 202.
- Almeida, S. A., Maxwell-Williams, K. M., Shaffer, R. A., Luz, J. T., & Badong, E. (1997). *A physical training program to reduce musculoskeletal injuries in us marine corps recruits, Version 1.0* (No. NHRC-TD-97-2B). San Diego, CA: Naval Health Research Center
- Almeida, S. A., Maxwell-Williams, K. M., Shaffer, R. A., & Brodine, S. K. (1999). Epidemiological patterns of musculoskeletal injuries and physical training. *Medicine & Science in Sports & Exercise, 31*(8), 1176-1182.
- Bennell, K. L., & Crossley, K. (1996). Musculoskeletal injuries in track and field: incidence, distribution and risk factors. *Australian Journal of Science & Medicine in Sport, 28*(3), 69-75.
- Bernard, B. P., & Fine, L. (1997). *Musculoskeletal disorders and workplace factors*. Cincinnati, OH: US Department of Health and Human Services. National Institute for Occupational Safety and Health, USA.

- Beynnon, B. D., Murphy, D. F., & Alosa, D. M. (2002). Predictive factors for lateral ankle sprains: a literature review. *Journal of Athletic Training, 37*(4), 376.
- Breheny, P. and Huang, J. (2015). Group descent algorithms for nonconvex penalized linear and logistic regression models with grouped predictors. *Statistics & Computing, 25*, 173-187.
- Brown, S. H. M., Haumann, M. L., & Potvin, J. R. (2003). The responses of leg and trunk muscles to sudden unloading of the hands: implications for balance and spine stability. *Clinical Biomechanics, 18*(9), 812-820.
- Bush, R. A., Brodine, S. K., & Shaffer, R. A. (2000). The association of blisters with musculoskeletal injuries in male marine recruits. *Journal of the American Podiatric Medical Association, 90*(4), 194-198.
- Cachupe, W. J., Shifflett, B., Kahanov, L., & Wughalter, E. H. (2001). Reliability of biodex balance system measures. *Measurement in Physical Education & Exercise Science, 5*(2), 97-108.
- Canty, A. & Ripley, B. (2017). boot: Bootstrap R (S-Plus) Functions. R package version 1.3-20.
- Caraffa, A., Cerulli, G., Projetti, M., Aisa, G., & Rizzo, A. (1996). Prevention of anterior cruciate ligament injuries in soccer. *Knee Surgery, Sports Traumatology, Arthroscopy, 4*(1), 19-21.

- Chorba, R. S., Chorba, D. J., Bouillon, L. E., Overmyer, C. A., & Landis, J. A. (2010). Use of a functional movement screening tool to determine injury risk in female collegiate athletes. *North American Journal of Sports Physical Therapy: NAJSPT*, 5(2), 47.
- Clifton, D. R., Harrison, B. C., Hertel, J., & Hart, J. M. (2013). Relationship between functional assessments and exercise related changes during static balance. *Journal of Strength & Conditioning Research*, 27, 966–972.
- Cook, EG, Burton, L, Hoogenboom, BJ. (2006a). The use of fundamental movements as an assessment of function-Part 1. *North American Journal of Sports Physical Therapy*, 1(2), 62-72.
- Cook, EG, Burton, L, Hoogenboom, BJ. (2006b). The use of fundamental movements as an assessment of function-Part 2. *North American Journal of Sports Physical Therapy*, 1(3), 132-139.
- Davidson, A. C. & Hinkley, D. V. (1997). *Bootstrap methods and their applications*. Cambridge: Cambridge University Press.
- de la Motte, S. J., Gribbin, T. C., Lisman, P., Beutler, A. I., & Deuster, P. (2016). The interrelationship of common clinical movement screens: Establishing population-specific norms in a large cohort of military applicants. *Journal of Athletic Training*, 51(11), 897-904.
- Dorrel, B. S., Long, T., Shaffer, S., & Myer, G. D. (2015). Evaluation of the functional movement screen as an injury prediction tool among active adult populations: a systematic review and meta-analysis. *Sports Health*, 7(6), 532-537.

Feeney, A., North, F., Head, J., Canner, R., & Marmot, M. (1998). Socioeconomic and sex differentials in reason for sickness absence from the Whitehall II Study.

Occupational & Environmental Medicine, 55(2), 91-98.

Gertheiss, J., & Tutz, G. (2009). Penalized regression with ordinal predictors.

International Statistical Review, 77(3), 245- 365.

Gertheiss, J. (2015). ordPens: Selection and/or Smoothing of Ordinal Predictor. R

package version 0.3-1. <https://CRAN.R-project.org/package=ordPens>

Glass, S. M., & Ross, S. E. (2015). Modified functional movement screening as a predictor of tactical performance potential in recreationally active adults.

International Journal of Sports Physical Therapy, 10(5), 612.

Gribble, P. A., & Hertel, J. (2003). Considerations for normalizing measures of the Star

Excursion Balance Test. *Measurement in Physical Education & Exercise*

Science, 7(2), 89-100.

Gribble, P. A., Hertel, J., & Plisky, P. (2012). Using the star excursion balance test to

assess dynamic postural-control deficits and outcomes in lower extremity injury: a literature and systematic review. *Journal of Athletic Training*, 47, 339-357.

Gribble, P. A., Brigle, J., Pietrosimone, B. G., Pfile, K. R., & Webster, K. A. (2013).

Intrarater reliability of the functional movement screen. *The Journal of Strength & Conditioning Research*, 27(4), 978-981.

- Hartigan, E. H., Lawrence, M., Bisson, B. M., Torgerson, E., & Knight, R. C. (2014). Relationship of the functional movement screen in-line lunge to power, speed, and balance measures. *Sports Health: A Multidisciplinary Approach*, 6(3), 197-202.
- Heir, T., & Eide, G. (1996). Age, body composition, aerobic fitness and health condition as risk factors for musculoskeletal injuries in conscripts. *Scandinavian Journal of Medicine & Science in Sports*, 6, 222-227.
- Holme, E., Magnusson, S. P., Becher, K., Bieler, T., Aagaard, P., & Kjaer, M. (1999). The effect of supervised rehabilitation on strength, postural sway, position sense and reinjury risk after acute ankle ligament sprain. *Scandinavian Journal of Medicine & Science in Sports*, 9(2), 104-109.
- Hootman, J. M., Macera, C. A., Ainsworth, B. E., Addy, C. L., Martin, M., & Blair, S. N. (2002). Epidemiology of musculoskeletal injuries among sedentary and physically active adults. *Medicine & Science in Sports & Exercise*, 34(5), 838-844.
- Hotta, T., Nishiguchi, S., Fukutani, N., Tashiro, Y., Adachi, D., Morino, S., & Aoyama, T. (2015). Functional movement screen for predicting running injuries in 18-to 24-year-old competitive male runners. *The Journal of Strength & Conditioning Research*, 29(10), 2808-2815.
- Jones, B. H., Bovee, M. W., Harris, J. M., & Cowan, D. N. (1993). Intrinsic risk factors for exercise-related injuries among male and female army trainees. *The American Journal of Sports Medicine*, 21(5), 705-710.

- Jones, B. H., Cowan, D. N., Tomlinson, J. P., Robinson, J. R., Polly, D. W., & Frykman, P. N. (1993). *Epidemiology of injuries associated with physical training among young men in the army* (No. USARIEM-M78-91). Natick, MA: Army Research Institute of Environmental Medicine.
- Jones, B., Manikowski, R., Harris, J., Dziados, J., & Norton, S. (1988). *Incidence of and risk factors for injury and illness among male and female Army basic trainees* (No. USARIEM-T19-88). Natick, MA: Army Research Institute of Environmental Medicine.
- Kaufman, K. R., Brodine, S., & Shaffer, R. (2000). Military training-related injuries: surveillance, research, and prevention. *American Journal of Preventive Medicine, 18*(3), 54-63.
- Kelleher, L. K., Frayne, R. J., Beach, T. A., Higgs, J. M., Johnson, A. M., & Dickey, J. P. (2017). Relationships between the Functional Movement Screen Score and Y-Balance Test Reach Distances. *International Journal of Human Movement & Sports Sciences, 5*(3), 51-56.
- Kiesel, K., Plisky, P. J., & Voight, M. L. (2007). Can serious injury in professional football be predicted by a preseason functional movement screen. *North American Journal of Sports Physical Therapy, 2*(3), 147-158.
- Koplan, J. P., Siscovick, D. S., & Goldbaum, G. M. (1985). The risks of exercise: a public health view of injuries and hazards. *Public Health Reports, 100*(2), 189.

- Leeder, J.E., Horsley, I.G., & Herrington, L.C. (2013). The inter-rater reliability of the functional movement screen within an athletic population using untrained raters. *Journal of Strength & Conditioning Research*, 30(9), 2591-2599.
- Lisman, P., O'Connor, F. G., Deuster, P. A., & Knapik, J. J. (2013). Functional movement screen and aerobic fitness predict injuries in military training. *Medicine & Science in Sports & Exercise*, 45(4), 636-643.
- Lockie, R. G., Callaghan, S. J., Jordan, C. A., Luczo, T. M., Jeffriess, M. D., Jalilvand, F., & Schultz, A. B. (2015). Certain actions from the functional movement screen do not provide an indication of dynamic stability. *Journal of Human Kinetics*, 47(1), 19-29.
- Malliou, P., Gioftsidou, A., Pafis, G., Beneka, A., & Godolias, G. (2004). Proprioceptive training (balance exercises) reduces lower extremity injuries in young soccer players. *Journal of Back & Musculoskeletal Rehabilitation*, 17(3, 4), 101-104.
- McGuine, T. A., Greene, J. J., Best, T., & Levenson, G. (2000). Balance as a predictor of ankle injuries in high school basketball players. *Clinical Journal of Sport Medicine*, 10(4), 239-244.
- Minick, K. I., Kiesel, K. B., Burton, L., Taylor, A., Plisky, P., & Butler, R. J. (2010). Interrater reliability of the functional movement screen. *The Journal of Strength & Conditioning Research*, 24(2), 479-486.

- Moran, R. W., Schneiders, A. G., Mason, J., & Sullivan, S. J. (2017). Do Functional Movement Screen (FMS) composite scores predict subsequent injury? A systematic review with meta-analysis. *British Journal of Sports Medicine*. Ahead of print: <http://doi.org/10.1136/bjsports-2016-096938>
- National Research Council, The Institute of Medicine. (2001). *Musculoskeletal disorders and the workplace: Low back and upper extremities*. Washington, DC: National Academy Press.
- O'Connor, F. G., Deuster, P. A., Davis, J., Pappas, C. G., & Knapik, J. J. (2011). Functional movement screening: predicting injuries in officer candidates. *Medicine & Science in Sports & Exercise*, 43(12), 2224-30.
- Pate, R. R., Pratt, M., Blair, S. N., Haskell, W. L., Macera, C. A., Bouchard, C., & Kriska, A. (1995). Physical activity and public health: a recommendation from the Centers for Disease Control and Prevention and the American College of Sports Medicine. *Journal of the American Medical Association*, 273(5), 402-407.
- Perry, F. T., & Koehle, M. S. (2013). Normative data for the functional movement screen in middle-aged adults. *The Journal of Strength & Conditioning Research*, 27(2), 458-462.
- Pincivero, D. M., Lephart, S. M., & Henry, T. J. (1995). Learning effects and reliability of the biodex stability system. *Journal of Athletic Training*, 30, 35.

- Physical Activity Guidelines Advisory Committee. (2008). *Physical Activity Guidelines Advisory Committee Report*. Washington (DC): U.S. Department of Health and Human Services.
- <http://www.health.gov/paguidelines/Report/pdf/CommitteeReport.pdf>
- Plisky, P. J., Rauh, M. J., Kaminski, T. W., & Underwood, F. B. (2006). Star Excursion Balance Test as a predictor of lower extremity injury in high school basketball players. *Journal of Orthopedic & Sports Physical Therapy*, 36(12), 911-919.
- Pollock, M. L., Schmidt, D. H., & Jackson, A. S. (1980). Measurement of cardiorespiratory fitness and body composition in the clinical setting. *Comprehensive Therapy*, 6,12-27.
- R Core Team. (2017). R: A language and environment for statistical computing. R Foundation for Statistical Computing, Vienna, Austria. <https://www.R-project.org/>.
- Riihimäki, H. (1995). Hands up or back to work—future challenges in epidemiologic research on musculoskeletal diseases. *Scandinavian Journal of Work, Environment & Health*, 21, 401-403.
- Robinson, R. H., & Gribble, P. A. (2008). Support for a reduction in the number of trials needed for the Star Excursion Balance Test. *Archives of Physical Medicine & Rehabilitation*, 89(2), 364-370.
- Rusling, C., Edwards, K. L., Bhattacharya, A., Reed, A., Irwin, S., Boles, A., & Hodgson, L. (2015). The functional movement screening tool does not predict injury in football. *Progress in Orthopedic Science*, 1(2), 41-46.

- Teyhen, D. S., Shaffer, S. W., Lorenson, C. L., Greenberg, M. D., Rogers, S. M., Koreerat, C. M., & Childs, J. C. (2014). Clinical measures associated with dynamic balance and functional movement. *The Journal of Strength & Conditioning Research*, 28(5), 1272-1283.
- Trojian, T. H., & McKeag, D. B. (2006). Single leg balance test to identify risk of ankle sprains. *British Journal of Sports Medicine*, 40(7), 610-613.
- Tropp, H., Askling, C., & Gillquist, J. A. N. (1985). Prevention of ankle sprains. *The American Journal of Sports Medicine*, 13(4), 259-262.
- Tropp, H., Ekstrand, J., & Gillquist, J. (1983). Stabilometry in functional instability of the ankle and its value in predicting injury. *Medicine & Science in Sports & Exercise*, 16(1), 64-66.
- U.S. Department of Health and Human Services. (1996). *Physical Activity and Health: A Report of the Surgeon General*. Atlanta, GA: U.S. Department of Health and Human Services, Centers for Disease Control and Prevention, National Center for Chronic Disease Prevention and Health Promotion.
- Wiese, B. W., Boone, J. K., Mattacola, C. G., McKeon, P. O., & Uhl, T. L. (2014). Determination of the functional movement screen to predict musculoskeletal injury in intercollegiate athletics. *Athletic Training & Sports Health Care*, 6, 161-169.

- Willems, T. M., Witvrouw, E., Delbaere, K., Mahieu, N., De Bourdeaudhuij, I., & De Clercq, D. (2005). Intrinsic risk factors for inversion ankle sprains in male subjects a prospective study. *The American Journal of Sports Medicine*, 33(3), 415-423.
- Verhagen, E., van der Beek, A., Twisk, J., Bouter, L., Bahr, R., & van Mechelen, W. (2004). The effect of a proprioceptive balance board training program for the prevention of ankle sprains: a prospective controlled trial. *The American Journal of Sports Medicine*, 32(6), 1385-1393.
- Zarei, M., Samani, Z., Reisi, J. (2015). Can functional movement screening predict injuries in Iranian soldiers? *Journal of Military Medicine*, 17(2), 107-114.

CHAPTER IV
TRADITIONAL AND TORSO-LOADED FUNCTIONAL MOVEMENT SCREEN
SCORES AND BALANCE WITH MILITARY LOAD

Introduction

Musculoskeletal injuries (MSKI) are one of most common types of injury in military populations, and especially among military recruits (Almeida, Maxwell-Williams, Shaffer, & Brodine, 1999; Almeida, Maxwell-Williams, Shaffer, Luz, & Badong, 1997; Bush, Brodine, & Shaffer, 2000; Kaufman, Brodine, & Shaffer, 2000; Jones, Bovee, Harris, & Cowan, 1993a; Jones et al., 1993b). The incidence rate of MSKI varies from 26.0 to 50.5%, with 75% or more of MSKI occurring at or below the knee (Almeida et al., 1999; Jones et al., 1993a; Jones, Bovee, & Knapik, 1992; Jones et al., 1993b; Kaufman et al., 2000). MSKI affects not only the livelihood of military recruits, but also results in significant losses of duty/training days and imposes a significant financial burden. At a Marine Corps training camp, an estimated 53,000 training days and \$16.5 million were lost annually due to MSKI (Almeida et al., 1997). Furthermore, the rate of limited duty days associated with MSKI is estimated to be 5 to 22 times greater than the number of limited duty days attributable to disease or illness (Jones, Manikowski, Harris, Dziados, & Norton, 1988).

The well-documented impact of MSKI on personnel, monetary resources, and readiness has led to the study of risk factors that may predispose military recruits to

injury. Several studies have reported that recruits with low physical fitness levels and high training volumes are at increased risk of incurring an MSKI (Almeida et al., 1999; Jones et al., 1993a; Jones et al., 1993b). Additionally, balance, joint proprioception, and general functional joint stability are factors which have been tied to a greater incidence of MSKI in the lower extremities (McGuine, Greene, Best, & Levenson, 2000; Tropp, Ekstrand, & Gillquist, 1983; Wedderkopp, Kalsoft, Holm, & Froberg, 2003). As evaluated by the Star Excursion Balance Test, poor balance is associated with a 2.5- to 6.5-fold increase and a 48% higher risk of ankle MSKI in athletic and healthy young adult populations, respectively (Butler, Lehr, Fink, Kiesel, & Plisky, 2013; Noronha, Franca, Hauptenthal, & Nunes, 2013; Plisky, Rauh, Kaminski, & Underwood, 2006). Based on the link between balance and MSKI in the aforementioned populations, a similar relationship may exist among military personnel entering basic training. Military recruits are often required to perform field maneuvers while their torso is loaded with a 35-lb rucksack and additional gear (Basic Standards of the Airborne, 2011), which can result in significant stress on the skeleton, connective tissues, and skeletal muscles (Harman, Han, & Frykman, 2001; Polcyn, Bensen, Harman, & Obusek, 2001). Altered body mechanics due to excessive load carriage can also have negative implications on mobility, balance, and the injury status of soldiers (Harman et al., 2001; Knapik, Reynolds, & Harman, 2004; May, Tomporowski, & Ferrara, 2009; Yen, Ling, Magill, McDonough, & Gutierrez, 2011).

In view of the detrimental effects of MSKI in military recruits on readiness, resources, and training, a need exists to develop and implement pre-participation

screening tools and targeted fitness programs to decrease the incidence of MSKI in this active population (Kaufman et al., 2000; Teyhen et al., 2014). Along these lines, the Functional Movement Screen™ (FMS), an evaluative tool that assesses functional stability, mobility, and symmetry of the body, has been shown to be reliable when used in athletes and active-duty infantrymen (Cook, Burton, & Hoogenboom, 2006a; Cook, Burton, & Hoogenboom, 2006b; Gribble, Brigle, Pietrosimone, Pfile, & Webster, 2013; Leeder, Horsley, & Herrington, 2013; Minick et al., 2010; Teyhen et al., 2014). Among military recruits, an overall FMS score of 14 or less (out of a possible score of 21) is associated with a 5.6- to 12.0-fold increase in injury incidence (Lisman, O'Connor, Deuster, & Knapik, 2013; O'Connor, Deuster, Davis, Pappas, & Knapik, 2011; Zarei, Samani, & Reisi, 2015). Bushman and colleagues (2015) also reported an inverse relationship between lower FMS composite scores (≤ 14) and injury risk in a sample of U.S. Army soldiers, but noted that the sensitivity of the FMS instrument was low. In this investigation (Bushman et al., 2015), injuries were grouped into three general categories (overuse, traumatic, or any injury), which may have diminished the predictive ability of the FMS compared to using more precise diagnoses. While several studies have identified an FMS score of 14 or less as a risk threshold in military recruits and infantrymen, other studies suggest that specific subscores of the FMS are better predictors of injury than an overall FMS score threshold (Hotta et al., 2015; Rusling et al., 2015).

In summary, the FMS appears to be an effective screening tool for predicting MSKI in military recruits (Bushman et al., 2015; Lisman et al., 2013; O'Connor et al., 2011; Zarei et al., 2015). Given the use of the FMS to evaluate components of

proprioceptive awareness and joint stability that comprise balance, and in view of the positive relationship between torso-loaded balance and MSKI risk, the FMS screening tool may provide a relatively simple and inexpensive means of identifying MSKI risk in military recruits under both loaded and non-loaded conditions. Against this backdrop, the 2-part purpose of this investigation was to determine if unloaded and torso-loaded FMS composite scores are associated with torso-loaded balance and evaluate the ability of FMS item subscores to predict torso-loaded balance in adult males and females who possess anthropometric and physical fitness characteristics typical of military recruits entering basic training.

Methods

Participants

Physically active males ($n = 19$) and females ($n = 11$) between the age of 18 and 30 years were recruited to participate in this study (age = 24.8 ± 3.1 years, height = 173.6 ± 7.6 cm, weight = 79.5 ± 16.9 kg, body fat = 16.2 ± 7.1 %). Prior to data collection, testing procedures were explained to study participants and informed consent was obtained. Each participant completed a Physical Activity Readiness Questionnaire, an ACSM-AHA health classification form, and were classified as low or moderate risk using ACSM-AHA criteria. An International Physical Activity Questionnaire (Booth et al., 2003) indicated that 21 participants were classified as having high physical activity levels, with the remaining 9 participants exhibiting moderate physical activity levels. Participants who reported musculoskeletal injury or underwent surgery within 12 months prior to the start of the investigation were excluded from the study. Participants were

asked to abstain from heavy exercise and consuming alcohol or caffeine 24 hours leading up to each data collection session and medication usage was continued as prescribed. A t-shirt, athletic shorts, and the same athletic shoes were worn during all laboratory visits. All procedures of the current study were approved by the university Institutional Review Board.

Procedures

Participants' height and body mass were measured using a digital scale (Tanita BF-522; Tanita Corporation, Tokyo, Japan) and a standard stadiometer. Height, weight, and body fat percentage measurements were obtained according to "The Army Body Composition Program" (2013). To ensure that participants resembled military recruits as closely as possible, the minimum criteria for acceptable measures weight and body fat percentage according to "The Army Body Composition Program" (2013) were used as study inclusion criteria. Using a 3-site method (male: chest, abdomen, thigh; female: tricep, suprailiac, thigh) (Pollock, Schmidt, & Jackson, 1980), body fat percentage was estimated from skinfold thicknesses measured using a calibrated Lange skinfold caliper (Cambridge, MD, USA). Duplicate skinfold values were obtained at each anatomical site in a serial fashion and average skinfold thickness at each site was reported. If two skinfold measurements varied by more than 2 mm at any site, a third measurement was made and the two closest measures within a 2-mm range were used to estimate body fat percentage. Anatomical leg length, taken as the distance from the anterior superior iliac spine to the center of the ipsilateral medial malleolus while in the supine position, was measured twice for each leg using a Gulick tape measure (Perform Better, West

Warwick, RI, USA). The average of leg length measurements for each leg was used to normalize balance assessment data for the right and left legs (Gribble & Hertel, 2003).

Physical Fitness Testing

Following a description of U.S. Army entry-level physical fitness tests, fitness testing was conducted to ensure that all participants possessed minimum physical fitness levels required to enter the U.S. Army. Fitness testing data included the maximal number of push-ups and sit-ups completed in one minute and a timed 1-mile run (Knapik et al., 2006). Strength testing criteria for males and females were ≥ 13 pushups and ≥ 17 sit-ups in one minute for males and ≥ 3 push-ups and ≥ 17 sit-ups in one minute for females. All push-up and sit-up assessments were performed on a stable mat and conducted by a certified strength and conditioning specialist. One-mile run time inclusion criteria were 8.5 minutes for males and 10.5 minutes for females. Run times for the 1-mile distance were recorded using a stopwatch while participants ran individually on an indoor track. The course distance was verified using a calibrated measuring wheel (Line Seiki RSL-204-5, Tokyo, Japan). Individuals who were unable to meet the minimum criteria for any of the aforementioned fitness tests were excluded from further study participation.

Functional Movement Screening™

Participants returned to the laboratory at least two days after fitness testing to complete the Functional Movement Screen™ (FMS) and modified FMS (mFMS) assessments. Participants were asked to perform each assessment to the best of their ability. While completing the traditional FMS, participants performed two to three repetitions of seven movements: (1) deep squat, (2) hurdle step, (3) in-line lunge, (4)

shoulder mobility, (5) active straight leg raise, (6) trunk stability pushup, (7) rotary stability (Cook et al., 2006a; Cook et al., 2006b). All movements, with the exception of the deep squat and trunk stability pushup, were performed bilaterally. Following the shoulder mobility, stability push-up, and rotary stability movements, clearing exams, or movements designed to identify painful movement and pre-existing injury, were performed to assess pain.

The mFMS included performance of the same movements as those used in the FMS while participants wore a 15.8-kg Modular Lightweight Load-carrying Equipment (M.O.L.L.E.) pack, a 1.5-kg standard issue helmet, and a 6.9-kg weighted vest with a total external load of 24.2 kg (M.O.L.L.E. pack, helmet, and weight vest). The load-carriage equipment and weight were chosen to simulate loads worn by U.S. Army recruits while traversing terrain during basic training (Basic standards of the airborne, 2011). Because the M.O.L.L.E. pack resulted in an inability to perform the shoulder mobility and active straight leg raise tests, both of these movements were completed while wearing only a helmet and a vest (total load = 8.4 kg).

Participants performed the FMS and mFMS in a counterbalanced order, with 10 minutes separating both screening tests. For both screening procedures, movements were scored on a 0 to 3 ordinal scale by the same certified strength and conditioning specialist, with the lowest score used for statistical analysis. For movements that were assessed bilaterally (i.e., in-line lunge, hurdle step, shoulder mobility, active-straight leg raise, rotary stability), the lowest score was used for analysis (Cook et al., 2006a; Cook et al., 2006b). A total score for each screening test was calculated as the sum of scores for all

seven movements, with a total possible score of 21 each for the FMS and the mFMS. If pain was reported during a clearing exam, a score of zero was recorded. All scoring was based on criteria established by Cook et al. (2006a).

Balance Assessments

During a 5-minute rest period after movement screening, participants were briefed on procedures for two balance tests that were performed while wearing the same 24.2 kg military load. The order of balance testing was randomized for each participant, with a 10-min rest period separating both tests.

The loaded Biodex balance test (Test 1) (Biodex Balance System, Shirley, NY, USA) consisted of standing on a multiaxial platform with a 20° maximal platform tilt. A display illustrating the center of the platform using a cursor within a bullseye was visible to the participant at all times. Trials were performed with hands on hips and with eyes open. Participants were asked to stand on the platform and assume a comfortable position. The platform of the device consisted of a grid for standardizing foot position. After a comfortable foot position was established and both feet were placed evenly on the platform, heel and toe coordinates were recorded and used for all subsequent testing. After standardizing foot position, participants were instructed to watch the monitor and keep the cursor as close to the center of the bullseye as possible. Participants performed six sets of the loaded Biodex balance testing with each set consisting of three repetitions. The first three loaded sets served to familiarize participants with testing procedures and were separated from the three remaining loaded Biodex balance sets by a 3- to 5-min rest period (Cachupe, Shifflett, Kahanov, & Wughalter, 2001; Pincivero, Lephart, & Henry,

1995). Only data from the last three loaded sets were used for statistical analyses. All Biodex trials were performed at an instability level of 1 (1 = least stable, 8 = most stable) and each repetition lasted 20 seconds. Handrails were available for participants to grab onto if balance was lost, but if the handrails were grasped, testing was repeated. The Biodex software reported the mean loaded overall stability indices (LOSI) of balance for each set of three repetitions, with lower LOSI scores indicating better balance.

Participants also performed six loaded Y balance test testing trials (Test 2), with each testing trial consisting of three maximal reach distances in the anterior direction, three maximal reach distances in the posterolateral direction, and three maximal reach distances in the posteromedial direction. All Y balance test trials were separated by three to five minutes of rest. The first four Y balance test trials were not used for statistical analyses, but were performed to acquaint participants with the test and prevent a learning effect from occurring (Robinson & Gribble, 2008). Participants began the Y balance test at the center of the Y balance test platform with the distal aspect of the first toe located at the starting line (Plisky et al., 2006). The free limb was then extended as far as possible in the anterior, posteromedial, and posterolateral directions. The maximal anterior reach distance, posteromedial reach distance, and posterolateral reach distance were recorded as the points at which the most distal part of the foot pushed the measurement block in the designated plane. Maximal reach attempts were performed three times with each leg, with starting legs counterbalanced between participants. Reach distances were expressed relative to leg length to normalize Y balance test data (Gribble & Hertel, 2003). For the last two balance test trials, the average of the final three normalized reach distances in

each direction were used for statistical analysis and a loaded composite reach distance (LCR) was calculated as the sum of normalized anterior, posteromedial, and posterolateral reach distances.

Statistical Analysis

Wilcoxon signed-rank tests for matched pairs were used to determine differences between unloaded and loaded FMS subscores. Pearson-product moment correlation values were calculated to quantify relationships between composite scores (FMS and mFMS) and loaded balance scores (LCR and LOSI). FMS and mFMS composite data were recoded into binary variables separated at the composite score of ≤ 14 , a threshold that has been identified previously as a score associated with a 1.65- to 11.67-fold increased chance of injury (Kiesel, Plisky, & Voight, 2007; Lisman et al., 2013; O'Connor et al., 2011; Zarei et al., 2015). Differences in LCR and LOSI between groups with FMS and mFMS composite scores of ≤ 14 and ≥ 15 were compared using an $\alpha \leq .05$. IBM SPSS software was used for the above-mentioned analyses (SPSS Statistics v20.0, IBM Corporation, Armonk, New York). Effect sizes were calculated as

$$d = \frac{Mean_1 - Mean_2}{\sqrt{\frac{Variance_1 + Variance_2}{2}}}$$

Previous research has shown that traditional regression procedures are not appropriate for fitting a model of FMS subscores to predict dependent variable scores (Glass & Ross, 2015). The use of linear regression techniques would require ordinal level data of FMS subscores to be subjected to continuous variable scaling, whereas dummy coding may lead to an overestimation of model fit due to the relatively large number of ordinal-level predictors (Gertheiss & Tutz, 2009). To address these dual limitations,

Lasso penalized regression was employed to develop FMS and mFMS subscore models to predict LCR and LOSI, as this predictive technique allows for ordinal scaling through penalization of predictor coefficients rather than removing them from the model, thereby minimizing the sum of squared errors for coefficient terms. Group penalization parameters (λ) were obtained for FMS and mFMS subscores to predict LCR scores, as well as LOSI scores. For each subscore, a score of “1” was used as the reference category and statistical significance was tested using bootstrap 95% confidence intervals for each coefficient retained in the final model. All Lasso penalized regression analyses were conducted in R Version 3.4.2 (R Core Team, 2017) using ordPens (Gertheiss, 2015), gpreg (Breheny & Huang, 2015), boot (Canty & Ripley, 2017; Davidson & Hinkley, 1997), and base packages.

Results

The average FMS and mFMS composite scores were 15.97 ($SD = 2.44$) and 13.67 ($SD = 1.95$), respectively. Mean LCR was 91.76 % ($SD = 6.58$ %), and average LOSI was 12.21 ($SD = 2.19$). Analysis of Wilcoxon signed-rank tests (Table 1) indicated that deep squat, in-line lunge, shoulder mobility, trunk stability pushup, and rotary stability subscores while wearing the external load were significantly lower than FMS subscores measured under unloaded conditions. Pearson-product correlation analyses revealed that composite scores from both FMS ($r(28) = .53, p = .003$) and mFMS ($r(28) = .37, p = .043$) were positively associated with LCR. Conversely, no composite scores were related to LOSI scores (FMS ($r(28) = -.29, p = .12$); mFMS ($r(28) = .03, p = .88$)). When participants were grouped by FMS scores ≤ 14 ($n = 12$) and ≥ 15 ($n = 18$), the high-

scoring group displayed a significantly higher LCR compared to the low-scoring group ($t(21.56) = 3.15, p = .006, d = 1.16$). In a similar fashion, LCR values for the high-scoring group were also elevated compared to the low-scoring group when mFMS scores were categorized as being at or below the composite threshold score ($\leq 14; n = 22$) or above the threshold score ($\geq 15; n = 8$) ($t(27.98) = 2.28, p = .031, d = 0.75$). LOSI was not significantly different between individuals with low and high composite scores on the FMS ($t(27.07) = 0.90, p = .38, d = 0.33$) or mFMS ($t(12.21) = 1.68, p = .12, d = 0.70$).

Table 1

Wilcoxon signed-rank tests of item scores for unloaded and torso-loaded FMS conditions.

| | Score | FMS Subscore | | | | | | |
|------|----------|--------------|--------|--------|--------|--------|--------|--------|
| | | DS | HS | ILL | SM | ASLR | TSP | RS |
| FMS | 1 | 4 | 9 | 9 | 3 | 0 | 1 | 0 |
| | 2 | 14 | 14 | 17 | 10 | 11 | 7 | 25 |
| | 3 | 12 | 7 | 4 | 17 | 19 | 22 | 5 |
| mFMS | 1 | 9 | 12 | 14 | 4 | 0 | 15 | 8 |
| | 2 | 14 | 13 | 15 | 15 | 12 | 4 | 19 |
| | 3 | 7 | 5 | 1 | 11 | 18 | 11 | 3 |
| | V | -3.162 | -1.387 | -1.999 | -2.333 | -1.000 | -3.624 | -2.673 |
| | <i>p</i> | .002* | .166 | .046* | .020* | .317 | <.001* | .008* |

Note. * $p \leq .05$. FMS = traditional FMS, mFMS = loaded FMS, DS = deep squat, HS = hurdle step, ILL = in-line lunge, SM = shoulder mobility, ALSR = active straight-leg raise, TSP = trunk stability pushup, RS = rotary stability.

Unsmoothed and smoothed penalized regression coefficients, along with 95% confidence intervals, can be found in Table 2. Two FMS items were represented as binary variables (3 vs 2) because no ratings of 1 were achieved. One FMS item, the trunk stability push-up, was recoded as binary [(3) vs (2 or 1)] because only a single rating of 1 was recorded (See Table 1). Traditional rotary stability scores of 3 were compared to scores of 2 or 1. Of the mFMS items, loaded in-line lunge scores were recoded to compare the reference category (1) to all higher scores because only one score of 3 was recorded. Loaded active straight-leg raise scores were represented as a binary variable (3 vs 2) because no ratings of 1 were achieved.

In the penalized regression analyses predicting LCR, a penalty parameter of $\Lambda = 1.80$ was applied to the traditional FMS items and the in-line lunge item was the only significant predictor of LCR. Participants scoring a 1 on the in-line lunge exhibited significantly shorter LCR. No mFMS items were significant predictors of LCR ($\Lambda = 1.94$). Penalty parameters of $\Lambda = 0.49$ and $\Lambda = 0.42$ were also applied to traditional FMS and mFMS items when predicting LOSI, respectively. Of the traditional FMS items, only a score of 3 on the shoulder mobility item predicted better LOSI. However, a score of 3 on the loaded trunk stability pushup item predicted worse LOSI scores.

Table 2

Coefficients and 95% confidence intervals for retained traditional and modified FMS items predicting performance on torso-loaded balance tests.

| Item | Score | FMS | | | | mFMS | | | |
|--------------------------|-------|------------|-----------------|----------|-----------------|------------|-----------------|----------|-----------------|
| | | Unsmoothed | | Smoothed | | Unsmoothed | | Smoothed | |
| | | Coeff | 95% CI | Coeff | 95% CI | Coeff | 95% CI | Coeff | 95% CI |
| Composite Reach Distance | | | | | | | | | |
| ILL | 2 | 7.74 | (3.30, 12.75)* | 6.86 | (2.88, 10.93)* | - | - | - | - |
| | 3 | 9.12 | (4.50, 14.81)* | 8.36 | (3.96, 13.70)* | - | - | - | - |
| Overall Stability Index | | | | | | | | | |
| SM | 2 | -0.33 | (-1.55, 1.37) | -0.37 | (-1.67, 1.11) | -1.43 | (-3.31, 0.53) | -1.38 | (-3.19, 0.40) |
| | 3 | -2.43 | (-3.73, -1.77)* | -2.38 | (-3.56, -0.57)* | -2.17 | (-4.51, -0.20)* | -2.11 | (-4.12, -0.26)* |
| RS | 3 | -1.41 | (-3.22, 1.48) | -1.42 | (-3.26, 1.59) | - | - | - | - |
| ILL | 2 & 3 | - | - | - | - | 1.06 | (-0.45, 2.71) | 1.08 | (-0.51, 2.50) |
| TSP | 2 | - | - | - | - | 1.71 | (-0.99, 3.76) | 1.58 | (-0.63, 3.40) |
| | 3 | - | - | - | - | 1.62 | (-0.18, 3.18) | 1.61 | (0.08, 3.13)* |

Note. * $p \leq .05$. FMS = functional movement screen, mFMS = torso-loaded functional movement screen, ILL = in-line lunge, SM = shoulder mobility, RS = rotary stability, TSP = trunk stability pushup. Confidence intervals for composite reach distances were based on 986 samples for unsmoothed and smoothed coefficients. Confidence intervals for overall stability indices were based on 979 samples for unsmoothed coefficients, and 969 samples for smoothed coefficients. Lower OSI scores represent better balance.

Discussion

Although torso-loading imposes significant stress upon the musculoskeletal system (Harman et al., 2001; Polcyn et al., 2001) and alters body mechanics which are fundamental in maintaining balance (Harman et al., 2001; Knapik et al., 2004; May et al., 2009; Yen et al., 2011), the current study is the first to document the relationship between FMS composite scores and balance while wearing a standard military training load. Specifically, our findings revealed that FMS and mFMS composite scores were positively correlated with loaded composite reach distances while wearing a 24.2 kg military load. Additionally, participants scoring ≤ 14 on the FMS and mFMS exhibited significantly lower loaded composite reach values compared to those scoring greater than 14.

Incorporating external loads during movement screenings has been proposed as a means of improving the consistency and accuracy of assessing performances such as balance under loaded conditions (Glass & Ross, 2015; McKeown, Taylor-McKeown, Woods & Ball, 2014). In the present investigation, the application of the 24.2 kg military load effectively decreased item scores on five of the seven movements compared to unloaded item scores in potential military recruits (see Table 1). However, our findings did not support this hypothesis with respect to performance on balance tests, as (1) the traditional FMS composite score exhibited the strongest correlation ($r = 0.53$) with loaded composite reach distances, and (2) the highest effect size ($d = 1.16$) was achieved when loaded composite reach distances were compared between low- and high-scoring groups during FMS testing.

While it is important to determine if FMS conditions are related to loaded balance, the primary focus of this study was to determine if FMS and mFMS test items, or a combination of items within a given test, were particularly strong predictors of loaded balance. Our data revealed that the unloaded in-line lunge item was the only significant predictor of loaded composite reach distance and a similar study using active duty service members reported a significant association between in-line lunge scores and unloaded composite reach distance (Teyhen et al., 2014). The authors of this latter paper suggested that the ability to achieve greater reach distances on the Y balance test, especially in the anterior direction, reflected superior stability and balance ability demonstrated while performing the in-line lunge movement (Teyhen et al., 2014). With respect to the current project, it is also possible that the medial-lateral balance required to score well on the in-line lunge test item may have helped our participants attain greater posteromedial and posterolateral reach distances.

Penalized regressions for loaded overall stability indices showed that shoulder mobility scores of 3 under unloaded and loaded FMS conditions predicted better loaded balance performance. In considering both FMS conditions, unloaded shoulder mobility was a better predictor of loaded overall stability indices than torso-loaded shoulder mobility scores. Teyhen and colleagues (2014) also identified shoulder mobility movement as a predictor of unloaded composite reach distances; with higher item scores predicting greater unloaded balance. Poor flexibility is often a product of altered strength or neuromuscular control of muscles around a joint (Gossman, Sahrman, & Rose, 1982), which can influence spinal alignment and postural stability (Falvo, Sirevaag, Rohrbaugh,

& Earhart, 2010; Folland & Williams, 2007) and ultimately reduce dynamic stability. Viewed within this context, results from the Teyhen et al. study (2014) and the current investigation lend credence to the notion that individuals who scored higher on the shoulder mobility item displayed proper spinal alignment and good dynamic posture when stability under loaded conditions was challenged during the Biodex balance test. In commenting on the potential role of shoulder mobility on loaded balance performance, it is worth noting that some participants did report greater difficulty during the shoulder mobility test while wearing the military load, which likely influenced loaded shoulder mobility scores.

The loaded trunk stability pushup was also a predictor of loaded overall stability indices, with a score of 3 indicating significantly worse balance than a score of 1. Glass and Ross (2015) also found that higher torso-loaded deep squat scores predicted worse unloaded anterior-posterior center of pressure excursion in potential military recruits. These findings are surprising, given the underlying theories used to develop the Functional Movement Screen instrument. Although these relationships between torso-loaded item scores and balance are difficult to explain, Glass and Ross (2015) postulated that the ordinal point system used to score FMS items may lack the sensitivity needed to detect meaningful differences in balance performance. For example, an individual may have performed the eccentric motion of the torso-loaded trunk stability pushup correctly while using a compensatory concentric movement pattern (Kraus et al., 2014). In this scenario, a score of 2 would have been recorded, which would be the same score achieved when compensatory movements were used during eccentric and concentric

motions of the loaded pushup maneuver. First discussed by Kraus and colleagues (2014) as a limitation of the traditional FMS scoring system, this scoring sensitivity issue may be exacerbated when external loads are incorporated during the screening process. In view of the preceding discussion, it seems reasonable to suggest that employing an ordinal approach to score the FMS may result in an insufficient number of occurrences of particular item scores, thus obscuring the relationship between the FMS and dynamic balance in persons with a general fitness profile reflective of military recruits.

Results from this study demonstrated that FMS and torso-loaded FMS composite scores were associated with greater torso-loaded composite reach distances in male and female adults who displayed body composition and fitness records typical of soldiers entering basic training. Despite the use of identical loading strategies during movement screening and balance testing, torso-loaded FMS composite scores and loaded composite reach distances were only moderately correlated. The traditional FMS composite score exhibited the strongest association with loaded composite reach distance and participants who achieved high FMS scores (≥ 15) displayed markedly higher loaded composite reach distances when compared to participants with lower FMS scores (≤ 14).

The key finding of this study was that the traditional in-line lunge test item predicted performance on a dynamic balance test while wearing a typical military load. Given this finding, it is recommended that tactical strength and conditioning coaches who observe compensatory patterns during in-line lunge movements in entering military recruits should conduct additional testing to quantify the magnitude of loaded balance deficits. From a military preparedness standpoint, the identification of recruits with sub-

optimal balance during maneuvers with a military load is an important step for the primary prevention of musculoskeletal injuries and could conceivably lead to decreased treatment costs, fewer missed duty-days, and less attrition in an already-challenging recruiting environment.

The ability of military personnel to maintain balance under loaded conditions is particularly important during long-distance marching and explosive multi-directional military maneuvers commonly performed in urban environments. Although investigators have proposed incorporating external loads during the FMS to improve the sensitivity and prediction of athletic and military performances, this strategy may only amplify existing limitations associated with the use of FMS scoring criteria. Consequently, future investigations in this area should explore the development and testing of modified FMS scoring criteria featuring a wider range of numerical scores to improve the sensitivity of scoring, especially when external loads are imposed as part of the movement screening process.

CHAPTER IV REFERENCES

- Almeida, S. A., Maxwell-Williams, K. M., Shaffer, R. A., Luz, J. T., & Badong, E. (1997). *A physical training program to reduce musculoskeletal injuries in us marine corps recruits, Version 1.0* (No. NHRC-TD-97-2B). San Diego, CA: Naval Health Research Center.
- Almeida, S. A., Maxwell-Williams, K. M., Shaffer, R. A., & Brodine, S. K. (1999). Epidemiological patterns of musculoskeletal injuries and physical training. *Medicine & Science in Sports & Exercise*, *31*(8), 1176-1182.
- Booth, M. L., Ainsworth, B. E., Pratt, M., Ekelund, U., Yngve, A. Sallis, J. F., & Oja, P. (2003). International physical activity questionnaire: 12-country reliability and validity. *Medicine & Science in Sports & Exercise*, *195*(9131/03), 3508-1381.
- Breheny, P. and Huang, J. (2015). Group descent algorithms for nonconvex penalized linear and logistic regression models with grouped predictors. *Statistics & Computing*, *25*, 173-187.
- Bush, R. A., Brodine, S. K., & Shaffer, R. A. (2000). The association of blisters with musculoskeletal injuries in male marine recruits. *Journal of the American Podiatric Medical Association*, *90*(4), 194-198.
- Bushman, T. T., Grier, T. L., Canham-Chervak, M., Anderson, M. K., North, W. J., & Jones, B. H. (2015). The functional movement screen and injury risk association and predictive value in active men. *The American Journal of Sports Medicine*, *44*(2), 297-304.

- Butler, R. J., Lehr, M. E., Fink, M. L., Kiesel, K. B., & Plisky, P. J. (2013). Dynamic balance performance and noncontact lower extremity injury in college football players: An initial study. *Sports Health: A Multidisciplinary Approach*, 5(5), 417-422.
- Cachupe, W. J., Shifflett, B., Kahanov, L., & Wughalter, E. H. (2001). Reliability of biodex balance system measures. *Measurement in Physical Education & Exercise Science*, 5(2), 97-108.
- Canty, A. & Ripley, B. (2017). boot: Bootstrap R (S-Plus) Functions. R package version 1.3-20.
- Cook, EG, Burton, L, Hoogenboom, BJ. (2006a). The use of fundamental movements as an assessment of function - Part 1. *North American Journal of Sports Physical Therapy*, 1(2), 62-72.
- Cook, EG, Burton, L, Hoogenboom, BJ. (2006b). The use of fundamental movements as an assessment of function - Part 2. *North American Journal of Sports Physical Therapy*, 1(3), 132-139.
- Davidson, A. C. & Hinkley, D. V. (1997). *Bootstrap methods and their applications*. Cambridge: Cambridge University Press.
- Falvo, M. J., Sirevaag, E. J., Rohrbaugh, J. W., & Earhart, G. M. (2010). Resistance training induces supraspinal adaptations: evidence from movement-related cortical potentials. *European Journal of Applied Physiology*, 109(5), 923-933.
- Folland, J. P., & Williams, A. G. (2007). Morphological and neurological contributions to increased strength. *Sports Medicine*, 37(2), 145-168.

- Gertheiss, J., & Tutz, G. (2009). Penalized regression with ordinal predictors. *International Statistical Review*, 77(3), 245- 365.
- Gertheiss, J. (2015). ordPens: Selection and/or Smoothing of Ordinal Predictor. R package version 0.3-1. <https://CRAN.R-project.org/package=ordPens>
- Glass, S. M., & Ross, S. E. (2015). Modified functional movement screening as a predictor of tactical performance potential in recreationally active adults. *International Journal of Sports Physical Therapy*, 10(5), 612.
- Gossman, M. R., Sahrman, S. A., & Rose, S. J. (1982). Review of length-associated changes in muscle: experimental evidence and clinical implications. *Physical Therapy*, 62(12), 1799-1808.
- Gribble, P. A., Brigle, J., Pietrosimone, B. G., Pfile, K. R., & Webster, K. A. (2013). Intrarater reliability of the functional movement screen. *The Journal of Strength & Conditioning Research*, 27(4), 978-981.
- Gribble, P. A., & Hertel, J. (2003). Considerations for normalizing measures of the Star Excursion Balance Test. *Measurement in Physical Education & Exercise Science*, 7(2), 89-100.
- Harman, E., Han, K. H., & Frykman, P. (2001). *Load-speed interaction effects on the biomechanics of backpack load carriage*. Natick, MA: Army Research Institute of Environmental Medicine.

- Hotta, T., Nishiguchi, S., Fukutani, N., Tashiro, Y., Adachi, D., Morino, S., & Aoyama, T. (2015). Functional movement screen for predicting running injuries in 18-to 24-year-old competitive male runners. *The Journal of Strength & Conditioning Research, 29*(10), 2808-2815.
- Leeder, J.E., Horsley, I.G., & Herrington, L.C. (2013). The inter-rater reliability of the functional movement screen within an athletic population using untrained raters. *Journal of Strength & Conditioning Research, 30*(9), 2591-2599.
- Lisman, P., O'Connor, F. G., Deuster, P. A., & Knapik, J. J. (2013). Functional movement screen and aerobic fitness predict injuries in military training. *Medicine & Science in Sports & Exercise, 45*(4), 636-643.
- Jones, B. H., Bovee, M. W., Harris, J. M., & Cowan, D. N. (1993a). Intrinsic risk factors for exercise-related injuries among male and female army trainees. *The American Journal of Sports Medicine, 21*(5), 705-710.
- Jones, B. H., Cowan, D. N., Tomlinson, J. P., Robinson, J. R., Polly, D. W., & Frykman, P. N. (1993b). *Epidemiology of injuries associated with physical training among young men in the army* (No. USARIEM-M78-91). Natick, MA: Army Research Institute of Environmental Medicine.
- Jones, B., Manikowski, R., Harris, J., Dziados, J., & Norton, S. (1988). *Incidence of and risk factors for injury and illness among male and female Army basic trainees* (No. USARIEM-T19-88). Natick, MA: Army Research Institute of Environmental Medicine.

- Jones, B. H., Bovee, M. W., & Knapik, J. J. (1992). Associations among body composition, physical fitness, and injury in men and women Army trainees. *Body Composition and Physical Performance* (pp. 141 – 174). Washington, DC: National Academy Press.
- Kaufman, K. R., Brodine, S., & Shaffer, R. (2000). Military training-related injuries: surveillance, research, and prevention. *American Journal of Preventive Medicine, 18*(3), 54-63.
- Kiesel, K., Plisky, P. J., & Voight, M. L. (2007). Can serious injury in professional football be predicted by a preseason functional movement screen. *North American Journal of Sports Physical Therapy, 2*(3), 147-158.
- Knapik, J. J., Reynolds, K. L., & Harman, E. (2004). Soldier load carriage: historical, physiological, biomechanical, and medical aspects. *Military Medicine, 169*(1), 45-56.
- Knapik, J. J., Sharp, M. A., Darakjy, S., Jones, S. B., Hauret, K. G., & Jones, B. H. (2006). Temporal changes in the physical fitness of US Army recruits. *Sports Medicine, 36*(7), 613-634.
- Kraus, K., Schütz, E., Taylor, W. R., & Doyscher, R. (2014). Efficacy of the functional movement screen: A review. *The Journal of Strength & Conditioning Research, 28*(12), 3571-3584.
- May, B., Tomporowski, P. D., & Ferrara, M. (2009). Effects of backpack load on balance and decisional processes. *Military Medicine, 174*(12), 1308-1312.

- McGuine, T. A., Greene, J. J., Best, T., & Levenson, G. (2000). Balance as a predictor of ankle injuries in high school basketball players. *Clinical Journal of Sport Medicine, 10*(4), 239-244.
- McKeown, I., Taylor-McKeown, K., Woods, C., Ball, N. (2014). Athletic ability assessments: A movement assessment protocol for athletes. *International Journal of Sports Physical Therapy, 9*(7), 862.
- Minick, K. I., Kiesel, K. B., Burton, L., Taylor, A., Plisky, P., & Butler, R. J. (2010). Interrater reliability of the functional movement screen. *The Journal of Strength & Conditioning Research, 24*(2), 479-486.
- Noronha, M. D., Franca, L. C., Hauptenthal, A., & Nunes, G. S. (2013). Intrinsic predictive factors for ankle sprain in active university students: a prospective study. *Scandinavian Journal of Medicine & Science in Sports, 23*(5), 541-547.
- O'Connor, F. G., Deuster, P. A., Davis, J., Pappas, C. G., & Knapik, J. J. (2011). Functional movement screening: predicting injuries in officer candidates. *Medicine & Science in Sports & Exercise, 43*(12), 2224-30.
- Pincivero, D. M., Lephart, S. M., & Henry, T. J. (1995). Learning effects and reliability of the biodex stability system. *Journal of Athletic Training, 30*, S35.
- Plisky, P. J., Rauh, M. J., Kaminski, T. W., & Underwood, F. B. (2006). Star Excursion Balance Test as a predictor of lower extremity injury in high school basketball players. *Journal of Orthopaedic & Sports Physical Therapy, 36*(12), 911-919.

- Polcyn, A. F., Bessel, C. K., Harman, E. A., & Obusek, J. P. (2001). *The effects of load weight: A summary analysis of maximal performance, physiological, and biomechanical results from four studies of load-carriage systems*. Natick, MA: Army Natick Soldier Center; Supporting Science and Technology Directorate.
- Pollock, M. L., Schmidt, D. H., & Jackson, A. S. (1980). Measurement of cardiorespiratory fitness and body composition in the clinical setting. *Comprehensive Therapy*, 6,12-27.
- R Core Team. (2017). R: A language and environment for statistical computing. R Foundation for Statistical Computing, Vienna, Austria: <https://www.R-project.org/>.
- Robinson, R. H., & Gribble, P. A. (2008). Support for a reduction in the number of trials needed for the Star Excursion Balance Test. *Archives of Physical Medicine & Rehabilitation*, 89(2), 364-370.
- Rusling, C., Edwards, K. L., Bhattacharya, A., Reed, A., Irwin, S., Boles, A., & Hodgson, L. (2015). The functional movement screening tool does not predict injury in football. *Progress in Orthopedic Science*, 1(2), 41-46.
- Teyhen, D., Bergeron, M. F., Deuster, P., Baumgartner, N., Beutler, A. I., Sarah, J., (2014). Consortium for health and military performance and American College of Sports Medicine Summit: utility of functional movement assessment in identifying musculoskeletal injury risk. *Current Sports Medicine Reports*, 13(1) 52-63.

- Tropp, H., Ekstrand, J., & Gillquist, J. (1983). Stabilometry in functional instability of the ankle and its value in predicting injury. *Medicine & Science in Sports & Exercise*, 16(1), 64-66.
- Wedderkopp, N., Kalsoft, M., Holm, R., & Froberg, K. (2003). Comparison of two intervention programmes in young female players in European handball—with and without ankle disc. *Scandinavian Journal of Medicine & Science in Sports*, 13(6), 371-375.
- US Department of the Army, 101st Airborne Division (Air Assault). (2011). *Basic standards of the airborne* (CAM Pam 600-1). Washington, DC: U.S. Government Printing Office.
- US Department of the Army. (2013). *The Army Body Composition Program*. (Army Regulation 600-9). Washington, DC: U.S. Government Printing Office.
- Yen, S. C., Ling, W., Magill, R., McDonough, A., & Gutierrez, G. M. (2011). Temporal relationship between trunk and thigh contributes to balance control in load carriage walking. *Gait & Posture*, 34(3), 402-408.
- Zarei, M., Samani, Z., Reisi, J. (2015). Can functional movement screening predict injuries in Iranian soldiers? *Journal of Military Medicine*, 17(2), 107-114.

CHAPTER V

PROJECT CONCLUSIONS

Musculoskeletal injuries (MSKI) are prevalent among sedentary and active adults, athletes, and military warfighters and recruits (Cohen et al., 2010; Feuerstein et al., 1997; Jones et al., 2010; Lincoln et al., 2002; Songer & LaPorte, 2000; US Department of Health and Human Services, 1996). The high incidence of MSKI in these demographic groups leads to high treatment costs, missed work days, and reductions in military training time and overall military readiness (Almeida et al., 1999; Hootman et al., 2002; Jones et al., 1993a; Jones et al., 1993b; Kaufman et al., 2000; National Research Council, 2001). These adverse consequences provide a clear and compelling need to identify modifiable risk factors associated with a heightened risk of MSKI (Butler et al., 2013; McGuine et al., 2000; Plisky et al., 2006; Trojian & McKeag, 2006; Watson, 1999). An existing screening tool, the Functional Movement ScreenTM, can be used to detect suboptimal movement patterns and deficits in stability, mobility, and functional balance that can lead to MSKI (Cook et al., 2006a; Cook et al., 2006b; Kiesel et al., 2007; Lisman et al., 2013; O'Connor et al., 2011). However, little is known regarding the ability of FMS test items to predict dynamic balance.

Against this backdrop, two studies were conducted in this dissertation project. The purpose of Study 1 was to quantify the relationship between FMS composite scores and subscores and dynamic balance in healthy and physically-active adults. Thirty-four

men and women completed the FMS test battery and dynamic balance was evaluated using the Y Balance Test (YBT) and Biodex Balance System (BBS). Results indicated that higher FMS composite scores were associated with better balance performance on the YBT and BBS. Participants who attained FMS composite scores of 14 or less exhibited worse YBT performances compared to those who achieved FMS composite scores greater than 14. Lasso penalized regression analyses also revealed that a deep squat score of 2 and a trunk stability push-up score of 3 were predictive of better balance scores on the YBT, whereas shoulder mobility scores of 2 and 3 and scores of 3 on the rotary stability item predicted better balance performance on the BBS.

The purpose of Study 2 was to quantify the degree to which unloaded and torso-loaded FMS composite and subscores predicted unloaded and torso-loaded balance in 30 men and women with body composition and fitness profiles typical of military recruits. Data analyses showed that both unloaded and loaded FMS composite scores were associated with loaded YBT scores. However, unloaded FMS composite scores displayed a stronger relationship with YBT scores obtained under loaded conditions and participants with higher FMS composite scores (≥ 15) attained higher loaded YBT scores compared to those with lower FMS composite scores (≤ 14). In considering unloaded FMS subscores, an in-line lunge score of 1 predicted lower balance scores on the loaded YBT and a shoulder mobility score of 3 predicted better performance on the loaded BBS. Shoulder mobility scores of 3 under loaded conditions also predicted better loaded BBS scores, while loaded trunk stability push-up scores of 3 predicted worse performance on the loaded BBS.

Taken together, results from this dissertation project provide support for using the traditional and loaded Functional Movement Screen™ to assess unloaded and loaded dynamic balance in active adults and military recruits. From a practical standpoint, clinicians, coaches, and military personnel who use the FMS to predict functional balance should consider poorer test-item scores as a possible indication to conduct further testing to determine if balance-specific interventions are needed. Future research in this area should explore the use of a wider range of scores when employing the FMS to improve the sensitivity of this assessment, especially when incorporating external loads to screen for movement deficiencies. Other modifications to the FMS, such as the development of sport-specific movement screenings, or the implementation of a weighted scoring system to calculate composite scores, could also improve the sensitivity of the screening.

DISSERTATION REFERENCES

- Akbari, M., Karimi, H., Farahini, H., & Faghihzadeh, S. (2006). Balance problems after unilateral lateral ankle sprains. *Journal of Rehabilitation Research & Development, 43*(7), 819.
- Almeida, S. A., Maxwell-Williams, K. M., Shaffer, R. A., Luz, J. T., & Badong, E. (1997). *A physical training program to reduce musculoskeletal injuries in us marine corps recruits, Version 1.0* (No. NHRC-TD-97-2B). San Diego, Ca: Naval Health Research Center.
- Almeida, S. A., Maxwell-Williams, K. M., Shaffer, R. A., & Brodine, S. K. (1999). Epidemiological patterns of musculoskeletal injuries and physical training. *Medicine & Science in Sports & Exercise, 31*(8), 1176-1182.
- Arnold, B. L., & Schmitz, R. J. (1998). Examination of balance measures produced by the biodex stability system. *Journal of Athletic Training, 33*(4), 323.
- Attenborough, A. S., Sinclair, P. J., Sharp, T., Greene, A., Stuelcken, M., Smith, R. M., & Hiller, C. E. (2017). The identification of risk factors for ankle sprains sustained during netball participation. *Physical Therapy in Sport, 23*, 31-36.
- Bernier, J. N., & Perrin, D. H. (1998). Effect of coordination training on proprioception of the functionally unstable ankle. *Journal of Orthopedic & Sports Physical Therapy, 27*(4), 264-275.

- Bullock, S. H., Jones, B. H., Gilchrist, J., & Marshall, S. W. (2010). Prevention of physical training–related injuries: recommendations for the military and other active populations based on expedited systematic reviews. *American Journal of Preventive Medicine*, *38*(1), S156-S181.
- Bush, R. A., Brodine, S. K., & Shaffer, R. A. (2000). The association of blisters with musculoskeletal injuries in male marine recruits. *Journal of the American Podiatric Medical Association*, *90*(4), 194-198.
- Bushman, T. T., Grier, T. L., Canham-Chervak, M., Anderson, M. K., North, W. J., & Jones, B. H. (2015). The functional movement screen and injury risk association and predictive value in active men. *The American Journal of Sports Medicine*, *44*(2), 297-304.
- Butler, R. J., Lehr, M. E., Fink, M. L., Kiesel, K. B., & Plisky, P. J. (2013). Dynamic balance performance and noncontact lower extremity injury in college football players: An initial study. *Sports Health: A Multidisciplinary Approach*, *5*(5), 417-422.
- Cachupe, W. J., Shifflett, B., Kahanov, L., & Wughalter, E. H. (2001). Reliability of biodex balance system measures. *Measurement in Physical Education & Exercise Science*, *5*(2), 97-108.
- Cavanaugh, T., Quigley, P. J., Hodgson, D., Reid, J. C., & Behm, D. G. (2016). Kinesiology tape or compression sleeve applied to the thigh does not improve balance or muscle activation before or following fatigue. *The Journal of Strength & Conditioning Research*, *30*(7), 1992-2000.

- Cohen, S. P., Brown, C., Kurihara, C., Plunkett, A., Nguyen, C., & Strassels, S. A. (2010). Diagnoses and factors associated with medical evacuation and return to duty for service members participating in Operation Iraqi Freedom or Operation Enduring Freedom: A prospective cohort study. *The Lancet*, 375 (9711), 301-309.
- Cook, G. (2011) *Movement: Functional movement systems. Screening-Assessment-Corrective Strategies*. Aptos, CA: On Target Publications.
- Cook, EG, Burton, L, Hoogenboom, BJ. (2006a). The use of fundamental movements as an assessment of function - Part 1. *North American Journal of Sports and Physical Therapy*, 1(2), 62-72.
- Cook, EG, Burton, L, Hoogenboom, BJ. (2006b). The use of fundamental movements as an assessment of function- Part 2. *North American Journal of Sports and Physical Therapy*, 1(3), 132-139.
- Cook, G., Burton, L., Hoogenboom, B. J., & Voight, M. (2014). Functional movement screening: the use of fundamental movements as an assessment of function□part 1. *International Journal of Sports Physical Therapy*, 9(3), 396.
- Cowan, D. N., Jones, B. H., Frykman, P. N., Polly Jr, D. W., Harman, E. A., Rosenstein, R. M., & Rosenstein, M. T. (1996). Lower limb morphology and risk of overuse injury among male infantry trainees. *Medicine and Science in Sports & Exercise*, 28(8), 945-952.
- Dalén, Å., Nilsson, J., & Thorstensson, A. (1978). *Factors influencing a prolonged foot march*. (FOA Report C50601-H6). Stockholm, Sweden: Karolinska Institute.

- Dean, C. E. (2008). The modern warrior's combat load-dismounted operations in Afghanistan. *Medicine & Science in Sports & Exercise*, 40(5), 60.
- DiStefano, L. J., Clark, M. A., & Padua, D. A. (2009). Evidence supporting balance training in healthy individuals: a systemic review. *The Journal of Strength & Conditioning Research*, 23(9), 2718-2731.
- Donald, J. G., & Fitts, W. T. (1947). March fractures. *Journal of Bone and Joint Surgery*, 29(2), 297-300.
- Ekstrand, J., Gillquist, J., & Liljedahl, S. O. (1983). Prevention of soccer injuries: Supervision by doctor and physiotherapist. *The American Journal of Sports Medicine*, 11(3), 116-120.
- Feuerstein, M., Berkowitz, S. M., & Peck Jr, C. A. (1997). Musculoskeletal-related disability in US Army personnel: prevalence, gender, and military occupational specialties. *Journal of Occupational & Environmental Medicine*, 39(1), 68-78.
- Freeman, M. (1965). Instability of the foot after injuries to the lateral ligament of the ankle. *Bone & Joint Journal*, 47(4), 669-677.
- Glass, S. M., & Ross, S. E. (2015). Modified functional movement screening as a predictor of tactical performance potential in recreationally active adults. *International Journal of Sports Physical Therapy*, 10(5), 612.
- Glencross, D., & Thornton, E. (1981). Position sense following joint injury. *The Journal of Sports Medicine & Physical Fitness*, 21(1), 23-27.

- Gribble, P. A., Brigle, J., Pietrosimone, B. G., Pfile, K. R., & Webster, K. A. (2013). Intrarater reliability of the functional movement screen. *The Journal of Strength & Conditioning Research*, 27(4), 978-981.
- Gusi, N., Adsuar, J. C., Corzo, H., del Pozo-Cruz, B., Olivares, P. R., & Parraca, J. A. (2012). Balance training reduces fear of falling and improves dynamic balance and isometric strength in institutionalised older people: a randomised trial. *Journal of Physiotherapy*, 58(2), 97-104.
- Harman, E., Han, K. H., & Frykman, P. (2001). *Load-speed interaction effects on the biomechanics of backpack load carriage*. Natick, MA: Army Research Institute of Environmental Medicine.
- Hartigan, E. H., Lawrence, M., Bisson, B. M., Torgerson, E., & Knight, R. C. (2014). Relationship of the functional movement screen in-line lunge to power, speed, and balance measures. *Sports Health: A Multidisciplinary Approach*, 6(3), 197-202.
- Haycock, C. E., & Gillette, J. V. (1976). Susceptibility of women athletes to injury: myths vs reality. *Journal of the American Medical Association*, 236(2), 163-165.
- Hootman, J. M., Macera, C. A., Ainsworth, B. E., Addy, C. L., Martin, M., & Blair, S. N. (2002). Epidemiology of musculoskeletal injuries among sedentary and physically active adults. *Medicine & Science in Sports & Exercise*, 34(5), 838-844.

- Hotta, T., Nishiguchi, S., Fukutani, N., Tashiro, Y., Adachi, D., Morino, S., & Aoyama, T. (2015). Functional movement screen for predicting running injuries in 18-to 24-year-old competitive male runners. *The Journal of Strength & Conditioning Research, 29*(10), 2808-2815.
- Jennings, B. M., Yoder, L. H., Heiner, S. L., Loan, L. A., & Bingham, M. O. (2008). Soldiers with musculoskeletal injuries. *Journal of Nursing Scholarship, 40*(3), 268-274.
- Jones, B. H. (1983). Overuse injuries of the lower extremities associated with marching, jogging, and running: A review. *Military Medicine, 148*(10), 783.
- Jones, B. H., Cowan, D. N., & Knapik, J. J. (1994). Exercise, training and injuries. *Sports Medicine, 18*(3), 202-214.
- Jones, B. H., Bovee, M. W., Harris, J. M., & Cowan, D. N. (1993a). Intrinsic risk factors for exercise-related injuries among male and female army trainees. *The American Journal of Sports Medicine, 21*(5), 705-710.
- Jones, B. H., Cowan, D. N., Tomlinson, J. P., Robinson, J. R., Polly, D. W., & Frykman, P. N. (1993b). *Epidemiology of injuries associated with physical training among young men in the army* (No. USARIEM-M78-91). Natick, Ma: Army Research Institute of Environmental Medicine.
- Jones, B. H., & Hansen, B. C. (1996). *Injuries in the military: A hidden epidemic*. (Report No. 29 HA 4844 978). Falls Church, VA: Armed Forces Epidemiological Board.
- Jones, B. H., & Knapik, J. J. (1999). Physical training and exercise-related injuries. *Sports Medicine, 27*(2), 111-125.

- Jones, B. H., Bovee, M. W., & Knapik, J. J. (1992). Associations among body composition, physical fitness, and injury in men and women Army trainees. *Body Composition and Physical Performance* (pp. 141 – 174). Washington, DC: National Academy Press.
- Jones, B. H., Canham-Chervak, M., Canada, S., Mitchener, T. A., & Moore, S. (2010). Medical surveillance of injuries in the US military: descriptive epidemiology and recommendations for improvement. *American Journal of Preventive Medicine*, 38(1), S42-S60.
- Kaminski, T. W., Buckley, B. D., Powers, M. E., Hubbard, T. J., & Ortiz, C. (2003). Effect of strength and proprioception training on eversion to inversion strength ratios in subjects with unilateral functional ankle instability. *British Journal of Sports Medicine*, 37(5), 410-415.
- Karimi, N., Ebrahimi, I., Kharizi, S., & Torkaman, G. (2011). Reliability of postural balance evaluation using the biodex balance system in subjects with and without low back pain. *Journal of Postgraduate Medical Institute (Peshawar-Pakistan)*, 22(2), 95-101.
- Kaufman, K. R., Brodine, S., & Shaffer, R. (2000). Military training-related injuries: surveillance, research, and prevention. *American Journal of Preventive Medicine*, 18(3), 54-63.

- Kelleher, L. K., Frayne, R. J., Beach, T. A., Higgs, J. M., Johnson, A. M., & Dickey, J. P. (2017). Relationships between the functional movement screen score and y-balance test reach distances. *International Journal of Human Movement & Sports Sciences*, 5(3), 51-56.
- Kiesel, K., Plisky, P. J., & Voight, M. L. (2007). Can serious injury in professional football be predicted by a preseason functional movement screen. *North American Journal of Sports Physical Therapy*, 2(3), 147-158.
- Kinoshita, H. (1985). Effects of different loads and carrying systems on selected biomechanical parameters describing walking gait. *Ergonomics*, 28(9), 1347-1362.
- Knapik, J. (1989). *Loads carried by soldiers: historical, physiological, biomechanical and medical aspects* (No. USARIEM-T19-89). Natick, MA: Army Research Institute of Environmental Medicine.
- Knapik, J., Ang, P., Reynolds, K., & Jones, B. (1993). Physical fitness, age, and injury incidence in infantry soldiers. *Journal of Occupational & Environmental Medicine*, 35(6), 598-603.
- Knapik, J. J., Bullock, S. H., Toney, E., Wells, J. D., Hoedebecke, E., & Jones, B. H. (2004a). Influence of an injury reduction program on injury and fitness outcomes among soldiers. *Injury Prevention*, 10(1), 37-42.

- Knapik, J. J., Hauret, K. G., Arnold, S., Canham-Chervak, M., Mansfield, A. J., Hoedebecke, E. L., & McMillian, D. (2003). Injury and fitness outcomes during implementation of physical readiness training. *International Journal of Sports Medicine, 24*(5), 372-381.
- Knapik, J. J., Darakjy, S., Scott, S., & Hauret, K. G. (2004b). *Evaluation of two Army fitness programs: the TRADOC standardized physical training program for basic combat training and the fitness assessment program* (No. USACHPPM-12-HF-5772B-04). Aberdeen Proving Ground, MD: Army Center for Health Promotion and Preventive Medicine.
- Knapik, J. J., Bullock, S. H., Toney, E., & Wells, J. D. (2003). *The Aberdeen Proving Ground Injury Control Project: influence of a multiple intervention program on injuries and fitness among ordnance school soldiers in advanced individual training* (No. USACHPPM-12-HF-7990-03). Aberdeen Proving Ground, MD: Army Center for Health Promotion and Preventive Medicine (Provisional).
- Knapik, J., Reynolds, K., Staab, J., Vogel, J. A., & Jones, B. (1992). Injuries associated with strenuous road marching. *Military Medicine, 157*(2), 64-67.
- Knapik, J. J., Reynolds, K. L., & Harman, E. (2004c). Soldier load carriage: historical, physiological, biomechanical, and medical aspects. *Military Medicine, 169*(1), 45-56.
- Kraus, K., Schütz, E., Taylor, W. R., & Doyscher, R. (2014). Efficacy of the functional movement screen: a review. *The Journal of Strength & Conditioning Research, 28*(12), 3571-3584.

- Lee, J. W. (2008). A Greek army on the march. *Soldiers and survival in Xenophon's Anabasis*. Cambridge, UK: Cambridge University Press.
- Leeder, J.E., Horsley, I.G., & Herrington, L.C. (2013). The inter-rater reliability of the functional movement screen within an athletic population using untrained raters. *Journal of Strength & Conditioning Research*, 30(9), 2591-2599.
- Lincoln, A. E., Smith, G. S., Amoroso, P. J., & Bell, N. S. (2002). The natural history and risk factors of musculoskeletal conditions resulting in disability among US Army personnel. *Work*, 18(2), 99-113.
- Lind, W. S. (2004). Understanding fourth generation war. *Military Review*, 84(5), 12.
- Lisman, P., O'Connor, F. G., Deuster, P. A., & Knapik, J. J. (2013). Functional movement screen and aerobic fitness predict injuries in military training. *Medicine & Science in Sports & Exercise*, 45(4), 636-643.
- May, B., Tomporowski, P. D., & Ferrara, M. (2009). Effects of backpack load on balance and decisional processes. *Military Medicine*, 174(12), 1308-1312.
- McGuine, T. A., Greene, J. J., Best, T., & Levenson, G. (2000). Balance as a predictor of ankle injuries in high school basketball players. *Clinical Journal of Sport Medicine*, 10(4), 239-244.
- McKeown, I., Taylor-McKeown, K., Woods, C., Ball, N. (2014). Athletic ability assessments: a movement assessment protocol for athletes. *International Journal of Sports Physical Therapy*, 9(7), 862.

- Minick, K. I., Kiesel, K. B., Burton, L., Taylor, A., Plisky, P., & Butler, R. J. (2010). Interrater reliability of the functional movement screen. *The Journal of Strength & Conditioning Research, 24*(2), 479-486.
- Myer, G. D., Ford, K. R., & Hewett, T. E. (2005). The effects of gender on quadriceps muscle activation strategies during a maneuver that mimics a high ACL injury risk position. *Journal of Electromyography & Kinesiology, 15*(2), 181-189.
- Nasher, L. M. (1997). *The Handbook of Balance Function Testing*. San Diego, CA: Singular Publishing Group, 261-279.
- Noronha, M. D., Franca, L. C., Hauptenthal, A., & Nunes, G. S. (2013). Intrinsic predictive factors for ankle sprain in active university students: a prospective study. *Scandinavian Journal of Medicine & Science in Sports, 23*(5), 541-547.
- O'Connor, F. G., Deuster, P. A., Davis, J., Pappas, C. G., & Knapik, J. J. (2011). Functional movement screening: predicting injuries in officer candidates. *Medicine & Science in Sports & Exercise, 43*(12), 2224-30.
- Oh, K.Y., Kim, S.A., Lee, S.Y., & Lee, Y.S. (2011). Comparison of manual balance and balance board tests in healthy adults. *Annals of Rehabilitation Medicine, 35*(6), 873-879.
- Olmsted, L. C., Carcia, C. R., Hertel, J., & Shultz, S. J. (2002). Efficacy of the star excursion balance tests in detecting reach deficits in subjects with chronic ankle instability. *Journal of Athletic Training, 37*(4), 501.

- Orr, R. M., Pope, R., Johnston, V., & Coyle, J. (2010). Load Carriage: Minimising soldier injuries through physical conditioning - A narrative review. *Journal of Military & Veterans' Health, 18*(3), 31.
- Orr, R., Pope, R., Johnston, V., & Coyle, J. (2011). Load carriage and its force impact. *Australian Defence Force Journal: Journal of the Australian Profession of Arms, 185*, 52.
- Orr, R. M., Johnston, V., Coyle, J., & Pope, R. (2015). Reported load carriage injuries of the Australian army soldier. *Journal of Occupational Rehabilitation, 25*(2), 316-322.
- Plisky, P. J., Rauh, M. J., Kaminski, T. W., & Underwood, F. B. (2006). Star Excursion Balance Test as a predictor of lower extremity injury in high school basketball players. *Journal of Orthopaedic & Sports Physical Therapy, 36*(12), 911-919.
- Polcyn, A. F., Bessel, C. K., Harman, E. A., & Obusek, J. P. (2001). *The effects of load weight: A summary analysis of maximal performance, physiological, and biomechanical results from four studies of load-carriage systems*. Natick, MA: Army Natick Soldier Center: Supporting Science and Technology Directorate.
- Pope, R. P. (1999). Prevention of pelvic stress fractures in female army recruits. *Military Medicine, 164*(5), 370.
- Reynolds, K. L., Heckel, H. A., Witt, C. E., Martin, J. W., Pollard, J. A., Knapik, J. J., & Jones, B. H. (1993). Cigarette smoking, physical fitness, and injuries in infantry soldiers. *American Journal of Preventive Medicine, 10*(3), 145-150.

- Reynolds, K. L., White, J. S., Knapik, J. J., Witt, C. E., & Amoroso, P. J. (1999). Injuries and risk factors in a 100-mile (161-km) infantry road march. *Preventive Medicine, 28*(2), 167-173.
- Riddell, D. I. (1989). Changes in the incidence of medical conditions at the Commando Training Centre, Royal Marines. *Journal of the Royal Naval Medical Service, 76*(2), 105-107.
- Rusling, C., Edwards, K. L., Bhattacharya, A., Reed, A., Irwin, S., Boles, A., & Hodgson, L. (2015). The functional movement screening tool does not predict injury in football. *Progress in Orthopedic Science, 1*(2), 41-46.
- Schiffman, J. M., Bensel, C. K., Hasselquist, L., Norton, K., & Piscitelle, L. (2004). *The effects of soldiers' loads on postural sway*. Natick, MA: Army Natick Soldier Center.
- Shaffer, R. A., Brodine, S. K., Almeida, S. A., Williams, K. M., & Ronaghy, S. (1999). Use of simple measures of physical activity to predict stress fractures in young men undergoing a rigorous physical training program. *American Journal of Epidemiology, 149*(3), 236-242.
- Songer, T. J., & LaPorte, R. E. (2000). Disabilities due to injury in the military. *American Journal of Preventive Medicine, 18*(3), 33-40.
- Sutton, E. L. (1976). Preparing for combat: athletic injuries incurred and performance limiting orthopedic and medical conditions. *Medicine and Science in Sports and Exercise, 8*(1), 74.

- Testerman, C., & Vander Griend, R. (1999). Evaluation of ankle instability using the Biodex Stability System. *Foot & Ankle International*, 20(5), 317-321.
- Teyhen, D. S., Shaffer, S. W., Lorensen, C. L., Halfpap, J. P., Donofry, D. F., Walker, M. J., & Childs, J. D. (2012). The functional movement screen: a reliability study. *Journal of Orthopaedic & Sports Physical Therapy*, 42(6), 530-540.
- Teyhen, D., Bergeron, M. F., Deuster, P., Baumgartner, N., Beutler, A. I., Sarah, J., (2014). Consortium for health and military performance and American College of Sports Medicine Summit: utility of functional movement assessment in identifying musculoskeletal injury risk. *Current Sports Medicine Reports*, 13(1), 52-63.
- Thacker, S. B., Stroup, D. F., Branche, C. M., Gilchrist, J., Goodman, R. A., & Weitman, E. A. (1999). The prevention of ankle sprains in sports A systematic review of the literature. *The American Journal of Sports Medicine*, 27(6), 753-760.
- Tomlinson, J. P., Lednar, W. M., & Jackson, J. D. (1987). Risk of injury in soldiers. *Military Medicine*, 152(2), 60-64.
- Trojian, T. H., & McKeag, D. B. (2006). Single leg balance test to identify risk of ankle sprains. *British Journal of Sports Medicine*, 40(7), 610-613.
- Trone, D. W., Hagan, R. D., & Shaffer, R. A. (1999). *Physical Training Program Guidelines for US Navy Recruits: Preparing Recruits for Battle Stations* (No. TD99-1A). San Diego, CA: Naval Health Research Center.

- Tropp, H., Ekstrand, J., & Gillquist, J. (1983). Stabilometry in functional instability of the ankle and its value in predicting injury. *Medicine & Science in Sports & Exercise, 16*(1), 64-66.
- Truax, A. L., Chandnani, V. P., Chacko, A. K., & Gonzalez, D. M. (1997). Incidence and methods of diagnosis of musculoskeletal injuries incurred in Operations Desert Shield and Desert Storm. *Investigative Radiology, 32*(3), 169-173.
- US Department of the Army, Headquarters. (1958). *Foot Marches* (FM 21-18). Washington, DC.
- US Department of the Army, 101st Airborne Division (Air Assault). (2011). *Basic standards of the airborne* (CAM Pam 600-1). Washington, DC.
- U.S. Department of Health and Human Services. (1996). *Physical Activity and Health: A Report of the Surgeon General*. Atlanta, GA: U.S. Department of Health and Human Services, Centers for Disease Control and Prevention, National Center for Chronic Disease Prevention and Health Promotion.
- Wasserman, G. M., Martin, B. L., Hyams, K. C., Merrill, B. R., Oaks, H. G., & McAdoo, H. A. (1997). A survey of outpatient visits in a United States Army forward unit during Operation Desert Shield. *Military Medicine, 162*(6), 374-379.
- Watson, A. W. S. (1999). Ankle sprains in players of the field-games Gaelic football and hurling. *Journal of Sports Medicine & Physical Fitness, 39*(1), 66.

- Wedderkopp, N., Kalsoft, M., Holm, R., & Froberg, K. (2003). Comparison of two intervention programmes in young female players in European handball—with and without ankle disc. *Scandinavian Journal of Medicine & Science in Sports*, 13(6), 371-375.
- Wilkerson, G. B., & Nitz, A. J. (2010). Dynamic ankle stability: mechanical and neuromuscular interrelationships. *Journal of Sport Rehabilitation*, 3(1),43-57.
- Williams, K. M., Brodine, S. K., Shaffer, R. A., Hagy, J., & Kaufman, K. (1997). *Biomechanical properties of infantry combat boot development* (No. NHRC-97-26). San Diego, CA: Naval Health Research Center.
- World Health Organization. (2006). Report of a workshop on tracking health performance and humanitarian outcomes. Retrieved from <http://www.who.int/hac/events/benchmarkmeeting/en/index.html>.
- Zarei, M., Samani, Z., Reisi, J. (2015). Can functional movement screening predict injuries in Iranian soldiers? *Journal of Military Medicine*, 17(2), 107-114.

APPENDICES

Institutional Review Board

Office of Compliance

Middle Tennessee State University

Continuing Review Schedule:

| Reporting Period | Requisition Deadline | IRB Comments |
|--------------------|----------------------|-----------------|
| First year report | 3/31/2018 | TO BE COMPLETED |
| Second year report | 3/31/2019 | TO BE COMPLETED |
| Final report | 3/31/2020 | TO BE COMPLETED |

Post-approval Protocol Amendments:

| Date | Amendment(s) | IRB Comments |
|------|--------------|--------------|
| None | NONE | NONE |

The investigator(s) indicated in this notification should read and abide by all of the post-approval conditions imposed with this approval. [Refer to the post-approval guidelines posted in the MTSU IRB's website.](#) Any unanticipated harms to participants or adverse events must be reported to the Office of Compliance at (615) 494-8918 within 48 hours of the incident. Amendments to this protocol must be approved by the IRB. Inclusion of new researchers must also be approved by the Office of Compliance before they begin to work on the project.

All of the research-related records, which include signed consent forms, investigator information and other documents related to the study, must be retained by the PI or the faculty advisor (if the PI is a student) at the secure location mentioned in the protocol application. The data storage must be maintained for at least three (3) years after study completion. Subsequently, the researcher may destroy the data in a manner that maintains confidentiality and anonymity. IRB reserves the right to modify, change or cancel the terms of this letter without prior notice. Be advised that IRB also reserves the right to inspect or audit your records if needed.

Sincerely,

Institutional Review Board
Middle Tennessee State University

Quick Links:

[Click here](#) for a detailed list of the post-approval responsibilities.
More information on expedited procedures can be found [here](#).