THE RELATIONSHIPS BETWEEN FUNDAMENTAL MOVEMENT PATTERNS, SPIKE JUMP TECHNIQUE, AND OVERUSE PAIN IN COLLEGIATE VOLLEYBALL PLAYERS

by

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Abstract

Despite an exceptionally high prevalence of overuse injury among elite volleyball players, very little is known about the aetiology of these conditions. Fundamental movement patterns have been found to be predictive of serious acute athletic injury, however the relationship between fundamental movement patterns and overuse injury has yet to be determined. Sport-specific jumping biomechanics have been shown to play an additional role in the development of overuse injuries in sport, and it is likely that combining fundamental and sport-specific movement assessment may possess greater predictive power than either alone. The purpose of this investigation was to evaluate how volleyball-related overuse injuries are related to fundamental movement patterns and volleyball spike jump technique. We hypothesized that volleyball players with a history of overuse injury would exhibit more dysfunctional fundamental and sport-specific movement than players without a history of injury. Fifty-seven male and female collegiate volleyball players took part in Functional Movement Screen testing, and athletes free of lower body pain (n=31) took part in a 2-dimensional kinematic analysis of spike jump technique using Dartfish video analysis software. Volleyball players with a history of overuse low back injury had significantly lower Active Straight Leg Raise scores compared to healthy players ($p=0.011$). Various aspects of hip mechanics during the spike jump were significantly related to a history of shoulder, low back, and knee pain ($p<0.01$), and the Shoulder Mobility test was significantly correlated to 2 aspects of hip mechanics during the spike jump for females ($R^2 = 0.560$, $p<0.01$). Additionally, males with a history of overuse pain tended to jump 14 cm higher than their healthy teammates ($p<0.01$). Both fundamental and sport-specific hip mechanics appear to have a link to overuse injuries among collegiate volleyball players.

Preface

A version of chapter 2 - "The Functional Movement Screen: A Systematic Review" – will be submitted for peer-review with Dr. Bredin, Dr. Taunton and Dr. Warburton as co-authors and Mischa Harris as the first author. The co-authors contributed to the generation of the review structure and served as second and third reviewers where necessary. Mischa Harris was responsible for writing the manuscript, with edits coming from all co-authors.

The data from the research investigation (presented in Chapter 4) will be submitted for peer review with the same list of co-authors. Mischa Harris was responsible for generating the manuscript, but co-authors also made significant contributions to the content and provided methodological guidance, as well as comprehensive edits.

The content in chapter 4 was obtained with the approval of the UBC Behavioural Research Ethics Board certificate number H11-02123.

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List of Abbreviations

FMS	Functional Movement Screen
PT	Patellar Tendinopathy
ACLR	Anterior Cruciate Ligament Reconstruction
APTA	Asymptomatic Patellar Tendon Abnormality
IRR	Inter-Rater Reliability
ICC	Intra-Class Correlation Coefficient
CIS	Canadian Inter-University Sport
VISA	Victorian Institute of Sport Assessment
FFP	First Foot Plant
SFP	Second Foot Plant
2D	2-Dimensional
3D	3-Dimensional
ICC	Intra-class Correlation Coefficient
SEM	Standard Error of Measurement
NSAID	Non-Steroidal Anti-Inflammatory Drugs
VAS	Visual Analogue Scale
SFMA	Selective Functional Movement Assessment

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Dedication

For my parents - the values that I learned from you spawned my desire to look for a better solution, which continues to guide my academic, professional and personal pursuits. Love always.

Chapter 1: Introduction

The purpose of this chapter is to provide an introduction to this document, whereby a brief presentation of the background and rationale for the original research conducted as part of this thesis, will be presented. Specifically, injuries in the sport of volleyball and how of fundamental and sport-specific movement patterns are related to injury risk will be discussed first, followed by the purpose of the thesis investigation. An overview of the entire thesis document will conclude the chapter.

1.1 Background and Rationale

Volleyball, like any sport, carries an inherent risk of injury with participation. However, volleyball is a non-contact sport; as such, the traumatic injuries that plague sports such as rugby and football are uncommon, and the risk of severe injury while playing volleyball is low relative to other sports. The most common time loss injury afflicting volleyball players of all ages, genders, and skill levels is acute ankle sprains. Beyond that, occasional non-contact knee ligament injuries or finger sprains also cause time loss from sport, but these occurrences are rare. Instead of severe acute injuries, volleyball players are prone to repetitive overuse injuries that arise from high-volume repetition of maximal jumping and forceful spiking armswings. These overuse injuries are incredibly prevalent among elite volleyball players; with up to 80% of players playing with pain at one of the shoulder, knee, or low back (Bahr, 2009). Because sports-injury literature has been so focused on time loss injuries, there is currently a paucity of information regarding the etiology, treatment, and prevention of these overuse injuries. Unfortunately, many players are

forced to end their career as seemingly minor aches and pains accumulate into a debilitating dysfunction.

Some research has attempted to elucidate risk factors for volleyball-related overuse injuries of the knee, shoulder, and low back, but very few results have been reproducible or carried much predictive power. One reason for this lack of success could be due to the typically reductionist approach of the available research, choosing to focus solely on one joint or muscle local to the site of the painful symptoms. While this approach is likely to capture some sort of symptom, or even a portion of the underlying cause, the theory of Regional Interdependence has demonstrated that seemingly unrelated musculoskeletal dysfunction in regions far from the site of pain can also contribute to the etiology of an injury. This concept of kinetic linking within the body supports the notion that a weak link in a connected chain can lead to compensations, overload, and breakdown at another site in the body. In order to investigate global musculoskeletal function, a non-specific set of tests called the Functional Movement Screen was developed by Gray Cook and unveiled in the literature in 2006 (Cook and Burton, 2006; Cook et al., 2006). The Functional Movement Screen investigates mobility and stability throughout the body, with a focus on the neuromuscular connection between regions and the movement patterns generated by a combination of body segments working in concert. Since 2006, the Functional Movement Screen has shown success predicting serious injury in both athletic and occupational cohorts, and has also demonstrated excellent inter-rater reliability (Minick et al., 2010). However, no research has investigated the link between the Functional Movement Screen and overuse injuries.

With a large volume of repetitive high velocity skills such as jumping and spiking, it makes theoretical sense that a limitation in mobility, stability, or neuromuscular control within the body may adversely affect the force distribution during a skill, resulting in greater load in another area of the body. Similarly, a dysfunctional motor pattern in jumping or spiking skills could also theoretically lead to increased load in a certain area, irrespective of mobility or stability limitations. In order to truly investigate the role of global movement patterns in the etiology of volleyball-related overuse injuries, both spectrums of neuro-musculoskeletal dysfunction should be examined: non-specific functional movement patterns and sport-specific movement patterns such as jumping and spiking. This novel approach to overuse injury investigation may increase our understanding of the complex, multifactorial etiology of common musculoskeletal complaints.

1.2 Purpose of the Research

The primary objective of this investigation was to determine whether non-specific functional movement patterns or volleyball-specific spike jump mechanics are related to overuse injuries of the shoulder, low back and knee among elite volleyball players. A secondary objective was to compare the measures of functional movement patterns and spike jump mechanics to each other to determine any patterns of association.

We hypothesized that volleyball players with a history of overuse injury at the shoulder, low back or knee would score lower on the Functional Movement Screen than healthy players. Additionally, we hypothesized that players with a history of knee pain would exhibit significantly different spike jump mechanics compared to healthy players. Finally, it

was our hypothesis that significant relationships would exist between the 7 individual tests of the Functional Movement Screen and the spike jump characteristics.

1.3 Overview of the Document

Beginning with a brief background on the sport of volleyball and an outline of the injuries that plague the sport, the second chapter of this document introduces the reader to the field of volleyball-related injuries in greater depth. Epidemiological data and risk factors are presented and discussed, with a specific focus on the under-reported and poorly understood overuse injuries at the knee, low back, and shoulder. In addition to a review of the current literature surrounding volleyball injuries, Chapter 2 also introduces a framework for future injury prediction and prevention as well as a functional movement assessment tool, the Functional Movement Screen. Chapter 3 provides a comprehensive systematic review of the 12 studies that have investigated the Functional Movement Screen and concludes with recommendations for how the screen should be used. Chapter 4 first introduces a theoretical link between fundamental movement patterns and learned, sport-specific patterns, offering a rationale for why the two paradigms should not be studied in isolation. Following the introduction, objectives, and hypotheses, Chapter 4 provides a detailed account of the methodology used to carry out the thesis investigation, as well as a thorough reporting of the results, discussion, and limitations of the study design. The final chapter, Chapter 5, ties together the information presented in Chapters 2 and 3 with the novel evidence from the thesis investigation, giving the final conclusions of the thesis document. Practical recommendations for sports medicine and strength and conditioning professionals are also offered in Chapter 5, along with directions for future research.

Chapter 2: Narrative Review of Volleyball Injury Research

This chapter provides a brief introduction to the physiological demands placed on volleyball players, followed by a literature review to familiarize the reader with the state of injuries in the sport of volleyball. Next, risk factors for common overuse injuries in volleyball are reviewed and the limitations of current research models are discussed. Chapter 2 concludes by introducing a new approach to musculoskeletal evaluation, Regional Interdependence, and discussing the potential merits of incorporating this model into future research.

2.1 Background on the Sport

Volleyball has grown into one of the most popular participation sports worldwide, with recreational and competitive athletes of all ages playing both the indoor and beach disciplines all across the globe. The Federation Internationale de Volleyball (FIVB) reports over 200 National volleyball organizations and hundreds of millions of players (Bahr and Bahr, 2007). Physiologically it demands a high capacity for explosive, powerful efforts with relatively long rest periods between efforts (Lidor and Ziv, 2010). Defensive skills rely on exceptional speed, agility, mobility, and coordination; and impose only a manageable load on the body. The more demanding offensive skills in volleyball include jump serving and spiking (or attacking) which involve a maximal vertical jump followed by a powerful arm swing that includes forceful trunk extension and rotation as well as extreme shoulder external rotation (Bahr and Reeser, 2003; Lidor and Ziv, 2010; Smith et al., 2008). As volleyball is a highly technical sport requiring many repetitions to perfect and fine-tune the skills, players are tasked with frequently repeating their jumping and arm swing patterns.

As there is no contact with players from the opposing team in volleyball, contact injuries are rare and restricted to incidental contacts with players from the same team or an occasional contact under the net. However, executing a high volume of maximal vertical leaps and maximum velocity arm swings poses other risks to volleyball players of all levels of ability and gives the sport a unique spectrum of injuries.

2.2 Epidemiology of Volleyball Injuries

Numerous studies have investigated injury rates among elite volleyball players, with the most comprehensive publication coming from 16 years of injury surveillance data on female NCAA teams from 1988 to 2004 (Agel et al., 2007). Agel et al. (2007) reported that time loss injuries were observed at a rate of 4.58 injuries per 1000 athlete exposures during competition and 4.10 injuries per 1000 athlete exposures during practice (Agel et al., 2007). This injury incidence was quite consistent throughout the 16-year period of observation. Fifty-five percent of injuries occurred in the lower extremity, with 44.1% of game injuries coming from acute ankle sprains that most commonly resulted from landing on another player's foot after a block jump or spike jump. Second to ankle injuries, non-contact knee internal derangements accounted for 14.1% of game injuries, followed by muscle strains to the shoulder and low back at 5.2 and 4.8%, respectively. Twenty-three percent of game injuries and 19% of practice injuries caused greater than 10 days of lost time. Other studies have supported this relatively low injury rate and site distribution for men and women combined, with reported injury incidences of 1.7 per 1000 hours for elite Norwegian players (Bahr and Bahr, 2007), 2.6 per 1000 hours for elite Dutch players (Verhagen, 2004), and 3.1 per 1000 competition hours for elite beach volleyball players (Bahr and Reeser, 2003).

Aside from acute injuries to the ankle, the majority of studies report that time loss injuries are primarily overuse in nature and primarily occur in the knees, shoulders, and low back (Agel et al., 2007; Bahr, 2009; Bahr and Bahr, 2007; Bahr and Reeser, 2003; Nesic et al., 2011; Reeser et al., 2006). Verhagen et al. (2004) found that the back and shoulder each accounted for 32% of overuse injuries with the knees accounting for an additional 20% (Verhagen, 2004). These authors also noted that while time loss overuse injuries had an incidence of only 0.6 per 1000 hours, the mean absence from volleyball due to one of these injuries was 4 weeks. In Bahr and Reeser's 2003 study of professional beach volleyball players, nearly one third of all players reported overuse injuries of the shoulder, knees or back that required medical attention and/or time loss (Bahr and Reeser, 2003).

Across all studies, the most common diagnoses for overuse injuries at the knee and shoulder were patellar tendinopathy, rotator cuff tendinopathy, shoulder impingement, traumatic glenohumeral instability, and suprascapular neuropathy (Agel et al., 2007; Bahr and Reeser, 2003; Reeser et al., 2010a; Reeser et al., 2006; Wang and Cochrane, 2001). No specific diagnosis has been offered for the diffuse low back pain reported by volleyball players (Smith et al., 2008).

However, volleyball is a non-contact, repetitive motion sport, and recent research has suggested that time loss injury studies may not accurately portray the state of injury within the sport of volleyball (Bahr, 2009). A typical injury definition for the epidemiological studies hinges upon a minimum of 1 day absent from training or competition, which captures only severe acute and overuse injuries (Bahr, 2009). In 2009, Bahr (2009) published an article commenting on the methodology for recording overuse symptoms in sports (Bahr, 2009). In this paper, he describes a scenario based on cell matrix response to tendon injury in

which microtraumatic breakdown occurs throughout an athlete's exposure to the stressor, but may not always result in an accumulation of symptoms that forces him or her to cease training. Bahr (2009) contends that aerobic and technical sports that have limited risk of falling or contact between players may have a lower prevalence of acute injuries, but due to high volume demands may exhibit a large proportion of overuse injuries compared to acute injuries (Bahr, 2009). As such, the time-loss injury definition applied to contact sports and other high-risk sports may not accurately capture the presence of pain and reduced function and quality of life.

In his retrospective study of 115 elite beach volleyball players over an 8-week competition period, Bahr (2009) found that while only 26 time loss injuries were reported (4.1 per 1000 competition hours, 0.5 per 1000 training hours), only 17% of players were free of pain over the 8 weeks. Fourty-nine percent of players reported pain in one of the low back, shoulder, or knees, 28% reported pain from 2 areas, and 6% of players reported pain from all three areas (Bahr, 2009). Despite the presence of pain, very few players had actually missed training or competition as a result.

Some additional evidence supports the high prevalence of overuse injuries among volleyball players that are not being captured by time loss injury reporting. Patellar tendinopathy or "jumper's knee" has gained considerable attention in the literature with a number of studies reporting a prevalence of 40-50% in both junior and senior elite volleyball players (Ferretti, 1986; Ferretti and Papandrea, 1990; Lian et al., 2005b; Nesic et al., 2011; Zwerver et al., 2011). As for shoulder pain, a study by Reeser et al. (2010) found that 60% of club volleyball players reported a history of shoulder pain or dysfunction related to volleyball, which was more prevalent in those playing "attacking" positions compared to a

setter or defensive specialist (Reeser et al., 2010a). Additionally, in a study of elite male volleyball players, Wang and Cochrane (2001) reported that 27 of 59 players experienced shoulder pain over the course of 2 seasons and 11 were forced to stop training (Wang and Cochrane, 2001).

Chronic overuse injuries such as these are concerning as they decrease function (Reeser et al., 2010a) that can continue later into life (Kettunen et al., 2002) and are often the cause of athletes ending their career (Kettunen et al., 2002). Overuse injuries may also indicate tissue degeneration that can increase risk of subsequent severe acute injuries (Bahr, 2009). Certainly an increased focus on the identification and prevention of such overuse injuries would be of benefit to all volleyball participants. To this end, sports medicine researchers must continue to search for risk factors and mechanisms of these overuse injuries, as this component of injury prevention has proven to be quite complex (Finch, 2006; van Mechelen et al., 1992).

2.3 Risk Factors for Overuse Injuries in Volleyball

2.3.1 Knee Injuries

The primary overuse knee injury observed in volleyball is patellar tendinopathy (PT) or "jumper's knee" (Reeser et al., 2006), characterized by activity-related anterior knee pain associated with focal patellar tendon tenderness (Sorenson, 2010). Due to a high prevalence of PT in volleyball and other sports (Lian et al., 2005a; Zwerver et al., 2011), an extensive amount of literature has attempted to elucidate risk factors for the condition.

A recent systematic review of risk factors for PT was conducted by van der Worp et al. (2011) and classified risk factors into 4 categories: demographics, anthropometrics,

sports-related factors, and strength/flexibility (van der Worp et al., 2011a). No biomechanical risk factors were included in this study, but a substantial body of literature has investigated these factors as well, and will be discussed following van der Worp's (2011) findings (van der Worp et al., 2011a).

In van der Worp et al. (2011) it was concluded that no demographic variables were conclusive risk factors for PT (van der Worp et al., 2011a). Various studies have investigated the role of age, gender, and menstrual history, and the results are variable from study to study. The strongest demographic trend is for males to be more likely than females to develop PT (Lian et al., 2005b; van der Worp et al., 2011b; Zwerver et al., 2011).

Several anthropometric factors were found to be associated with PT: weight, body mass index (BMI), waist to hip ratio, and arch height of the foot (van der Worp et al., 2011a). Weight and BMI have an intuitive mechanical connection to PT in that they theoretically increase the load placed upon the patellar tendon. Non-mechanical hypotheses that explain the association of waist to hip ratio with PT include reasoning that the same hormones that control fat distribution may also play a role in tendinopathy (Gaida et al., 2004; Malliaras et al., 2007), or that the increased free fatty acids and pro-inflammatory cytokines associated with abdominal adiposity may have a negative effect on tendon health (Gaida et al., 2008; Malliaras et al., 2007). Lower arch height has also been found to be associated to PT, however the mechanisms that explain this connection have not been proposed specifically for jumping sports.

Despite a myriad of individual studies supporting and refuting the role of years of experience, training history, training volume, playing surface, and strength and conditioning

programming, no consensus has been reached as to which of these factors is a consistent risk factor for PT (van der Worp et al., 2011a).

In the strength/flexibility category, there was some evidence for the role of quadriceps flexibility, hamstring flexibility, quadriceps strength, and vertical jump performance as risk factors for PT. It is proposed that decreased flexibility in the quadriceps and hamstrings may increase patellar tendon strain and contribute to mechanical overload (Witvrouw et al., 2001), while it is unknown whether decreased quadriceps strength is a cause or a result of PT (van der Worp et al., 2011a). The finding of increased vertical jump height increasing the risk of PT seems to be contradictory to the quadriceps strength finding, and clearly indicates that factors other than quadriceps strength play a large role in determining jump performance (van der Worp et al., 2011a).

Since PT is commonly thought to be caused at least in part by repetitive overload of the patellar tendon (Sorenson, 2010), it stands to reason that lower extremity mechanics likely play a role in determining injury risk. Several studies have investigated various biomechanical variables during the takeoff and landing phases of the volleyball spike jump (Bisseling et al., 2007, 2008; Edwards et al., 2010a; Edwards et al., 2010b; Lobietti et al., 2010; Orishimo et al., 2009) due to the eccentric knee extensor loading that occurs during these phases. During the volleyball spike jump, athletes first accelerate into a 2 or 3 step horizontal approach before planting with a lead leg followed quickly by the trail leg and transitioning horizontal momentum to vertical displacement (Bisseling et al., 2008; Sorenson, 2010). This component of the spike jump involves both horizontal and vertical deceleration as the athlete crouches to pre-stretch the hip, knee, and ankle extensors (Edwards et al., 2010a; Edwards et al., 2010b). The vertical landing phase of the jump occurs as the athlete

comes down from his or her jump, landing on either 1 leg or 2, generally with some component of horizontal deceleration as well (Lobietti et al., 2010). Until recently, the final vertical landing phase of the spike jump has received the most attention in the PT literature, and studies have consistently found that a "stiffer" landing strategy that involves less knee flexion may be a risk factor for PT (Bisseling et al., 2007, 2008; Devita and Skelly, 1992; Dufek and Zhang, 1996). However, since the participants for these studies all had a previous history of PT, there is still no causal link between a "stiff" landing strategy and PT.

The take off component of the volleyball spike jump as a risk factor for PT has gained popularity very recently as a result of the work by Edwards et al. (2010) that found significantly higher rates of patellar tendon loading during the horizontal deceleration (takeoff) component of the stop jump compared to the vertical landing component (Edwards et al., 2010a). This finding was followed up by another study from the same authors comparing the landing strategies of healthy athletes to athletes with asymptomatic abnormalities of the patellar tendon (Edwards et al., 2010b). Innovative and new to this study was the identification of early stage patellar tendon degeneration using musculoskeletal ultrasonography, which allowed these authors to conduct their study entirely on athletes with no previous history of injury. This is superior to other commonly used methods comparing previously injured athletes to healthy athletes as it remains unknown whether the movement patterns that the previously injured athletes exhibit have caused, or been caused by, their injury (Edwards et al., 2010b). An additional important aspect of this study design is the measurement of kinematic data at the ankle, knee and hip together as opposed to solely the knee and ankle as in previous studies (Bisseling et al., 2008; Sorenson, 2010). Numerous studies have supported the importance of lumbopelvic mechanics in mediating lower body

injury (Cowan et al., 2009; Dierks, 2008; Dwyer and Boudreau, 2010; Leetun et al., 2004; Nadler et al., 2002; Reiman and Bolgla, 2009) but this aspect of jumping kinematics had yet to be investigated.

Edwards et al. (2010) found that participants with the asymptomatic patellar tendon abnormality demonstrated significantly different kinematic patterns compared to healthy athletes during the horizontal deceleration (takeoff) portion of the jump (Edwards et al., 2010b)Participants with the tendon abnormalities tended to show greater knee flexion at initial ground contact and then proceed to extend rather than flex their hips throughout the horizontal landing action (Edwards et al., 2010b). Healthy control participants landed with relatively less hip and knee flexion and continued to flex as they absorbed the horizontal landing. The authors speculate that by positioning the participant's centre of mass more posteriorly, these changes increase the load placed on the patellar tendon by increasing the amount of forward translation of the centre of mass during the horizontal deceleration, combined with greater patellar tendon load from the greater degree of knee flexion. Importantly, Edwards et al. (2010) note that the major kinematic findings of this study occur in the sagittal plane, and comment that they were easily observable without video complex video analysis (Edwards et al., 2010b). They propose that with further study, sagittal plane mechanics during a jump may provide a framework for the identification of athletes at risk of patellar tendinopathy and the movement pattern-based modification of this risk factor. Clearly more research is needed to validate the use of such an assessment, but the concept is nonetheless encouraging for a field in which risk factors, treatment, and prevention strategies for patellar tendinopathy remain elusive (Edwards et al., 2010b; Sorenson, 2010).

2.3.2 Shoulder Injuries

The aetiology of volleyball-related shoulder injuries is not well understood and very few studies have investigated the risk factors associated with shoulder injury among volleyball players (Reeser et al., 2010a; Reeser et al., 2006). In the one study aimed at identifying risk factors for volleyball related shoulder pain and dysfunction, Reeser et al. (2010) found that athletes who played attacking positions (i.e., not setter or defensive specialist) and athletes who employed an aggressive jump serve similar to a spike were at higher risk of shoulder injury (Reeser et al., 2010a). They comment that this is to be expected, as these players will perform a greater volume of high velocity arm swings compared to other players. Additionally, upon physical examination Reeser et al. (2010) found that core instability, coracoid tightness/pectoral shortening, imbalanced shoulder strength, impingement, restricted shoulder flexion, and a "SICK" scapula score ≥ 3 were all associated with shoulder pain (Reeser et al., 2010b). The "SICK" score is a physical examination tool that evaluates an athlete's shoulder based on **S**capular malposition, **I**nferior medial border prominence, **C**oracoid pain and malposition and dys**K**inesis of scapular movement (Reeser et al., 2010a). Reeser et al. (2010) go on to comment that further research is needed investigating volleyball-related shoulder injuries, as the mechanism of the volleyball spike is in many ways different from those used by other overhead athletes (Reeser et al., 2010a).

2.3.3 Low Back Injuries

Volleyball-related low back pain, to an even greater degree than shoulder pain, has received inadequate attention in the literature. While numerous papers reference low back pain as a common overuse injury in volleyball (Agel et al., 2007; Augustsson et al., 2006;

Bahr, 2009; Bahr and Bahr, 2007; Bahr and Reeser, 2003; Reeser et al., 2006; Verhagen, 2004), no study has investigated the risk factors that contribute to the condition. Several hypotheses have been presented, primarily surrounding the notion that volleyball players are at increased risk of both acute and overuse low back pain due to the forced hyperextension and rotation of the spine during the spiking motion (Augustsson et al., 2006; Reeser et al., 2006; Smith et al., 2008). Despite a lack of identified risk factors, one clinical commentary has suggested a "Conceptual Back Injury Prevention Program" for volleyball players focused on dynamic trunk stabilization exercises (Smith et al., 2008). The program aims to develop proper timing and co-activation patterns of the trunk musculature and to maintain neutral spinal alignment in the key positions involved with volleyball. The authors also suggest that athletes should possess adequate hamstring extensibility and have pain free active trunk mobility with a negative Stork test. Several other conceptual recommendations are made regarding best practices for training for low back injury prevention in volleyball players, but the concepts remain conjecture and require further investigation based upon known mechanisms of injury (Finch, 2006; van Mechelen et al., 1992).

2.4 A New Model for Injury Prediction: Regional Interdependence

Even with decades of research investigating risk factors for overuse injury in sport, little conclusive evidence exists regarding modifiable risk factors (Mottram and Comerford, 2008). Factors such as strength, flexibility, balance, and biomechanics seem inherently connected to overuse musculoskeletal injuries, and yet empirical evidence for the contribution of each of these factors is often mixed between supporting and refuting this very notion (van der Worp et al., 2011a). While some of this disagreement is likely due to the

multifactorial nature of injury combined with an inherent component of unpredictability, not to mention variation in research methods, it has also been proposed that researchers have simply been studying risk factors under a somewhat flawed paradigm (Wainner, 2007).

Stemming from an ever-expanding scope of knowledge of the complexities that surround human movement and injury, physical therapy researchers and clinicians have recently proposed a new model of injury rehabilitation, one that can benefit all disciplines concerned with human movement or musculoskeletal injury (McMullen and Uhl; Mottram and Comerford, 2008; Wainner, 2007). This new perspective is termed Regional Interdependence, defined by Wainner et al. (2007) as "the concept that seemingly unrelated impairments in a remote anatomical region may contribute to, or be associated with, the patient's primary complaint" (Wainner, 2007). This model is in stark contrast to a reductionist, biomedical model of disease that necessitates a firm diagnosis of the local pathology (Wainner, 2007). Recent research, combined with decades of clinical practice have demonstrated that while focusing on the location of the problem or symptom may occasionally be of some benefit, ultimately addressing the underlying source of pain or injury is the only way to effect optimal results (McMullen and Uhl, 2000; Reiman and Bolgla, 2009; Reiman and Weisbach, 2009; Strunce et al., 2009; Vaughn, 2008b; Wainner, 2007). A multitude of research studies promote the connection between proximal and distal musculoskeletal dysfunction that can elicit symptoms in a remote location (Dierks, 2008; Reiman and Bolgla, 2009; Reiman and Weisbach, 2009; Strunce et al., 2009; Vaughn, 2008b), and physical therapy examinations and interventions based on this philosophy are now much more advanced and comprehensive than in the past.

Based on this progressive model of injury rehabilitation, it stands to reason that injuries are not caused solely by a local source or even by a consistent non-local source from patient to patient (Vaughn, 2008a; Wainner, 2007). Numerous accounts of one of the most common physical therapy complaints (i.e., anterior knee pain) have found causes ranging from the arch of the foot to the hip musculature and sacroiliac joint (Cowan et al., 2009; Dierks, 2008; Reiman and Bolgla, 2009; Vaughn, 2008a; Willson et al., 2011), so clearly a research model that investigates only the function of the arch or only the function of the hip will be missing an important aspect of physical function that could contribute to anterior knee pain. Even combining these factors into a multiple regression analysis treats each of the factors as independent, which negates the neuromuscular connection between all areas of the body (Mottram and Comerford, 2008). It seems then, that an alternative way to elucidate meaningful risk factors for musculoskeletal injury is to examine all areas of the body, while respecting their connection to each other (Mottram and Comerford, 2008; Wainner, 2007).

Based upon the same premise as regional interdependence, the kinetic chain or kinetic link model depicts the body as a linked system of interdependent segments, often working in a proximal to distal sequence, to impart a desired action at the distal segment (McMullen and Uhl, 2000). This model, proposed for use in both rehabilitation and risk assessment, gives respect to the complex neuromuscular connections that have been implicated as being of extreme relevance in injury risk assessment (Mottram and Comerford, 2008; Plisky et al., 2006).

In 2006, Gray Cook developed a tool for screening functional human movement under the umbrella of regional interdependence and kinetic linking (Cook and Burton, 2006; Cook et al., 2006). This screening tool, the Functional Movement Screen (FMS), has recently

gained immense popularity in sports medicine, strength and conditioning, and health and fitness industries. The FMS incorporates many aspects that are missing from a reductionist assessment of joint range of motion, muscle extensibility or muscle strength. Therefore, it may demonstrate itself as a more conceptually sound evaluation of neuromuscular control, kinetic linking, and fundamental mobility and stability that may contribute to injury (Cook and Burton, 2006; Cook et al., 2006; Mottram and Comerford, 2008). As the FMS is quite different from traditional investigations into injury risk factors, substantial empirical evidence will be necessary for the tool to gain efficacy as a useful tool. To date, a little over a dozen studies have been published on the FMS. Chapter 3 presents a systematic review of that literature as well as a thorough description of the test and its origins.

2.5 Conclusion

Due to the noncontact but repetitive nature of volleyball skills, elite athletes in the sport suffer relatively few time loss injuries but are afflicted with a very high prevalence of overuse injury-related pain. The most common sites for overuse injuries among elite volleyball players are the knees, low back, and shoulders. While the severity of these injuries is much lower than an acute time loss injury, chronic overuse injuries often cause players to end their careers prematurely, and can cause long lasting musculoskeletal dysfunction. Risk factors for these overuse injuries remain elusive, as the majority of volleyball-related injury research has focused on time loss injuries. Patellar tendinopathy has received the most attention as a volleyball overuse injury, but the research has returned very few reproducible risk factors. Future research into the aetiology of chronic overuse injuries in volleyball may be aided by the concept of regional interdependence, which promotes a more global

investigation of the body in search of any musculoskeletal dysfunction that may affect a seemingly unrelated region. The Functional Movement Screen, to be explored in Chapter 3, is a relatively new screening tool that can identify global movement dysfunction and will allow the concept of regional interdependence to play a larger role in injury risk factor research.

Chapter 3: The Functional Movement Screen: A Systematic Review

The purpose of this chapter is to provide an objective review of the evidence surrounding the use of the Functional Movement Screen. Research papers are discussed in detail and concluding comments and recommendations are provided.

3.1 Introduction

Musculoskeletal injuries are very common in many sports and occupations (Hootman et al., 2007; Rivara and Thompson, 2000) and pose severe implications ranging from increased health care costs to retirement from sport and decreased quality of life (Kettunen et al., 2002; Peate et al., 2007; Rivara and Thompson, 2000). In an effort to reduce the occurrence of musculoskeletal injuries, models for injury prevention have proposed to follow the order of: injury surveillance, identification of injury aetiology and mechanisms and finally development, implementation and monitoring of preventative measures (Finch, 2006; van Mechelen et al., 1992). However, despite decades of extensive research, this cycle is largely stalled in the second stage, as modifiable injury risk factors remain highly inconsistent from study to study (Emery, 2005; Hootman et al., 2007; Mottram and Comerford, 2008; Neely, 1998; van der Worp et al., 2011a). One possible reason for a lack of consistent findings is that research has typically investigated whether an isolated joint, muscle or movement can predict injury, an approach which has recently received criticism for its reductionist focus and inability to capture the complex interactions that exist within the human musculoskeletal system (Cook and Burton, 2006; Cook et al., 2006; Mottram and Comerford, 2008; Plisky et al., 2006; Wainner, 2007). Recent research has initiated a move away from this view, heeding a model termed *regional interdependence* (Reiman and Bolgla,

2009; Reiman and Weisbach, 2009; Vaughn, 2008a; Wainner, 2007). Built upon the premise that seemingly unrelated impairments in remote anatomical regions can affect a primary complaint such as an injury, regional interdependence promotes a more holistic look at the body (Wainner, 2007). This approach has had substantial success in the clinical evaluation and rehabilitation of musculoskeletal injuries and is quickly gaining popularity as more and more clinicians come to understand the fundamental tenets of the model (Dierks, 2008; Mottram and Comerford, 2008; Reiman and Bolgla, 2009; Reiman and Weisbach, 2009; Strunce et al., 2009; Vaughn, 2008b; Wainner, 2007).

In an effort to bring this model into the practice of injury prediction and prevention, Cook et al. (2006) developed the Functional Movement Screen (FMS), a tool that bridges the gap between pre-participation medical screens and performance testing with an evaluation of functional and fundamental movement patterns (Cook and Burton, 2006; Cook et al., 2006). The FMS uses 7 fundamental movement patterns that require a combination of mobility, stability, and neuromuscular control and challenge the body's kinetic linking patterns (Cook and Burton, 2006; Cook et al., 2006). With the use of this screen, sports medicine and health and fitness professionals are able to assign quantitative value to movement dysfunction that is typically observed qualitatively but without objective markers. Pictures and scoring descriptions are available for each of the 7 tests in Appendix A.

Each test in the FMS is scored on a scale ranging from 0 to 3 with 3 as the best possible score. A checklist of points that classifies aspects of the movement guides the tester in assigning objective scores. A score of 0 is assigned if the participant experiences pain anywhere in the body as a result of the movement. A score of 1 represents that the individual is unable to perform the movement or cannot assume the position necessary to initiate the

movement. A score of 2 is given when the participant can complete the fundamental movement but uses some degree of compensation. Finally, a score of 3 indicates that the movement was performed without any compensation. Five of the 7 tests are scored bilaterally and asymmetry is recorded. Additionally, there are 3 clearing tests associated with specific exercises of the FMS, which simply look to elucidate pain and are scored as positive (fail) or negative (pass). A positive result on a clearing test indicates pain and results in the associated fundamental movement test receiving a score of 0. Scores are then combined to give a composite score out of maximum 21 points.

The goal of the FMS is to identify dysfunctional movement patterns or asymmetries that may predispose an individual to injury in his or her sport or occupation (Cook and Burton, 2006; Cook et al., 2006). This dysfunction is proposed to play a role in overuse and microtrauma in certain areas of the body, which may result in a subsequent traumatic injury. With the rating and ranking system of the FMS, sports medicine professionals are able to identify the area of greatest dysfunction and prescribe individualized corrective exercises to restore the quality of fundamental movement. It is hypothesized that by then improving these fundamental movement patterns, an individual may decrease his or her risk of injury (Cook and Burton, 2006; Cook et al., 2006).

Since the introduction to the FMS was first published in 2006 (Cook and Burton, 2006; Cook et al., 2006), the concept has quickly gained popularity in the sports medicine, strength and conditioning and health and fitness industries and additional research has been published evaluating various aspects of the screen. However, no studies have objectively reviewed the efficacy of the FMS as tool for injury prediction and prevention. Thus the

purpose of this paper is to systematically evaluate the evidence surrounding the use of the Functional Movement Screen.

3.2 Methods

3.2.1 Search Strategy and Inclusion Criteria

On November 5th, 2011, the MEDLINE, EMBASE, Cochrane, CINAHL and Pubmed databases were searched for studies that involved the Functional Movement Screen in any capacity. Keywords used included “Functional Movement Screen$" or "Movement Screen$" or "Functional Movement Test$" or "Functional Movement Assessment$". Search results were limited to peer reviewed papers written in English and studying humans. Conference proceedings and abstracts were excluded. The search included a timeline from the earliest date listed in the databases until November 2011. All search results were downloaded to RefWorks (RefWorks, Bethesda, Maryland, USA) and full text was added wherever possible. All online database searches were initially performed by the lead investigator (MH) and repeated by a second reviewer (SB).

3.2.2 Screening

References downloaded to RefWorks were screened by the lead investigator to remove any duplicates and determine whether the study fit the inclusion criteria. Any study that did not use the FMS was excluded, as well as studies without available full text. Peer reviewed clinical commentaries on the FMS were excluded from the analysis but included as relevant background information for the introduction to this systematic review. Reference

lists of the included papers were then searched to find any studies that were missed in the initial electronic database search.

3.2.3 Data Extraction

Title, author, year, study design, objective, methodologies, results pertaining to the FMS and conclusions regarding the FMS were recorded for each study (Tables 2.2 – 2.6). Studies were grouped into 5 categories based on the information that they provided about the FMS: Injury Prediction, Reliability, Modifiability, Relationship to Performance, or General Description.

3.2.4 Quality Assessment

Methodological quality for each study was assessed using the Modified Downs and Black scale designed for use with non-randomized observational investigations (Downs, 1998; Prince et al., 2008). Using this scale, 15 items were included which were scored either 1 or 0, giving a maximum possible score of 15. Higher scores correspond with a higher quality of evidence. Quality assessments were conducted by the lead investigator (MH) as well as a second reviewer (SB) and in the case of any disagreement a third reviewer (DW) was used to lead a discussion and come to a consensus.

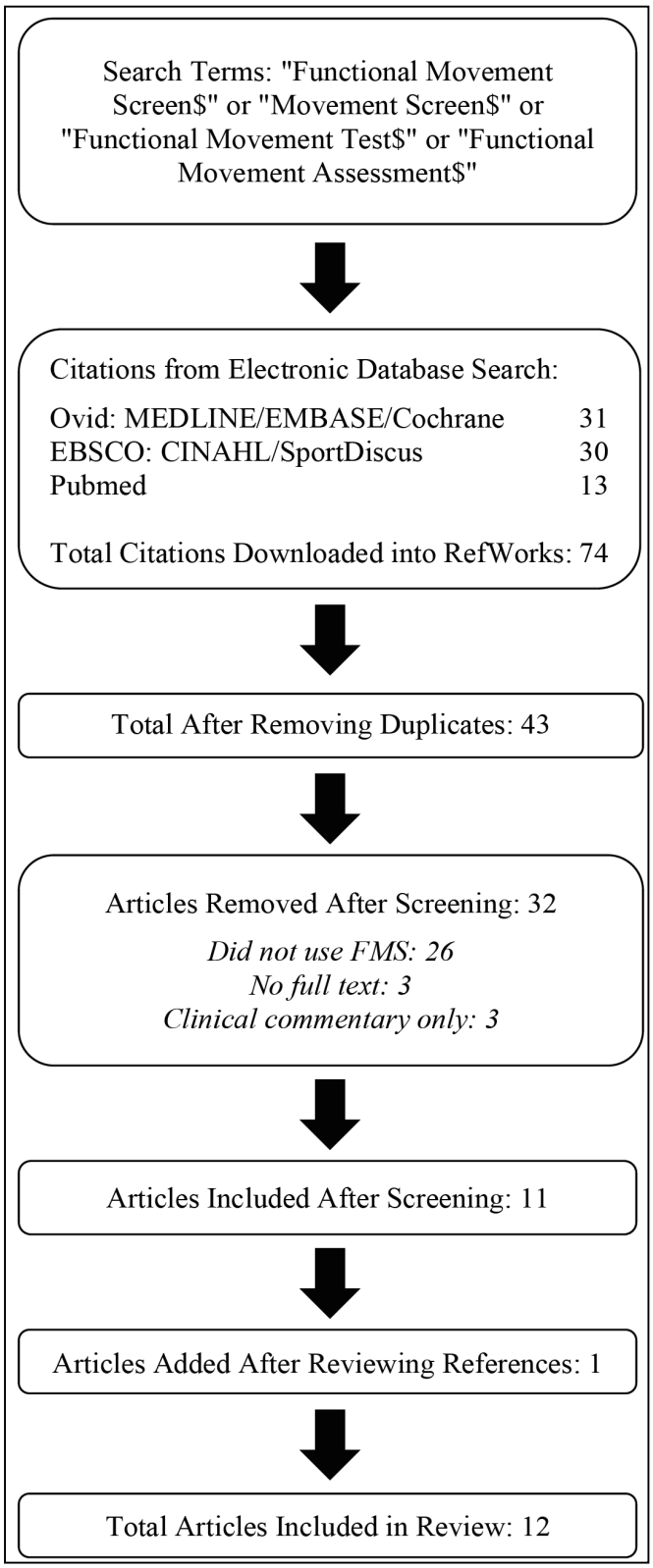

Figure 3.1. Functional Movement Screen Search Results.

3.2.5 Level and Grade of Evidence

Levels and grades of evidence were assessed using a modified version of a rating system developed for use in creating the Canadian clinical practice guidelines on the management and prevention of obesity in adults and children (Lau et al., 2007) (Table 2.1). The level of evidence is based on study design and provides an objective evaluation of the strength of the evidence. The grade of evidence is specific to the Functional Movement Screen and indicates if the study in question provides any evidence in support of its use.

Level of Evidence	**Criteria**
Level 1	Randomized control trials *without* important limitations
Level 2	Randomized control trials *with* important limitations or Observational studies (non-randomized clinical trials or cohort studies) with overwhelming evidence
Level 3	Observational studies (prospective cohort studies, case-control studies, case series)
Level 4	Inadequate or no data in population of interest, anecdotal evidence or clinical experience
Grade of Evidence	**Criteria**
A	Strong evidence that the Functional Movement Screen is effective at predicting injuries, is reliable, or that a participant's score can be modified with an intervention
B	Weak to moderate evidence that the Functional Movement Screen is effective at predicting injuries, is reliable, or that a participant's score can be modified with an intervention
C	No evidence for using the Functional Movement Screen

Table 3.1. Levels and Grades of Evidence Used to Evaluate the Articles.

3.3 Results

3.3.1 Study Selection Results

An electronic database search returned 74 papers, which was reduced to 43 after removing duplicates. Screening the abstracts and/or full text of articles resulted in the removal of 32 studies: 26 because they did not involve the FMS, 3 because they did not have full text and 3 because they were a clinical commentary. Eleven articles remained and after reviewing the reference lists of included papers, 1 more paper was added for a total of 12 papers that were included in the systematic review (Figure 2.1).

Based on a predetermined classification system, 3 studies were found investigating the injury prediction utility of the FMS, 3 studies investigated the reliability of the FMS, 3 studies reported on the modifiability of a participant's FMS score, 3 studies investigated the relationship of FMS scores to performance testing, and 3 studies offered general descriptive findings about the FMS. Three studies were included in more than 1 category as they provided more than 1 type of information.

All of the included studies were classified as Level 3 Evidence, owing to the fact that they were all observational and although some involved an intervention there was never a control group. No studies achieved a Level 2 Evidence ranking for the presence of overwhelming evidence provided by an observational study (Table 2.1). 4 papers received an "A" grade of evidence for providing strong evidence that the Functional Movement Screen is effective at predicting injuries, is reliable, or that a participant's score can be modified with an intervention. 5 papers received a "B" grade for providing weak evidence supporting the FMS, and 3 papers were graded "C" for providing no evidence in support of the FMS.

Based on the Modified Downs and Black quality assessment, the 12 studies received a mean (SD) score of 10.7 (1.6) out of a maximum possible score of 15. The scores ranged from 8 (1 paper) to 13 (2 papers). Notably, no studies received a passing mark on either of the questions regarding participant selection. Sampling was never random and it was never mentioned if the sample characteristics were consistent with the population parameters because no population parameters are known for the FMS.

3.3.2 The FMS and Injury Prediction

All 3 papers investigating the ability of the Functional Movement Screen to predict injury found significant ($p<0.05$) predictive value. Odds ratios for sustaining an injury after scoring ≤ 14 ranged from 2.0 to 11.67 (Chorba et al., 2010; Kiesel et al., 2007; O'Connor et al., 2011). Only Chorba et al. (2010) used a regression analysis and did not find significant results (Chorba et al., 2010). In all 3 studies, a 14-point "cut off" score was used to dichotomize low versus high injury risk. The sensitivity of the 14-point "cut off" ranged from 0.54 to 0.58 while specificity ranged from 0.74 to 0.91. Three different populations were studied: female collegiate athletes, male military recruits and professional male football players.

3.3.3 Reliability of the FMS

Three studies investigated the inter-rater reliability of the Functional Movement Screen and found that reliability for the composite 21-point score was excellent when scored by clinicians experienced in clinical use of the FMS (Chorba et al., 2010; Minick et al., 2010; Schneiders et al., 2011). Intra-class correlation coefficients (ICC) for the composite 21-point

score ranged from .971 to .976 (Chorba et al., 2010; Schneiders et al., 2011). Minick et al. (2010) reported weighted kappa scores for the individual tests ranging from 0.54 to 1.00 between novice raters, 0.40 to 0.95 between expert raters, and .74 to 1.00 when comparing average scores of two novice and expert raters (Minick et al., 2010). Various statistical methods were used and were not consistent between the papers. A detailed description of the statistical methods is provided in the discussion.

3.3.4 Modifiability of FMS Scores

One study directly investigated the ability of an individualized intervention to improve FMS scores (Kiesel et al., 2011) while 2 others investigated a more general intervention and used FMS scores as one of the pre/post measures (Cowen, 2010; Goss et al., 2009). Cowen (2010) and Kiesel et al. (2011) found significant ($p<0.05$) improvements in FMS scores (13.3 to 16.5 and 11.8 to 14.8, respectively) after 6-7 weeks of a training intervention (Cowen, 2010) (Kiesel et al., 2011). Goss et al. (2009) reported significant improvements in FMS scores (15.14 to 17.62) after their intervention but did not report the p-value (Goss et al., 2009). Additionally, Kiesel et al. (2011) reported that the number of participants with scores above 14 improved significantly ($p<0.01$) and that asymmetries decreased significantly ($p=0.01$) after their intervention with professional male football players (Kiesel et al., 2011).

3.3.5 Relationship of the FMS to Performance Testing

No strong relationships between FMS scores and performance testing results were found in the 3 papers that examined the topic (O'Connor et al., 2011; Okada et al., 2011;

Parchmann and McBride, 2011). Parchmann and McBride (2011) found no relationship between FMS scores and vertical jump, t-test, 10 or 20 metre sprints, or golf club head swing velocity among male and female collegiate golfers (Parchmann and McBride, 2011). Okada et al. (2011) found significant relationships between a variety of individual FMS test scores and a backwards overhead medicine ball toss, t-run and single leg squat, however were unable to offer much explanation for the random nature of the results (Okada et al., 2011). These authors also found no correlation between FMS scores and core stability tests. In contrast to other findings, O'Connor et al. (2011) reported that military personnelle with what they classified as a "low" fitness testing score were 2.2 times more likely to have FMS scores ≤ 14 (O'Connor et al., 2011).

3.3.6 General Descriptive Information about the FMS

In an investigation into factors that could be associated with FMS scores, Peate et al. (2007) found that increasing age, rank and tenure in fire fighters was significantly correlated ($p<0.001$) with lower FMS scores (Peate et al., 2007). Additionally, these authors reported that there was a significant ($p=0.001$) relationship between past musculoskeletal injury and FMS scores (Peate et al., 2007). In contrast to this study, an investigation into normative FMS scores by Schneiders et al. (2011) reported no significant difference in FMS scores between those with and without previous injury during the past 6 months (Schneiders et al., 2011). These authors also found no difference between male and female composite scores but did find that females scored significantly higher on the Active Straight Leg Raise and Shoulder Mobility tests ($p<0.001$) while males scored significantly higher on the Trunk Stability Push Up and Rotary Stability tests ($p<0.001$) (Schneiders et al., 2011). One

biomechanical analysis on the Deep Squat test was conducted by Butler et al. (2010) which demonstrated that individuals scoring a "3" had greater ankle dorsiflexion, knee flexion and knee flexion excursion than those with "2" or "1" scores (Butler et al., 2010). Participants with Deep Squat scores of "3" or "2" also demonstrated greater overall hip flexion, hip flexion excursion and peak hip extension moments than those with a score of "1" (Butler et al., 2010).

3.4 Discussion

The Functional Movement Screen (FMS) is a relatively new pre-participation screening tool aimed at predicting injuries and offering quantitative values to functional and fundamental movement patterns (Cook and Burton, 2006; Cook et al., 2006). In contrast to typical investigations into injury risk factors such as muscle strength or flexibility, the FMS is based off of the models of regional interdependence and kinetic linking, which view the systems of the body as inherently connected. The purpose of this study was to review the current literature providing evidence for the use of the FMS.

Our search strategy appeared to be very comprehensive, missing only 1 article initially that was easily caught during a review of other references. It should be noted that numerous papers involving the FMS are currently under review or in press and will likely be adding to the body of evidence on this subject very shortly. Of the 12 studies that were reviewed, very few addressed the same topics and therefore evidence in all areas surrounding the FMS is still very sparse and inconclusive. The level of evidence of the studies was primarily level 3: observational with some pre-post and intervention studies. No studies used control groups or randomization, an improvement that will be essential to improve the quality

of evidence for the FMS in the future. Modified Downs and Black quality ratings varied across the studies, with a notable trend that no studies received a point for having a sample representative of their targeted population or for using random sampling. This pattern is somewhat expected in this area of research as normative population data is difficult to come by. Convenience sampling is also quite common, but future efforts should be made to avoid selection bias that may occur as athletes with greater sports medicine or strength and conditioning experience may volunteer out of interest, potentially skewing the results.

In order to determine if the FMS is a useful tool in the realm of injury prediction and prevention, information is required in a number of key areas: prediction, reliability, modifiability, and finally the preventative value of performing corrective exercises based off of the FMS. As the screen is quite new, no evidence yet exists on the preventative value of FMS-based training; this area should be next to be explored.

3.4.1 Injury Prediction

Of the 3 studies (Chorba et al., 2010; Kiesel et al., 2007; O'Connor et al., 2011) that investigated the validity of the FMS in predicting injuries, all 3 reported that individuals with an FMS score ≤ 14 were at significantly greater risk of sustaining an injury than individuals with scores > 14. There is, however, quite a bit of variability between studies due to the different populations involved as well as inconsistent definitions of injury.

In a sample of 46 professional male football players, Kiesel et al. (2007) reported an odds ratio of 11.67 for sustaining an injury over the course of a 4.5 month season if an athlete's score was ≤ 14 (Kiesel et al., 2007). This odds ratio is much higher than documented in other studies (2.0 and 3.85) (Chorba et al., 2010; O'Connor et al., 2011),

despite the use of a 3 week time loss injury definition that was much more rigorous than other studies. Since the other studies used samples of female collegiate athletes (Chorba et al., 2010) and military recruits (O'Connor et al., 2011) it is likely that quite large population differences exist and that the screen is most effective for football players. Future research will need to study a variety of populations in order to validate the generalizability of the FMS.

To evaluate the effectiveness of a screening test, ratings of sensitivity and specificity must be calculated to determine the ability to correctly rule in or rule out a given condition. In the case of the FMS attempting to predict the presence of injury with a cut off score of 14, sensitivity is defined as the probability that the participant's score will be ≤ 14 if they are to sustain an injury. It is effectively a measure of how likely it is for the FMS to identify those who will sustain an injury. Specificity is the probability that the participant's score will be > 14 if they will not sustain an injury. It is a measure of how likely it is for the FMS to identify who will remain healthy.

Ratings of specificity for the FMS range from 0.74 (Chorba et al., 2010) to 0.91 (Kiesel et al., 2007) which is quite good for a screen. Therefore it can be interpreted that there will be limited false positive results or Type I errors that identify individuals as "at risk" who do not sustain an injury. Ratings of sensitivity for the FMS, however, are much worse. Sensitivity has been reported to range from 0.45 (O'Connor et al., 2011) to 0.58 (Chorba et al., 2010), demonstrating a mere 50% chance that someone who will sustain an injury will receive a score ≤ 14. This low probability creates a hazardous outcome of frequent Type II errors or false negatives that fail to identify those who will sustain an injury.

From a practical and clinical standpoint, Type II errors are of much greater consequence than Type I errors as the result may falsely assure the individual that he or she is not likely to sustain an injury. If that is the case, then the screen has essentially failed. However if the test were to have poor specificity ratings and commit more Type I or false positive errors, the cost incurred to the individuals with some movement dysfunction would be minimal and there is likely no downside to more people working to improve their fundamental movement patterns.

Future research should investigate the validity of a higher cut off score than 14, which may improve sensitivity at the cost of decreasing specificity. Additionally, research involving more robust definitions of injury and following athletes for longer than 1 season will help to provide useful evidence about the FMS.

3.4.2 Reliability

Some discrepancy exists in the measurement of inter-rater reliability of the FMS, as different statistical tests have been used. Since the individual tests of the FMS are scored on a 4-point ordinal scale (0,1,2,3) the appropriate statistic is the weighted Kappa (Mandrekar, 2011; Sim, 2005), as used by Minick et al. (2010) (Minick et al., 2010). Schneiders et al. (2011) however, reported the unweighted kappa score, which fails to account for the hierarchical nature of the 0-3 scoring system (Sim, 2005) and Chorba et al. (2010) reported the intra-class correlation coefficient which is valid only for use with continuous variables (Shrout and Fleiss, 1979; Sim, 2005) (Schneiders et al., 2011) (Chorba et al., 2010). Thus the statistics cannot be directly compared. Nonetheless, the results from these papers indicate high levels of inter-rater reliability between novices, experts and a combination of the two.

The hurdle step, in line lunge and rotary stability tests showed the least agreement between raters, but neither dropped below a moderate level of agreement.

Additionally debate is seen regarding the type of intra-class correlation coefficient (ICC) statistic to use to compare the results of the composite 21-point FMS scores, which represent a continuous variable. Rankin and Stokes (1998) suggest using a Model 2,1 for clinical studies in which the results are to be generalized to multiple raters in the same population (Rankin and Stokes, 1998). This model is a measure of true agreement between the raters and additionally provides information as to whether or not the raters are interchangeable (Rankin and Stokes, 1998). While Minick et al. (2010) did not report on the reliability of the composite score, Schneiders et al. (2011) reported an excellent ICC of .971 using an ICC model 3,1 and Chorba et al. (2010) reported a composite score inter-rater reliability of .976 using the correct model 2,1 ICC (Minick et al., 2010) (Schneiders et al., 2011) (Chorba et al., 2010).

According to the variety of statistical measures used to determine the inter-rater reliability of the FMS it appears to have moderate to excellent reliability for the individual tests and excellent reliability for the composite score. It would be beneficial for future studies to use identical and appropriate statistical measures to identify ongoing inter-rater reliability.

3.4.3 Modifiability

All 3 papers that tracked changes in FMS scores after an intervention found significant improvements in composite scores (Cowen, 2010; Goss et al., 2009; Kiesel et al., 2011). Additionally, Kiesel et al. (2011) reported that asymmetries were reduced from 50% to 32% among male football players and that percentage of players scoring above 14

increased from 11% to 63% at post-test (Kiesel et al., 2011). Cowen (2010) and Goss et al. (2009) also found that measures of agility, lower body power, core strength, body fat percentage, flexibility and perceived stress improved as a result of the same interventions that yielded FMS score improvements (Cowen, 2010) (Goss et al., 2009).

While these results look promising, one major limitation in all studies is the lack of a control group. It is possible that simply familiarization to the 7 tests of the FMS may allow individuals to improve during their next testing session. In Cowen's (2010) study, fire fighters attended an average of only 4 yoga classes over 6 weeks and saw an average 3.2 point improvement (13.3 to 16.5) (Cowen, 2010). This could either speak to the ease with which the FMS scores can be improved or the lack of intra-subject consistency between subsequent testing sessions. Additional research involving control groups and intra-subject reliability will be essential to validate the efficacy of true FMS score modifiability.

An additional limitation to the modifiability research is that both Kiesel et al. (2011) and Goss et al. (2009) conducted interventions specifically aimed at improving movements that are part of the FMS testing battery (Kiesel et al., 2011) (Goss et al., 2009). This could be seen as "training for the test" and may have limited transfer to injury prevention. Future research involving a prospective follow up of participants who show FMS score improvements will be necessary to confirm if increasing one's FMS score can reduce the risk of injury.

3.4.4 Relationship to Performance Testing

Limited research exists that supports a relationship between FMS scores and performance testing results. While Goss et al. (2009) found some moderate correlation,

Okada et al. (2011) and Parchmann and McBride (2011) found little or no relationship (Goss et al., 2009) (Okada et al., 2011) (Parchmann and McBride, 2011). However, it is important to note that this research does not provide evidence for or against the use of the FMS as a pre-participation screen for injury, only against its use as a predictor of performance. Since Cook et al. (2006) designed the FMS to address fundamental movement patterns as part of a comprehensive sports medicine assessment, it is not surprising that the FMS gathers different information from the performance tests which are already included in a typical assessment (Cook and Burton, 2006; Cook et al., 2006).

3.4.5 Other FMS Relationships

From the studies classified in this review as providing "general descriptive" information about the FMS, one particularly interesting topic arises. Extensive literature has demonstrated that previous injury is a risk factor for a subsequent injury, which has held true across a wide variety of populations and for many different injuries (Carter and Micheli, 2011; Emery, 2005; Faude, 2006; Hootman et al., 2007; Leetun et al., 2004; Nadler et al., 2002; Noyes et al., 2011; Reeser et al., 2010a). However, in 2 studies that report the relationship of FMS scores to previous injury, there is inconclusive evidence that a relationship does indeed exist (Chorba et al., 2010; Schneiders et al., 2011). Schneiders et al. (2011) reported no significant difference in FMS scores between healthy college students with and without injuries in the previous 6 months (Schneiders et al., 2011). Conversely, in a sample of fire fighters, Peate et al. (2007) found that past musculoskeletal injury and FMS score were significantly correlated ($p=0.001$) and that according to multiple linear regression, history of injury lowered the FMS score by 3.44 points (Peate et al., 2007). Chorba et al.

(2010) did not directly report a relationship between FMS scores and previous injury, but in their sample there were a number of female athletes who had undergone ACL reconstruction (ACLR) surgery, and those athletes were not found to have lower FMS scores compared to the rest of the sample (Chorba et al., 2010). However, the sub-group of 7 ACLR athletes suffered only 2 injuries (28.6% injured), less than the 38 non-ACLR athletes who suffered 19 injuries (50% injured). As the authors indicated, the differences between the FMS scores of these groups may be due to extensive rehabilitation with a functional movement focus (Chorba et al., 2010). Since previous injuries may predict subsequent injury in the case of incomplete recovery, it is possible that this group of ACLR athletes had actually recovered well, as evidenced by their higher FMS scores and lower injury rates.

Some differences in these results may be due to the very different populations studied. Further research should continue to evaluate the relationship between FMS and previous injury with larger sample sizes.

3.5 Conclusion

Current evidence suggests that the Functional Movement Screen is a reliable tool that has the ability to identify increased injury risk among female collegiate athletes, military personnelle and fire fighters with high specificity and moderate sensitivity. FMS scores are modifiable with a targeted intervention, however it is unknown if improvements in FMS score translate to decreased risk of injury. As the FMS is only a screen, it does not predict performance and should be used as part of a thorough pre-participation sports medicine or strength and conditioning assessment.

Future research should involve prospective studies with a long follow up and a variety of populations to determine if the FMS can eventually be used as a tool to identify and modify movement dysfunction, subsequently decreasing injury risk.

Author, Year, Study Design, Downs and Black Score, Level of Evidence, Grade of Evidence	Population, n, follow up length	Injury Definition/Measurement	Contingency Tables			Sensitivity and Specificity of 14 point cut off score	Odds Ratio (95% CI)
Chorba et al. (2010) Prospective Cohort DandB Score: 12 Level 3 Grade B	Female collegiate athletes n = 38 NCAA season	Any injury that occurred as a result of participation in an organized intercollegiate practice or competition setting and required medical attention or advice	*Significant at p<0.05	Injured	Not Injured	Sensitivity: 57.9% Specificity: 73.7%	3.85 (.98 - 15.13)
			FMS Score ≤ 14	11	5		
			FMS Score > 14	8	14		
O'Conner et al. (2011) Prospective Cohort DandB Score: 11 Level 3 Grade B	Male Marine Corps officer candidates n = 874 6 or 10 weeks	Physical damage to the body secondary to physical training which required medical care one or more times during the study period.	Not reported			Sensitivity: 45.2% Specificity: 78.2%	2.0 (1.3 - 3.1)
Kiesel et al. (2007) Prospective Cohort DandB Score: 10 Level 3 Grade A	Male NFL football players n = 46 4.5 months	"Membership on the injured reserve and time loss of 3 weeks"	*Significant at p<0.05	Injured	Not Injured	Sensitivity: 54% Specificity: 91%	11.67 (2.47 - 54.52)
			FMS Score ≤ 14	7	3		
			FMS Score > 14	6	30		

Table 3.2. Characteristics of studies investigating the FMS as a predictor of injury.

Author, Year, Study Design, Downs & Black Score Level of Evidence Grade of Evidence	Population, Total n, n included in reliability analysis	Live or Video FMS Scoring	Types of Scorers	Intra-class correlation for 21-point composite score	Range of reliability scores for individual FMS tests
Schneiders et al. (2011) Cross-sectional D&B Score: 13 Level 3 Grade A	Healthy, young males and females Total n = 209 (101 males, 108 females) Reliability n = 10	Live	2 physiotherapists with equal clinical experience using the FMS	0.971	ICC: .70 - 1.00
Chorba et al. (2010) Prospective Cohort D&B Score: 12 Level 3 Grade B	Female collegiate athletes Total n = 38 Reliability n = 8 (3 male, 5 female)	Video	2 licensed physical therapists with clinical practice emphasis in orthopaedic rehabilitation who were experienced using the FMS in daily practice	0.976	ICC: .774 - 1.000
Minick et al. (2010) Cross-sectional D&B Score: 9 Level 3 Grade B	Healthy college students Total n = 40 (17 males, 23 females) Reliability n = 39	Video	2 Experts defined as "an individual who was instrumental in the development of the FMS with over 10 years of experience with the tool" and 2 novices defined as having taken the standardized introductory training course and have used the FMS less than a year.	No composite score reliability reported	Weighted Kappa values: 0.54 - 1.00 between novice raters 0.40 - 0.95 between expert raters 0.74 - 1.00 between average scores of novices and experts

Table 3.3. Characteristics of studies investigating the inter-rater reliability of the FMS.

Author, Year, Study Design, Downs & Black Score, Level of Evidence Grade of Evidence	Population n follow up length	Intervention	Pre/Post changes
Kiesel et al. (2011) Prospective Cohort D&B Score: 11 Level 3 Grade A	Male NFL football players n = 62 7 weeks	Individualized training program based off of each subject's FMS scores and prescribed by the strength and conditioning staff. The program was supervised 4x/week for 7 weeks with an optional 2 additional unsupervised workouts.	Composite FMS score improvement: 11.8 - 14.8 for lineman, 13.3 - 16.3 for non-lineman ($p<0.01$) Scores above the injury threshold of 14 improved from 7/62 at baseline to 39/62 at follow up ($p<0.01$) Asymmetries decreased from 31/62 subjects at baseline to 20/62 at follow up ($p=0.01$)
Cowen (2010) Prospective Cohort D&B Score: 12 Level 3 Grade A	Male and female fire fighters n = 108 6 weeks	"Yoga classes that included pranayama (breathing), asana (postures), and savasana (relaxation). Yoga classes were conducted in stations, on-shift, at times and in locations agreed upon by the participants. Study participants attended an average of four yoga classes during the study."	Composite FMS score improvement (mean ± SD): 13.3 ± 2.3 at baseline to 16.5 ± 2.2 at follow up ($p<0.0005$) 95% Confidence Interval for mean difference: 2.77 - 3.82 Additional significant improvements were seen in flexibility and perceived stress ($p<0.05$)
Goss et al. (2009) Prospective Cohort D&B Score: 8 Level 3 Grade B	Male and female military personelle n = 90 8 weeks (6 weeks training, 2 weeks before testing)	75 minute group training classes that met 3x/week for 6 weeks. 1 class per week focused on agility, 1 on core strength and balance and 1 on power and explosiveness. Subjects also given an individualized strength and conditioning program based on their personal goals and/or strengths and weaknesses.	Composite FMS score improvement: 15.14 at baseline to 17.62 at follow up (no p-value) Greatest improvements in the active straight leg raise, shoulder mobility and deep squat Additional significant improvements were seen for body fat percentage, vertical jump and subjective fitness category self-evaluations ($p<0.05$)

Table 3.4. Characteristics of studies investigating the modifiability of the FMS.

Author, Year, Study Design, Downs and Black Score Level of Evidence Grade of Evidence	Population n	Performance Tests	Relationships between FMS scores and performance scores
Okada et al. (2011) Cross-sectional D&B Score: 9 Level 3 Grade C	Recreational Athletes n = 28 males and females (breakdown not specified)	1) Core Stability: McGill's trunk muscle endurance tests 2) Backward Overhead Medicine Ball (BOMB) Throw 3) T-Run Agility Test 4) Single Leg Squat	Significant Positive Correlations ($p<0.05$): BOMB to Hurdle Step (right), Push Up and Rotary Stability (right), T-Run to Shoulder Mobility (right). Significant Negative Correlations ($p<0.05$): BOMB to Shoulder Mobility (right), T-Run to Hurdle Step (right) and In Line Lunge (left), Single Leg Squat to Shoulder Mobility (right). No significant relationships between core stability tests and FMS scores. Shoulder Mobility (right) found predictive of combined performance score (BOMB, T-Run and Single Leg Squat)
O'Conner et al. (2011) Prospective Cohort D&B Score: 11 Level 3 Grade B	Male Marine Corps officer candidates n = 874	1) Max pull ups 2) 2-minute abdominal crunch test 3) 3-mile run for time	Subjects with composite physical fitness scores dichotomized as "low" (vs. high) were 2.2 times more likely to have FMS scores ≤ 14. Odds ratio (95% CI) = 2.2 (1.3 - 3.1), $p=0.002$
Parchmann and McBride (2011) Cross-sectional D&B Score: 10 Level 3 Grade C	NCAA division 1 golfers n = 25 (15 male, 10 female)	1) 1 Repetition Maximum Squat 2) 10 and 20 Metre Sprint Times 3) Vertical Jump 4) T-Test 5) Golf Club Head Swing Velocity (CHSV)	No correlation between FMS score and vertical jump, 10 or 20 metre sprint, t-test or club head swing velocity for either the composite score or individual test scores. The relationship between FMS scores and 1RM Squat was not reported.

Table 3.5. Characteristics of studies investigating the relationship of the FMS to performance.

Author, Year, Study Design, Downs & Black Score, Level of Evidence, Grade of Evidence	Population n	Objective	Conclusions
Schneiders et al. (2011) Cross-sectional D&B Score: 13 Level 3 Grade A	Healthy, young males and females n = 209 (101 males, 108 females)	To establish normative values for the FMS in a population of healthy active individuals and to investigate whether performance differed between males and females, between those with and without a previous history of injury, and to establish real-time interrater reliability of the FMS.	No significant difference between the composite FMS scores of males and females. Females scored significantly higher on the Active Straight Leg Raise and Shoulder Mobility ($p<0.001$). Males scored significantly higher on the Trunk Stability Push Up and Rotary Stability tests ($p<0.001$). No significant difference in FMS scores between those with and without previous injury in the past 6 months.
Butler et al. (2010) Cross-sectional D&B Score: 13 Level 3 Grade C	Healthy individuals between 18 and 30 years of age n = 28 (9 male, 19 female)	To examine the differences that exist between the different levels of the Deep Squat as scored using the FMS.	Subjects scoring a "3" had greater dorsiflexion, knee flexion and joint excursion than those with "2" or "1" scores. Subjects with scores of "3" or "2" demonstrated greater overall hip flexion, hip flexion excursion and peak hip extension moments than those with a score of "1".
Peate et al. (2007) Prospective Cohort D&B Score: 10 Level 3 Grade B	Fire fighters n = 433 (408 men, 25 women)	To determine whether results of measurement of functional movement were associated with a history of previous work-related injuries in fire fighters.	Increasing age, rank and tenure associated with lower FMS scores ($p<0.001$). Past musculoskeletal injury and FMS score were significantly correlated ($p=0.001$). History of injury lowered the FMS score by 3.44 points according to multiple linear regression ($p=0.001$).

Table 3.6. Characteristics of studies providing a general description of the FMS.

Chapter 4: Thesis Investigation: "The Relationship Between Fundamental Movement Patterns and Volleyball Spike Jump Technique"

The purpose of this chapter is to provide a brief rationale for the thesis investigation as well as a detailed description of the methods and results. The chapter will also include a thorough discussion of the results and limitations of the methodology.

4.1 Introduction

Although the Functional Movement Screen (FMS) is an important step forward in the field of injury prediction and prevention, there remain significant limitations to this method of screening human movement for athletic purposes. As the FMS is a self-professed evaluation of fundamental movement patterns (Cook and Burton, 2006), it makes no attempt to evaluate the mechanics of fast and powerful sport-specific movements. As discussed previously, sport biomechanics have shown some relationship to injury risk, particularly with regards to acute and overuse knee injury (Bisseling et al., 2008; Boden et al., 2010; Hewett et al., 2009; Myers, 2010; Sorenson, 2010), but neither the FMS nor currently identified biomechanical factors show excellent predictive power. As the low physical demand of fundamental movements and the high demand of sport-specific movements fall on opposite ends of a common spectrum of human movement, it stands to reason that performance on these tasks is not mutually exclusive. An athlete's ability to perform a certain movement draws not only from his or her fundamental mobility, stability, and developmentally engrained movement patterns, but also from the learned and practiced motor patterns specific to each sport technique (Cook et al., 2010). In the example of a volleyball spike jump, athletes must possess adequate mobility at the ankle and hip, high levels of stability at the

lumbopelvic complex, knee and ankle, and finally must utilize these joints in a sequence and pattern that minimizes excessive load on a particular joint while producing maximum power production. Many factors are at play in determining how the volleyball spike jump is executed, and each athlete's characteristics dictate their unique result.

While athletes with fundamental movement quality may have the capacity to develop efficient sport-specific patterns that carry a low risk of injury, whether they do so or not is determined by the pattern that they practice in their sport. Likewise, an athlete who has a functional limitation caused by poor mobility or stability may never be able to develop a proper sport-specific motor pattern if the movement requirements fall outside the realm of his or her fundamental abilities (Cook et al., 2010; Macrum et al., 2011). This is the common case that leads to compensatory movement patterns and may play a role in injury development (Cook et al., 2010). Of even greater consequence is that training or rehabilitation programs that incorrectly focus on the wrong aspect of movement ability (i.e. fundamental vs. sport-specific) will likely have limited benefit. In fact, in the presence of fundamental movement dysfunction, increasing technical training volume in an attempt to improve movement patterns may even increase injury risk by practicing a flawed compensatory pattern (Cook et al., 2010).

While some literature has examined the relationship between joint range of motion and kinematics during functional tasks such as squatting (Macrum et al., 2011) or landing (Fong et al., 2011), this research has been limited to passive goniometric assessments of joint motion, negating the impact of stability and neuromuscular control that affect functional movement of any joint (Cook et al., 2010). With the FMS providing a functional standard with which to measure fundamental movement patterns, it is now possible to investigate the

relationship between whole-body fundamental movement abilities and sport-specific kinematics. Knowledge of this relationship will give the fields of sports medicine and strength and conditioning a new perspective on how athletes come to execute their sport-specific skills and start a discussion regarding the complex interaction of fundamental and sport-specific movement patterns and their role within sport performance training and injury prevention.

4.1.1 Objectives and Hypotheses

The primary objective of this investigation was to determine whether fundamental movement patterns or spike jump mechanics are related to overuse injuries of the shoulder, low back and knee among elite volleyball players. A secondary objective was to compare the measures of fundamental movement patterns and spike jump mechanics to each other to determine any patterns of association.

We hypothesized that volleyball players with a history of overuse injury at the shoulder, low back or knee would score lower on the Functional Movement Screen than healthy players. Additionally, we hypothesized that players with a history of knee pain would exhibit spike jump mechanics with an earlier onset of hip extension compared to healthy players. Finally, it was our hypothesis that significant relationships would exist between the 7 individual tests of the Functional Movement Screen and the spike jump characteristics.

4.2 Methods

4.2.1 Participants

Fifty-seven (27 male, 30 female) Canadian Inter-University Sport (CIS) volleyball players were recruited from the University of British Columbia and the Trinity Western University varsity volleyball teams. Athletes currently experiencing low back or lower extremity pain were excluded from the spike jump analysis but included in the FMS testing. The investigation was completed in exact accordance to the guidelines set forth by the University of British Columbia's Behavioural Research Board of Ethics for research involving human participants.

4.2.2 Experimental Procedures

Testing with each player consisted of 3 components: Injury History and Participant Information Questionnaire, Functional Movement Screen Testing conducted in stations, and spike jump filming.

4.2.2.1 Questionnaire

Participants completed a novel questionnaire, providing the following information: general characteristics, training history and volume (practice, competition, strength and conditioning), time loss injury history, chronic pain history for the lower back, knee and shoulder, Victorian Institute of Sport Assessment (VISA) scores for both knees. This questionnaire was specifically created for this study and closely based off of previous questionnaires used for both time loss injury and pain surveillance (Bahr, 2009; Kuorinka et al., 1987).

History of time-loss injuries over the course of the athlete's athletic career was recorded based on a definition of injury adapted from Bahr (2009): "any injury causing cessation of participation in competition or training for at least 1 day following the onset of injury" (Page 971) (Bahr, 2009). Additional information on location, diagnosis, activity during which the injury occurred, acute vs. chronic injury, and time to return to play was collected for each time loss injury.

For the pain history portion of the questionnaire, participants answered questions for the shoulder, low back, and knee regions. These questions were developed from previous work involving pain surveillance in elite volleyball players (Bahr, 2009). Players were asked about pain during the past 7 days and 12 months, history of analgesic or anti-inflammatory use, medical treatment sought for the pain, and missed training or competition time due to pain. Finally, participants completed a visual analogue scale rating of pain while playing and during daily living for each region.

The VISA knee questionnaire was devised in 1998 as a quantitative assessment of knee symptoms and function in those suffering from patellar tendinopathy (Visentini et al., 1998). The questionnaire consists of 8 questions, 6 of which are scored according to visual analogue scale ratings with 10 as the optimal score. The highest possible score on the VISA questionnaire is 100. Previous investigations have demonstrated that the VISA knee questionnaire is both a valid and reliable tool for assessing knee symptoms and function (Visentini et al., 1998).

4.2.2.2 Functional Movement Screen Testing and Filming

For FMS tests, participants wore shorts and t-shirts as well as their regular volleyball shoes, including any orthotics worn for regular training. No ankle braces, kneepads, knee braces, or other external support devices were worn for the FMS testing.

Prior to testing, participants viewed a 2-minute instructional video introducing them to the tests of the FMS, after which the players moved through testing stations led by FMS certified physiotherapists, strength and conditioning coaches, or kinesiologists who each administered 2-3 of the FMS tests. Station 1 included the Overhead Deep Squat, Hurdle Step and In Line Lunge, station 2 involved the Shoulder Mobility test, Shoulder Clearing Test and Active Straight Leg Raise, and station 3 tested the Trunk Stability Push Up, Spinal Extension Clear, Rotary Stability Test and Spinal Flexion Clear (Appendix A). All instructions on how to complete the tests were delivered according to the protocols described by Cook et al. (2006) (Cook and Burton, 2006; Cook et al., 2006). Participants performed 3 trials of each test. During the testing, athletes were videotaped from front, back and side views according to a set of filming protocols developed during a pilot investigation. No live scoring was conducted for the FMS tests; all scores were determined through video analysis at a later date.

4.2.2.3 Spike Approach Jump Testing

Participants wore tight fitting spandex shorts and had rolled up sleeves (females) or were shirtless (males) in order to minimize movement artifacts produced by clothing. The athletes were outfitted with reflective tape at the lateral aspect of the acromion, greater trochanter, lateral femoral epicondyle and lateral malleolus of the dominant side, in accordance with the procedures described by Norris and Olson (2011) for 2-dimensional video analysis of knee and hip angles (Norris and Olson, 2011). Additional reflective tape was placed at the lateral aspect of the toes as a reference point for calculating ankle angle. Ankle braces and kneepads were permitted during the jump test protocols in order to most accurately capture the jumping patterns that the players are likely to experience during the majority of training and competition. Prior to their first jump, participants stood at a rough estimate of their takeoff point with the camera to their side and were instructed to "stand tall with your arms across your chest" as a reference for a "neutral" posture (Figure 4.1). This allowed joint angles to be discussed in relation to their deviation from a neutral posture, termed excursion in the subsequent analysis.

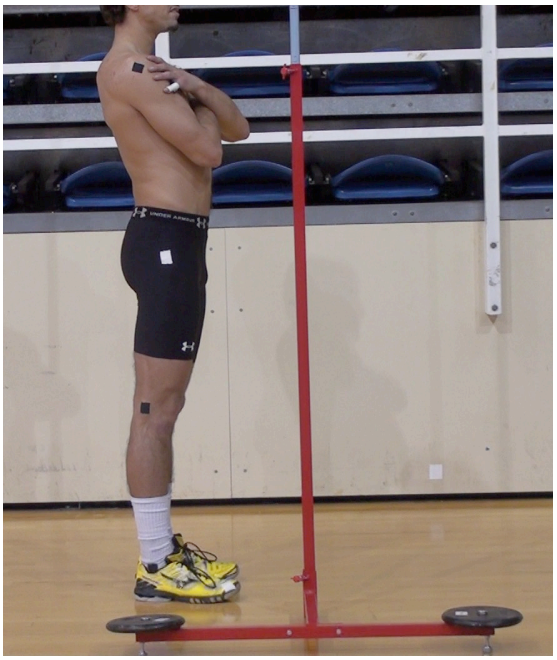

Figure 4.1. "Neutral" posture.

After a self-selected warm up lasting up to 15 minutes, participants measured their 1-arm standing reach using a Vertec jump-and-reach device (Sports Imports, Hilliard, OH) before attempting a practice spike jump. This jump was used to ensure that the athletes took off within the frame of the camera and to familiarize them with the jumping task. After 1

practice jump, athletes were given 1 minute of rest and instructed to jump as high as possible on the next attempt, which was filmed using a Sony Handycam (Sony Electronics Inc., Tokyo, Japan) set on a tripod approximately 5 metres to the side of the Vertec, in line with the "takeoff zone" on the athlete's dominant side (Figure 4.2).

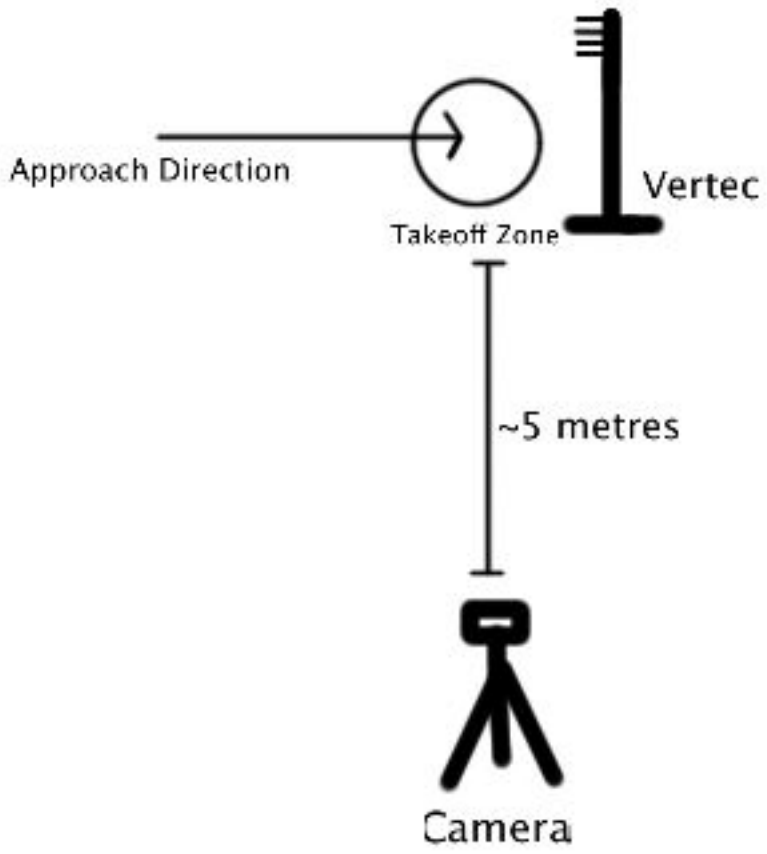

Figure 4.2. Equipment Setup for Spike Jump Filming.

4.2.3 Data Analysis

4.2.3.1 FMS Scoring

Using the scoring criteria described by Cook et al. (2006) one FMS certified kinesiologist experienced in clinical use of the screen (NS) scored all FMS tests from the video recordings (Cook and Burton, 2006; Cook et al., 2006). Scores were calculated using the standard 21-point scale (Appendix A) as well as the research based 100-point scale (Appendix C). The lead investigator (MH), an FMS certified kinesiologist experienced with use of the FMS, also scored 10 participants at random for a subsequent inter-rater reliability analysis of the video-based scoring.

4.2.3.2 Kinematic Analysis

Ankle, knee and hip joint angles were calculated in 2-dimensions using Dartfish Software 6 TeamPro Data Version 6.0.1 (Dartfish, 2011). In addition to the "neutral" frame that was taken with the athletes standing motionless (Figure 4.1), joint angles were calculated at 6 other points during the jump by manually positioning a marker in the Dartfish analysis program over top of the location of the reflective tape and connecting that point to other points using the "angle" tool in Dartfish.

The first measurement point was taken at the point of initial contact (IC) as the heel of the lead leg made contact with the ground (Figure 4.3), a second as the second foot made contact with the ground (SFP) (Figure 4.4) and another during the final frame in which at least one foot was in contact with the ground (takeoff, TO). Additionally, measurements of peak ankle, knee and hip flexion were determined using the "angle tracking" feature in Dartfish. Frame by frame analysis of the spike jump allowed the lead Dartfish analyst (GC)

to determine these points to within an accuracy of 0.018 seconds and time stamps were taken for each measurement.

Figure 4.3. Point of initial contact (IC) of the volleyball spike jump.

Figure 4.4. Second foot plant (SFP) point of the volleyball spike jump.

After inputting these angles into Microsoft Excel (Microsoft Office 2011), formulae were developed to determine ankle, knee and hip angular velocities during all phases of the jump as well as durations of each segment. Additionally, formulae were developed to measure various aspects of coordination during the jump.

All jumps were analyzed by one student trained in Dartfish analysis specifically for this study (GC). The lead investigator (MH) also analyzed 10 of the jumps in order to conduct an analysis of inter-rater reliability for the use of Dartfish to quantify joint angles during a volleyball spike jump.

4.2.4 Statistical Analysis

Due to the logistical limitations imposed by the size of the university volleyball player population in Greater Vancouver, a sample size calculation was not necessary. Descriptive statistics were performed for athlete characteristics and injury and pain history data.

To determine if fundamental movement patterns were related to overuse injury, independent t-tests were used to compare the mean composite FMS scores and individual 100-point scores of groups with and without a history of shoulder, low back, and knee pain. For the 21-point scores of the individual FMS tests, the Mann-Whitney U test was used to compare ordinal variables.

To determine if spike jump mechanics were related to overuse injury, independent t-tests were also performed to compare the means of all spike jump variables between groups with and without a history of shoulder, low back, and knee pain.

To investigate the relationship between fundamental movement patterns and spike jump technique, Pearson's product moment correlations (r) were calculated between the continuous 100-point FMS scores from each test and all spike jump variables.

Inter-rater reliability (IRR) of the FMS scoring was assessed for 10 randomly selected participants. For the 7 individual tests of the FMS that are scored using a 4-point ordinal scale (0,1,2,3), the weighted kappa statistic was calculated to account for the hierarchical nature of the scoring system (Sim, 2005). For the 21-point and 100-point composite FMS scores, continuous variables, a model 2,1 intra-class correlation coefficient (ICC) was calculated. Inter-rater reliability for the joint angle calculations in Dartfish was also assessed for 10 randomly selected individuals using a model 2,1 ICC. Repeatability of the results from

the novel injury history questionnaire was evaluated for 10 participants using the unweighted kappa statistic for categorical variables such as presence or absence of pain and the ICC for continuous variable responses such as VISA score and VAS pain ratings. Standard error of measurement (SEM) and 95% confidence intervals were calculated for each of the reliability statistics.

All statistical tests were calculated using SPSS Version 20. With a large number of comparisons, the analysis style in this study carries a high risk of incurring a Type I Error and finding significant results simply due to chance. However, since the purpose of this analysis is exploratory in nature and serves only to direct future investigations, the cost of a Type I Error is very low. Still, to reduce the likelihood that results are due to chance, significance was set at $p<0.01$ for this exploratory study.

4.3 Results

4.3.1 Participant Characteristics and Injury History

Participant characteristics are listed in Table 4.1. The vast majority of athletes had sustained a time loss injury during their volleyball careers (Table 4.1) and nearly 90% of players reported playing with pain during the previous 12 months (Figure 4.5). The majority of those athletes sought medical treatment and used a non-steroidal anti-inflammatory drug (NSAID) to manage pain (Figure 4.5). In the past 12 months, knee pain and shoulder pain were the most prevalent, with over 60% of players suffering from each. Twelve-month low back pain prevalence was only slightly lower, with the largest difference between males and females (52% vs. 67%, respectively) (Figure 4.6). Prevalence of pain in the previous 7 days was lower than for 12-month pain, with knee pain topping the charts at 48% for females and 53% for males (Figure 4.6). During the past 7 days, most participants experienced pain in either 1 or 2 locations (Figure 4.7), however the severity of the pain was low, generally below 4/10 on the 10-cm Visual Analogue Scale (VAS) (Figure 4.8). VISA scores for those experiencing knee pain are presented in Figure 4.9.

The repeatability analysis for the injury history questionnaire resulted in a kappa value of 0.845 (SE=0.047) for the categorical responses and an ICC of 0.975 (95% CI = 0.962 – 0.984) for the continuous responses.

	Male	**Female**
Number of Participants (n)	27	30
Age (years)	20.3 ± 1.6	20.0 ± 1.3
Height (cm)	194.4 ± 7.6	181.3 ± 8.6
Weight (kg)	88.0 ± 9.0	71.0 ± 6.7
Position (n)	Setter: 2 Left Side: 12 Right Side: 3 Middle Blocker: 8 Libero: 2	Setter: 5 Left Side: 9 Right Side: 4 Middle Blocker: 6 Libero: 6
Dominant Hand (n)	Right: 25 Left: 2	Right: 26 Left: 4
Athletes who have experienced time loss injuries in their career [n(%)]	24 (88.8)	28 (93.3)
Mean number of time loss injuries per athlete during their career	2.0 ± 1.2	2.2 ± 1.2

Table 4.1. Participant Characteristics (mean ± SD).

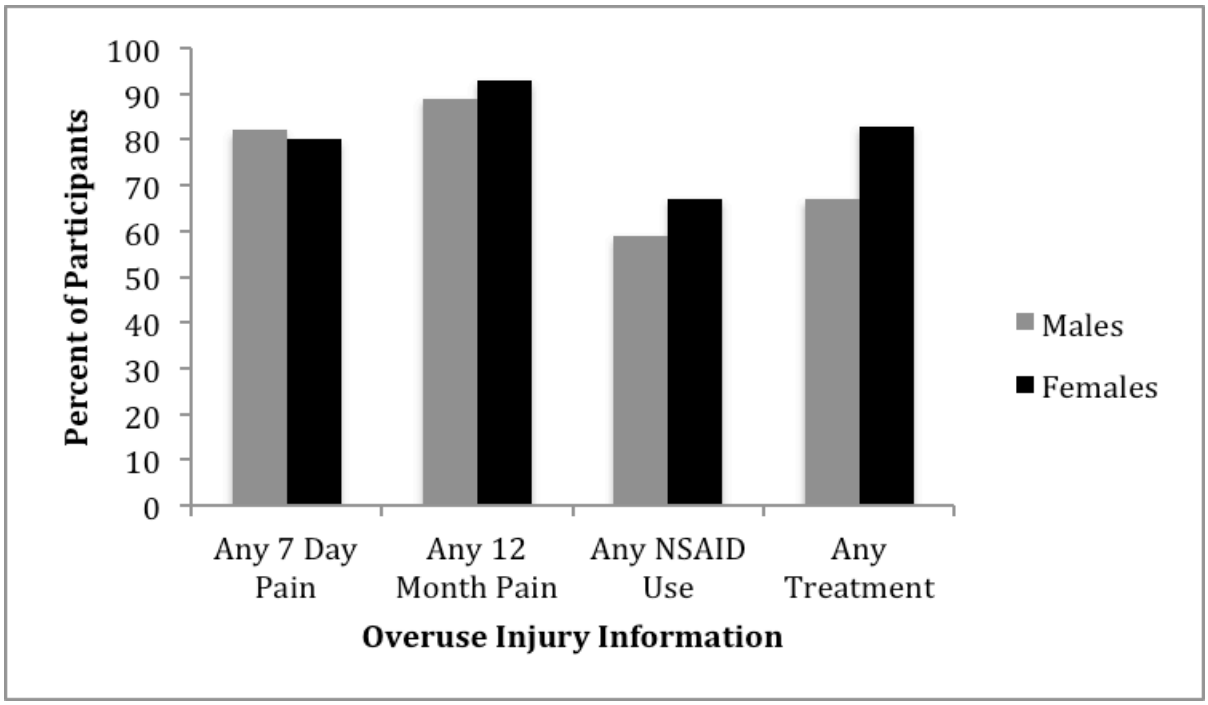

Figure 4.5. Percentage of participants with 7-day and 12-month pain in the shoulder, low back or knee as well as those who have used NSAIDs or sought medical treatment for their pain in the last 12 months, all areas combined.

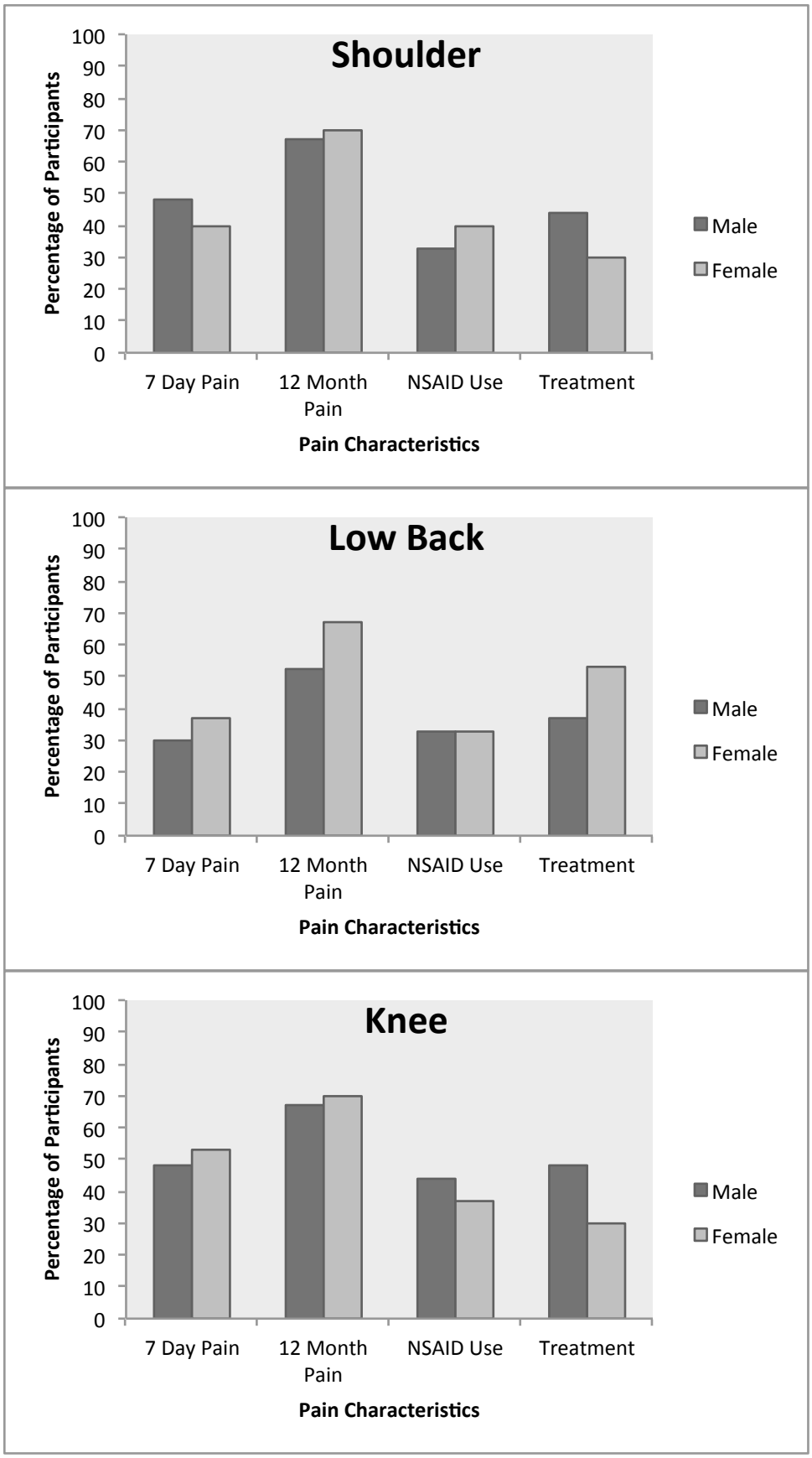

Figure 4.6. Percentage of participants with 7-day and 12-month pain in the shoulder, low back or knee as well as those who have used NSAIDs or sought medical treatment for their pain in the last 12 months, by location.

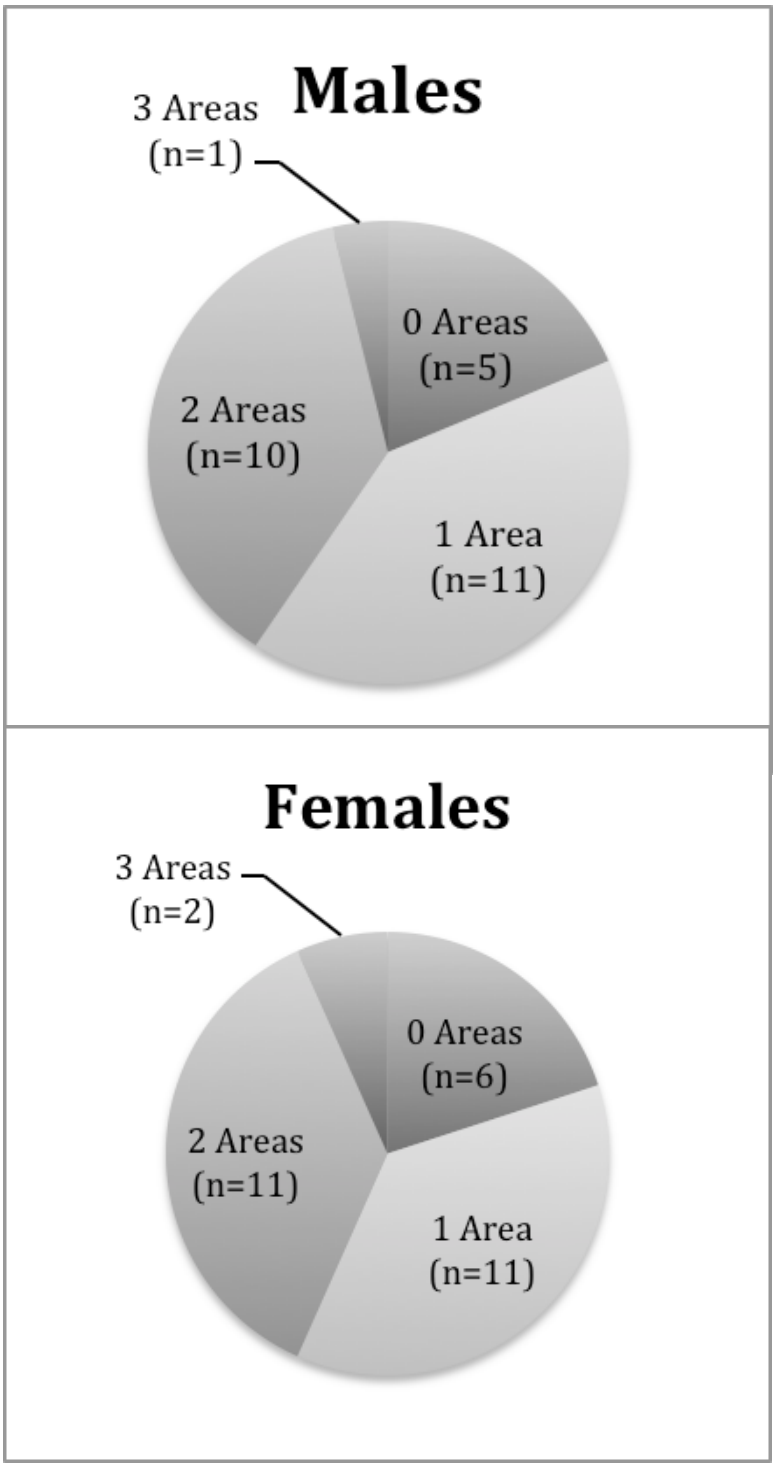

Figure 4.7. Number of locations (shoulder, low back, knee) in which participants have experienced pain in the past 7 days.

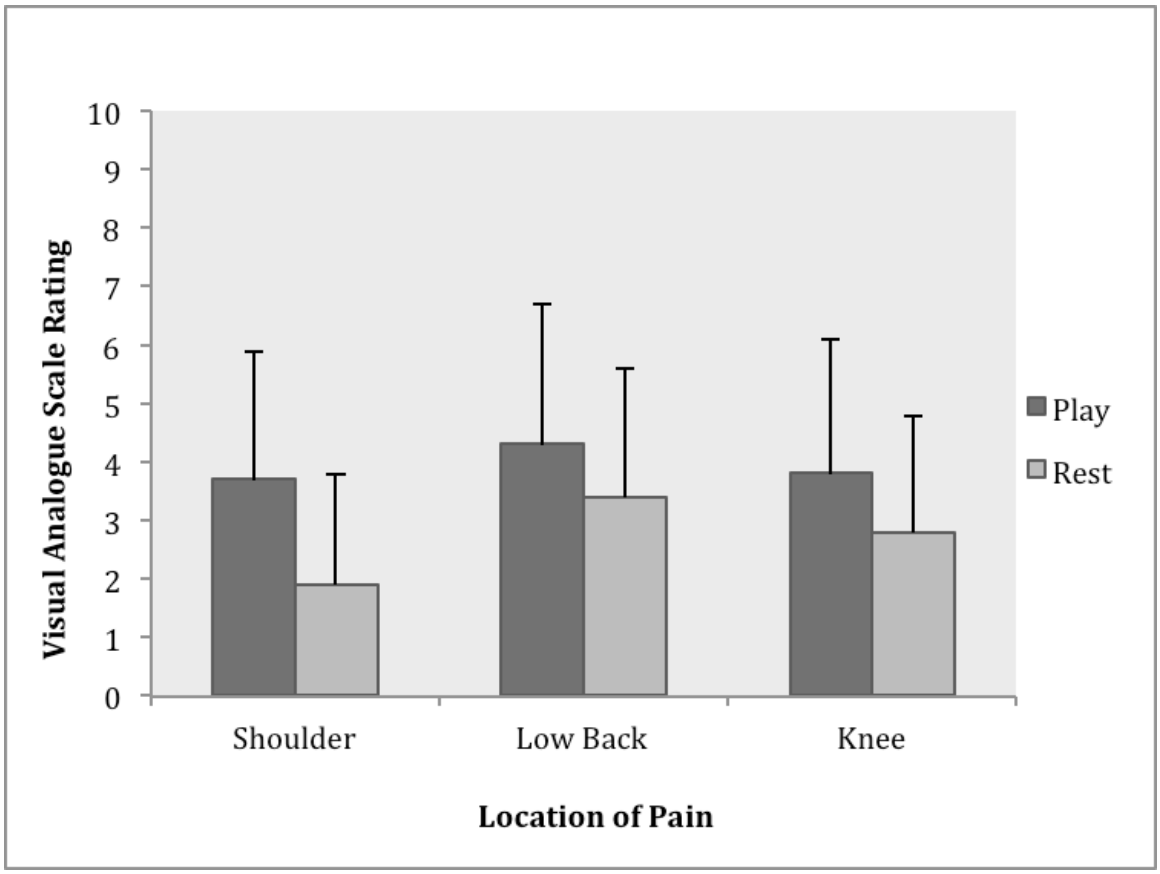

Figure 4.8. 10 cm Visual Analogue Scale (VAS) scores for participants currently experiencing shoulder, low back or knee pain during play and rest.

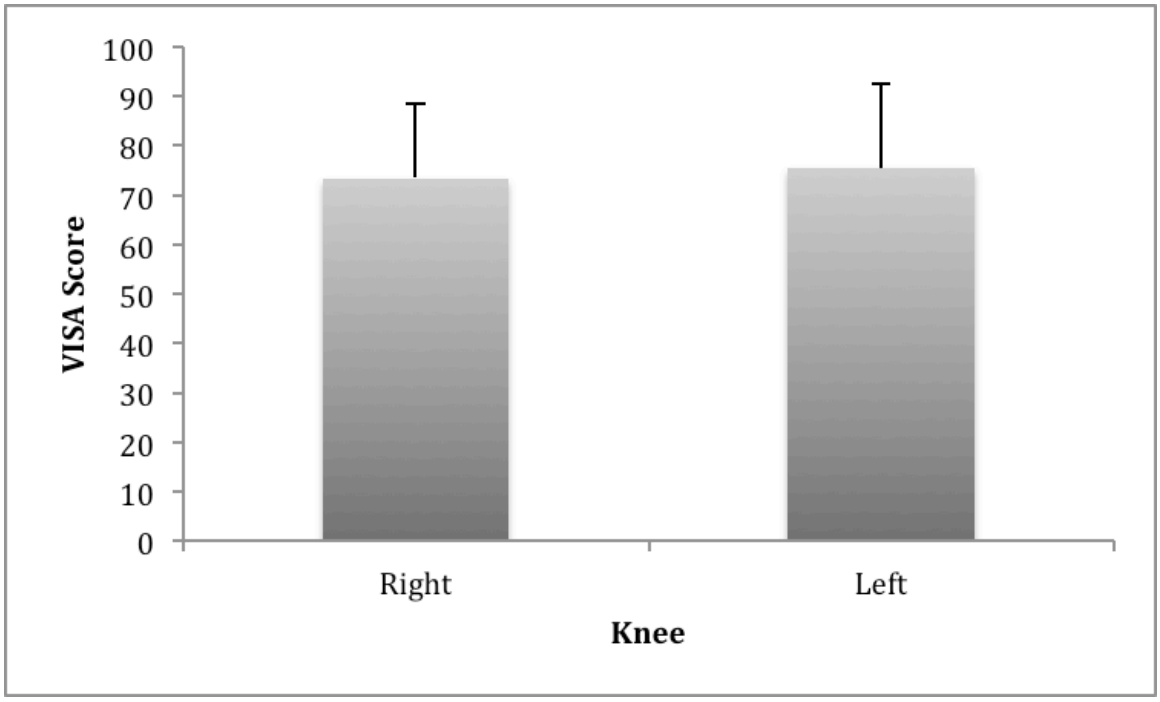

Figure 4.9. Victorian Institute of Sport Assessment (VISA) scores for the right and left knees of participants currently experiencing knee pain during practice or competition.

4.3.2 Functional Movement Screen

All 57 participants completed the Functional Movement Screen. Mean 21-point scores were 11.9 and 12.9 for males and females, and 100-point scores were 51.4 for females and 50.4 for males (Table 4.2). The majority of athletes had at least 1 asymmetry in the FMS tests (74% of males, 80% of females) and 40% of both males and females experienced pain during the FMS testing (Table 4.2). Only 8 males (30%) and 4 females (13%) scored above the 14-point score previously shown to be predictive of injury risk (Table 4.2). Distribution of individual test scores for males and females are presented in Figures 4.10 and 4.11 using the 0-3 scoring scale.

Mean composite and individual test scores were compared between players with and without 7-day pain in the shoulders, low back or knees (Table 4.3). The most significant predictors of pain were the Active Straight Leg Raise for male low back pain ($p=0.002$) and the In Line Lunge and 21-Point composite score for any pain among females ($p=0.002$ and $p=0.006$, respectively). With 40% of participants experiencing pain on the FMS tests, it is likely that any relationships between FMS results and pain history could be due to the presence of pain during the FMS testing, which results in a score of 0 for that test. Therefore, in an attempt to truly identify whether non-local fundamental movement dysfunction is related to overuse pain, an additional analysis was performed on the sub-group of 33 athletes who did not experience pain during the FMS testing. Two results were significant at the $p<0.05$ level in this sub-analysis, but neither were significant at $p<0.01$. As in the initial analysis, the Active Straight Leg Raise score was significantly different ($p=0.022$) between players with and without a history of low back pain. Additionally, the Hurdle Step score emerged as also significantly different for those experiencing low back pain ($p=0.011$)

although the healthy group actually had a lower score in this case. Only a combined group of males and females was analyzed for this follow up test in order to minimize the dilution of the groups.

Intra-class correlations (ICC) were calculated as 0.961 (95% CI = 0.849 – 0.990) for the composite 21-point scores and 0.925 (95% CI = 0.564 – 0.983) for the 100-point composite scores. ICC ratings for of the individual 100-point scores ranged from 0.696 – 1.00, with the Trunk Stability Push Up having the lowest reliability and the Rotary Stability showing the best reliability (Table 4.4). Weighted kappa values for the individual 21-point scores ranged from 0.231 (Trunk Stability Push Up) to 0.839 (Active Straight Leg Raise).

	Total 21-Point Score	Total 100-Point Score	% with Asymmetry	% with Pain	21-Point Range	100-Point Range	% with 21-Point Score > 14
Males	12.9 ± 2.0	50.4 ± 11.2	74% (20/27)	41% (11/27)	8 - 16	32 - 70	30% (8/27)
Females	11.9 ± 3.6	51.4 ± 14.0	80% (24/30)	40% (12/30)	3 - 16	17 - 75	13% (4/30)

Table 4.2. Descriptive data for the Functional Movement Screen results. Total scores are presented as mean ± SD, percentages are followed by proportions.

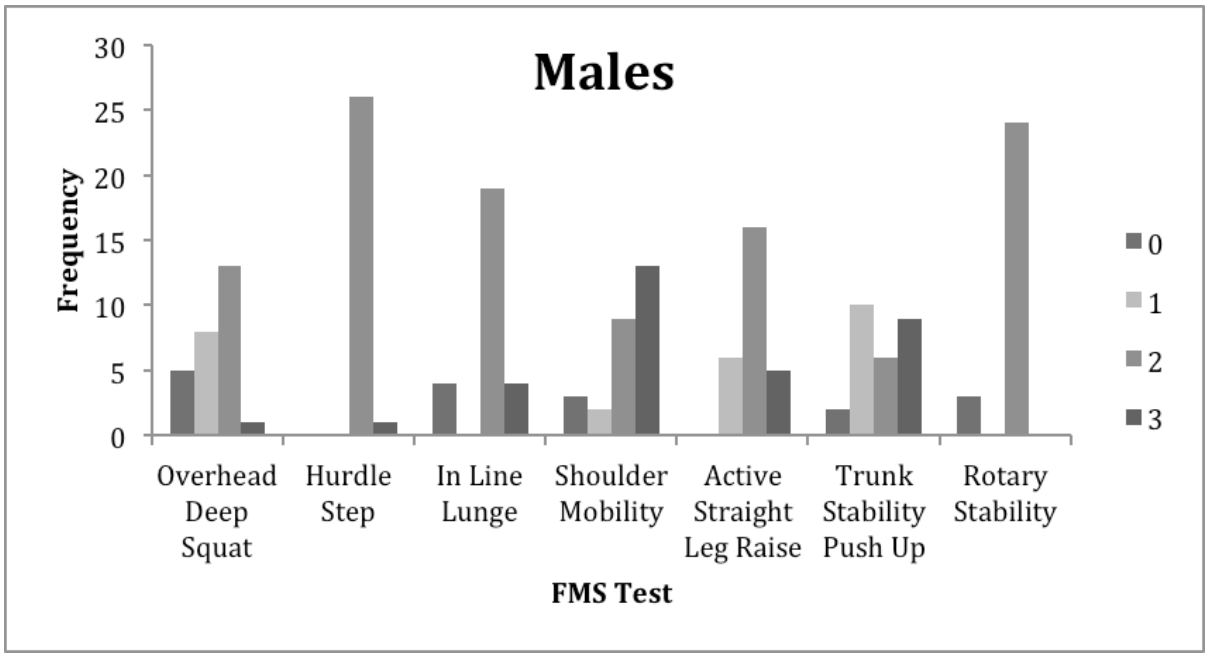

Figure 4.10 Frequency of 21-point Functional Movement Screen individual test scores for males.

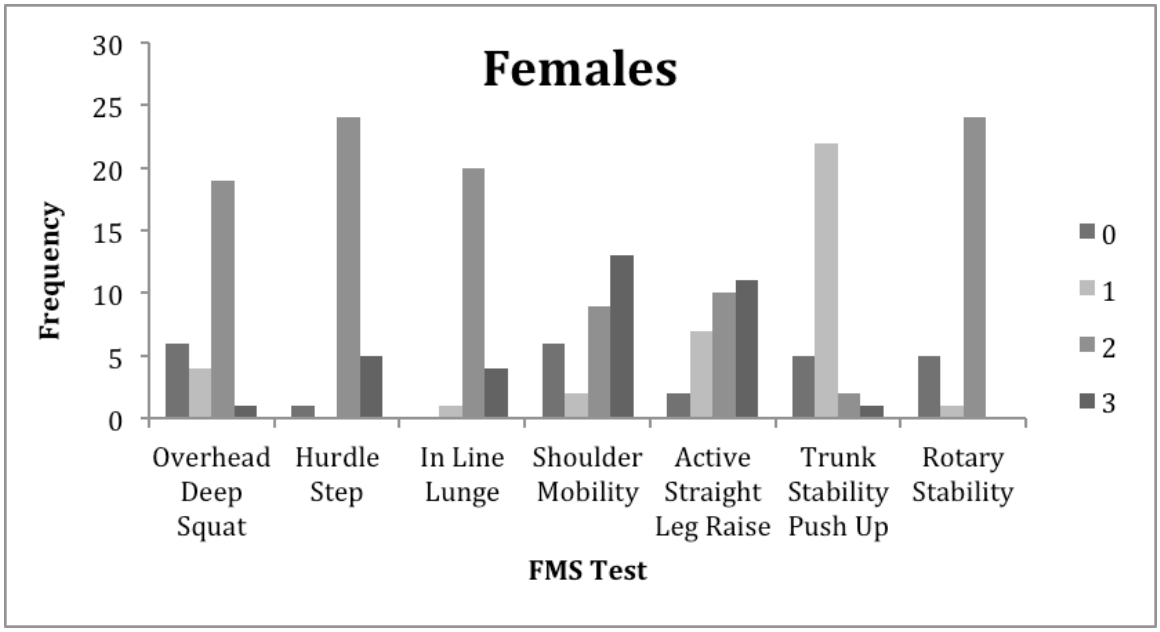

Figure 4.11. Frequency of 21-point Functional Movement Screen individual test scores for females.

Any Location			
Females	*Pain*	*No Pain*	*p*
Total 21 Point Score	11.3 ± 3.7	14.3 ± 1.5	0.006
In Line Lunge	12.2 ± 5.9	17.3 ± 2.1	0.002
Low Back			
Males	*Pain*	*No Pain*	*p*
Active Straight Leg Raise	2.5 ± 1.8	6.2 ± 3.9	0.002
Combined			
Active Straight Leg Raise	3.8 ± 3.8	7.2 ± 4.4	0.005
Knee			
Combined	*Pain*	*No Pain*	*p*
In Line Lunge	10.3 ± 6.5	14.3 ± 4.3	0.008
Sub Analysis of Subjects without FMS Pain			
Low Back			
Combined	*Pain*	*No Pain*	*p*
Hurdle Step	16.1 ± 1.5	14.1 ± 4.2	0.011
Active Straight Leg Raise	3.8 ± 4.1	7.8 ± 4.3	0.022

Table 4.3. Significant differences in FMS 100-point scores and 21-point composite score between participants with and without a history of pain in the shoulder, low back, knee or any location. Results displayed as mean ± SD.

	21-POINT		100-POINT	
Test	**Kappa**	**SE**	**ICC**	**95% CI**
Deep Squat	0.531	0.203	0.97	0.862 - 0.993
Hurdle Step	0.756	0.227	0.949	0.796 - 0.987
In Line Lunge	0.355	0.206	0.815	0.248 - 0.954
Shoulder Mobility	0.688	0.192	0.855	0.463 - 0.963
Active Straight Leg Raise	0.839	0.154	0.98	0.924 - 0.995
Trunk Stability Push Up	0.231	0.153	0.697	-0.052 - 0.922
Rotary Stability	0.615	0.337	1	-

Table 4.4. Inter-rater reliability for the 21-point and 100-point FMS scoring systems.

4.3.3 Jump Characteristics

Although 57 participants completed the questionnaire and FMS, only 31 were free of lower body pain at the time of testing, thus fewer individuals were involved in the spike jump kinematic analysis. Range of motion, eccentric and concentric angular velocities, timing and coordination were measured at the ankle, knee and hip throughout the takeoff phase of the spike jump and subsequently compared between healthy athletes and athletes with a history of shoulder, low back or knee pain.

Significant differences between healthy participants and those with a history of pain the shoulder, low back or knee are presented in Table. 4.5. Males with higher jump heights were significantly more likely to have pain in the previous 7 days (p=0.000). The only spike jump variable that was related to overuse knee pain was the angle of hip excursion at takeoff (p=0.006). Males with greater excursion from neutral (i.e. greater flexion in this case) were more likely to have knee pain. Surprisingly, a number of hip-related spike jump variables were associated with overuse shoulder pain. Males with greater eccentric hip velocity had significantly more shoulder pain (p=0.005). This significance improved when the eccentric hip velocity was compared to eccentric knee velocity to create a hip:knee eccentric velocity ratio; the closer the eccentric hip velocity to the knee velocity, the higher likelihood of knee pain. A healthy ratio appears to be approximately 1:2 (hip:knee).

Inter-rater reliability for the Dartfish kinematic analysis was excellent, with an ICC of 0.992 (95% CI = 0.990 – 0.994).

Any Location			
Males	*Pain*	*No Pain*	*p*
Relative Jump Height (cm)	86.1 ± 6.6	72.1 ± 0.6	0.000
Knee			
Males	*Pain*	*No Pain*	*p*
Hip Excursion at Takeoff (deg)	22.7 ± 12.9	5.9 ± 8.1	0.006
Low Back			
Males			
Eccentric Velocity Ratio of Hip:Knee	0.38 ± 0.16	0.76 ± 0.20	0.003
Shoulder			
Males	*Pain*	*No Pain*	*p*
Eccentric Hip Velocity (deg/sec)	277.5 ± 65.2	153.6 ± 53.3	0.001
Eccentric Velocity Ratio of Hip:Knee	0.89 ± 0.19	0.53 ± 0.21	0.002

Table 4.5. Significant differences in spike jump technique between participants with and without a history of pain in the shoulder, low back, knee or any location. Results displayed as mean ± SD.

4.3.4 Relationships Between Functional Movement Patterns and Spike Jump Mechanics

As many of the correlations in the analysis of males and females combined may be due to the difference in jumping mechanics and functional movement patterns between males and females, only correlations by gender were calculated. Scores of 0 that were caused by pain were removed from the data set for this particular analysis, since including those scores as part of the continuous response variable would not be a true representation of fundamental movement ability, but instead would measure solely the score of the test and be affected by the presence of pain.

Scatterplots for the significant correlations by gender reveal 3 trends (Figures 4.12 to 4.14). The first trend is for males with higher scores on the In Line Lunge test to exhibit a higher degree of ankle dorsiflexion at the time of Second Foot Plant (Figure 4.12). The second trend is for females with higher Shoulder Mobility scores to have a shorter time interval between the time of Peak Hip Flexion and the time of Peak Knee Flexion (Figure 4.13). Lastly, higher scores on the Shoulder Mobility test are associated with greater hip angles (i.e. less flexion) at the initial contact point of the spike jump for females (Figure 4.14).

Males			
In Line Lunge		*r*	*p*
	Ankle Excursion at SFP	0.665	0.005
Females			
Shoulder Mobility			
	Time Between Peak Hip Flexion and Peak Knee Flexion	-0.748	0.001
	Hip Angle at IC	0.692	0.004

Table 4.6. Significant correlations between FMS tests and spike jump characteristics. IC – initial contact. SFP – second foot plant. Scores of "0" due to pain have been removed from the analysis.

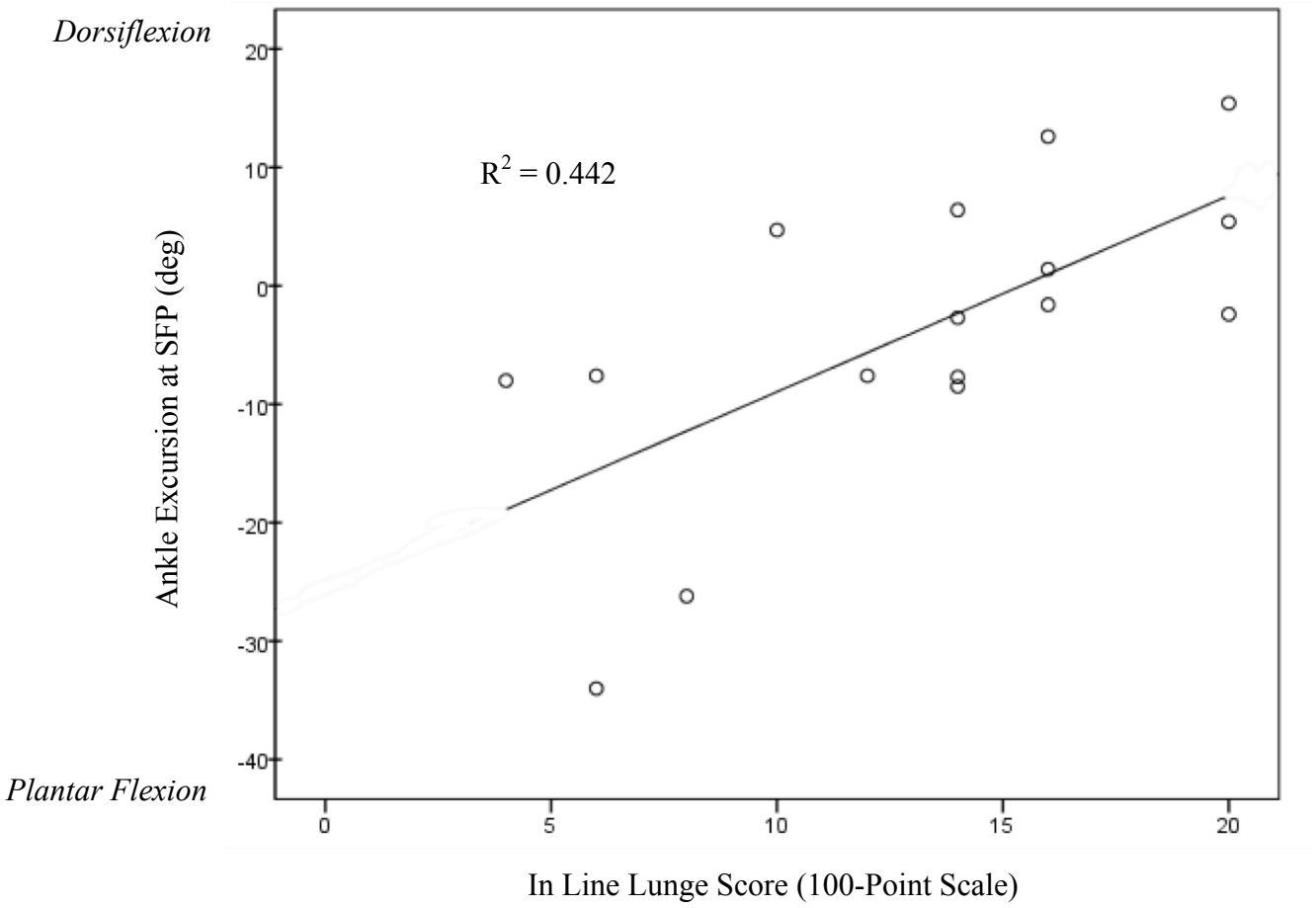

Figure 4.12. Relationship between In Line Lunge score and Ankle Excursion at Second Foot Plant for males.

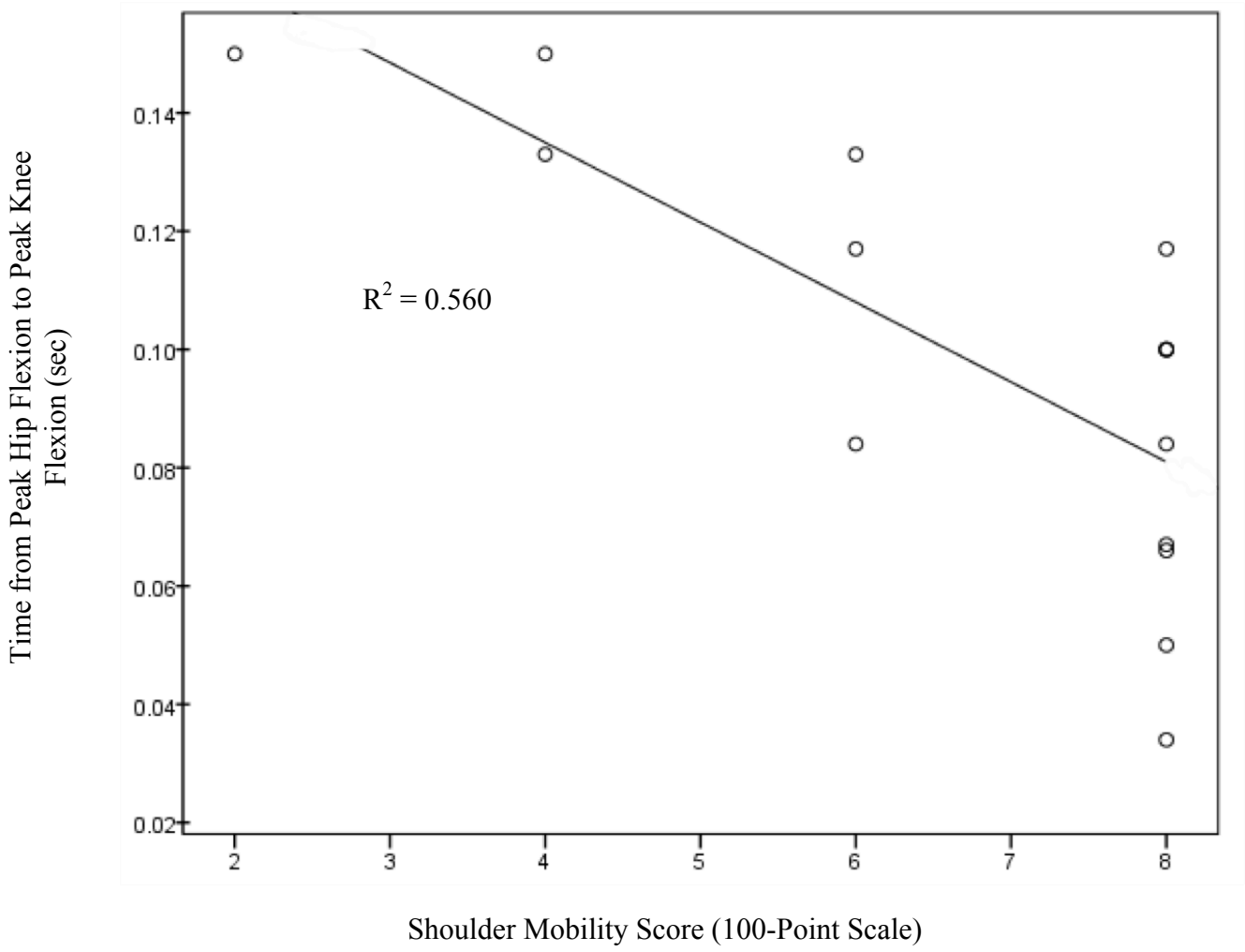

Figure 4.13. Relationship between Shoulder Mobility score and the time between Peak Hip Flexion and Peak Knee Flexion for females.

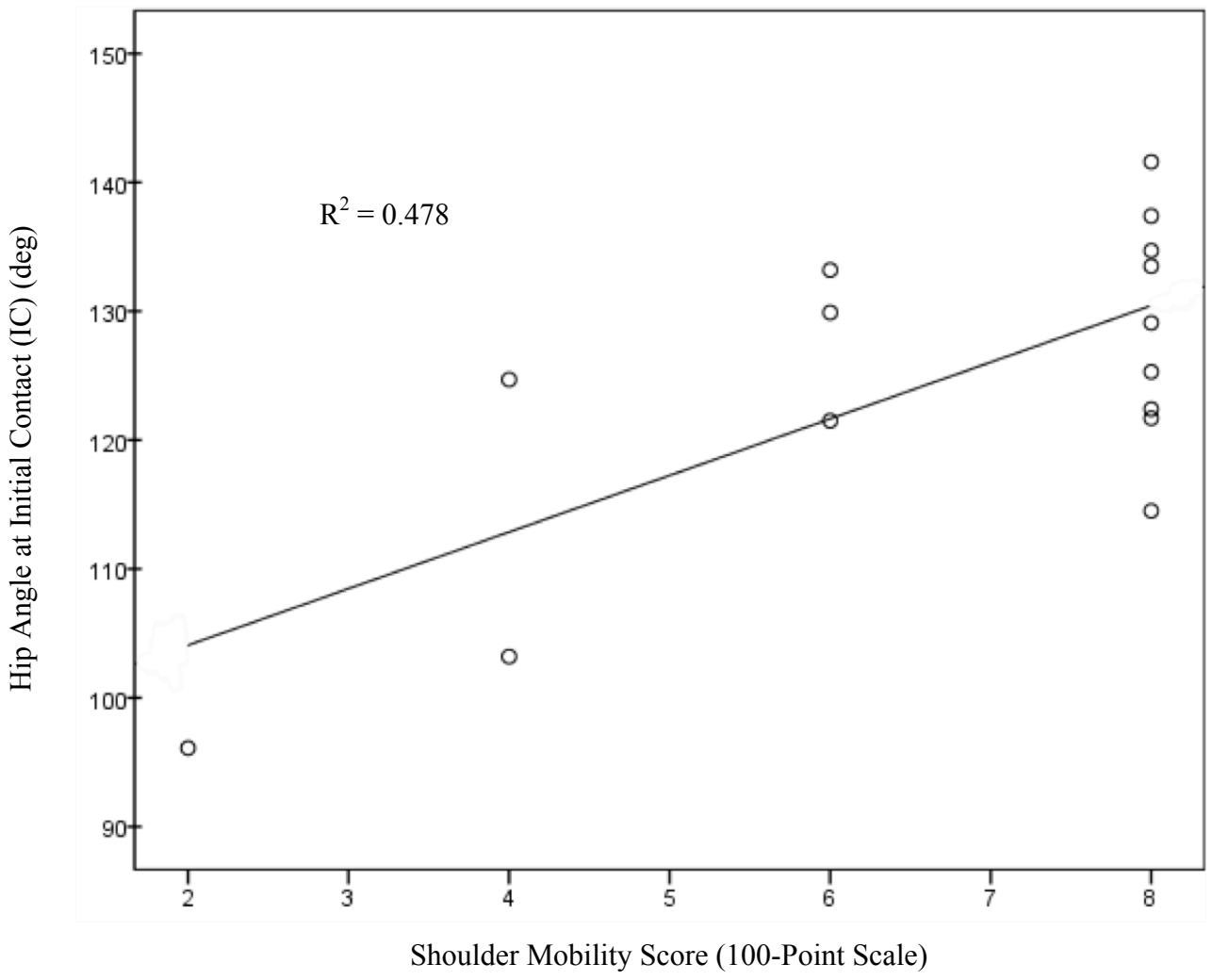

Figure 4.14. Relationship between Shoulder Mobility score and Hip Angle at Initial Contact for females.

4.4 Discussion

The primary objective of this study was to determine if fundamental movement patterns and spike jump mechanics are related to overuse injuries of the shoulder, low back and knee among university volleyball players. A secondary objective was to determine the relationships between aspects of fundamental movement patterns and the mechanics of a volleyball spike jump. The results will be discussed in 5 sections: 1) Overuse Injury and Pain Prevalence, 2) Relationships Between Fundamental Movement Patterns and Overuse Pain, 3) Relationships Between Spike Jump Mechanics and Overuse Pain, 4) Relationships Between Fundamental Movement Patterns and Spike Jump Technique and 5) Limitations.

4.4.1 Overuse Injury and Pain Prevalence

The exceptionally high prevalence of shoulder, low back and knee pain found in our sample of university volleyball players is consistent with Bahr's 2009 study that was the first to highlight the disconnect between symptoms of pain and the number of injuries reported by elite volleyball players (Bahr, 2009). He (Bahr, 2009) reported that 35% of the elite beach volleyball players in his study had experienced shoulder pain in the previous 7 days, 27% had experienced low back pain, and 29% were afflicted with knee pain. Only 36% of players reported no pain during the previous 7 days. The prevalence of 7-day pain from this study is actually higher than Bahr's (2009) results for the knee and shoulder, and identical for low back pain(Bahr, 2009). Additionally, only 20% of the players in this study reported having no pain in the past 7 days, indicating that the proportion of volleyball players experiencing pain was actually higher in our sample. This may be due in part to the difference in surface

between the two disciplines of the sport, as sand is proposed to be much more forgiving during jump landings and diving.

While the severity of pain appears to be quite low as measured by the 10-cm VAS (mean of 3.7/10 for shoulder pain, 3.8/10 for low back pain and 4.3/10 for knee pain), over 60% of players have used NSAIDS as pain relief, and over 80% of females have sought medical treatment as pain management in the past year (65% of males) (Figure 4.5). Such frequent treatment and NSAID use comes at a high cost to the athletes or athletics program. Since these are not the typical volleyball time loss injuries that have been studied quite extensively, very little is known about the causes, treatments and preventative measures for this overuse pain. The presence of overuse pain among university volleyball players appears to be quite uncontrolled, therefore further investigation in this area is warranted. In order to capture the true prevalence of pain and overuse injuries, future studies in volleyball and other non-contact sports should evolve from the time-loss definition of injury and adopt a pain and function based definition of injury.

4.4.2 Relationships Between Fundamental Movement Patterns and Overuse Pain

Functional movement screen scores for this sample of university volleyball players were on average much lower than observed in other populations. Schneiders et al. (2011) reported normative FMS values for healthy, active 18-40 year olds to be 15.6 for women and 15.8 for men (Schneiders et al., 2011). In the only other study investigating FMS scores among female collegiate athletes, including a sub-group of 11 volleyball players, the mean female score was reported as 14.3 (Chorba et al., 2010).

With the low mean FMS scores found in this study of 12.9 for males and 11.9 for females, the utility of the 14-point "cut off" score proposed by Kiesel et al. (2007) is questionable, as only 8/27 males and 4/30 females scored above 14 (Kiesel et al., 2007). The prevalence of overuse pain for participants above and below a score of 14 was not significantly different, so it does not appear that the same FMS cut point that can predict serious injury is able to identify movement pattern dysfunction that contributes to overuse injury pain.

To identify differences in FMS results between athletes with and without shoulder, low back and knee pain, the 100-point individual test scores were used since they offer more robust information about movement quality (Butler et al., 2012 – in press). Additionally, males and females were analyzed separately since their FMS score distribution has been shown to be different (Schneiders et al., 2011) and the aetiology of shoulder, low back and knee pain may be different between the genders. Presence versus absence of pain in the previous 7 days was used as the grouping variable. Several significant differences were identified between groups of athletes with and without 7 day pain (Table 4.3), however these results must be interpreted with caution as the FMS score is directly influenced by the presence of pain, in which case individuals receive a 0 for the test that elicits pain. In this case, the FMS score reflects the presence of pain as much as it does fundamental movement patterns, which is not the objective of this study. In an attempt to analyze only pain-free movement, a sub-analysis was conducted exclusively with participants who did not experience pain during the FMS. Unfortunately this eliminated 40% of participants from the analysis, so in order to avoid further dilution of the sample size both males and females were analyzed together.

Two significant relationships emerged from the sub-analysis, both related to low back pain and hip movement. The finding that the Hurdle Step scores are significantly higher (16.1 vs. 14.1) in athletes with low back pain is difficult to explain. The Hurdle Step involves a combination of unilateral active hip flexion and single leg stance stability on the contralateral side, all while maintaining a stable and neutral upper body. In order to achieve a high score on the test, one must clear the cord while maintaining a vertical alignment of the ankle, knees and hip, with minimal movement in the lumbar spine and upper body. Hypothetically these qualities should be related to high levels of lumbopelvic function, which is deemed important for low back health (Reiman and Weisbach, 2009; Zazulak et al., 2005). As the difference between the means is quite small, it may not be clinically relevant, but further research should attempt to replicate the results.

The significantly lower (3.8 vs. 7.8) Active Straight Leg Raise (ASLR) scores among participants with low back pain makes greater theoretical sense. The ASLR measures unilateral active hip flexion range, which inherently also measures hip extension on the contralateral leg as it must remain in contact with the ground. This test requires a moderate amount of hip flexion strength, but is mainly affected by hip mobility, both posteriorly on the moving leg and anteriorly on the down leg. Previous studies have documented the relationship between poor hip mobility and low back pain in adolescent and occupational cohorts, and the results from this study are in agreement with those findings (Mellin, 1988; Sjolie, 2004). Looking closer at the distribution of scores, 9 athletes were afflicted with low back pain, while 25 were healthy. Eleven athletes had perfect scores of 12/12, indicating that bilaterally they were able to raise their leg to the point that the lateral malleolus moved between mid-thigh and their anterior superior iliac spine (ASIS). All athletes with perfect

ASLR scores were free of low back pain. Of the athletes who scored between 4 and 8 (a 2/3 on the 21-point scoring system), 5/16 experienced low back pain, and 4/7 of those who scored 0/12 were also afflicted by low back pain. It appears that while having poor hip mobility indicated by low scores on the ASLR test does not mediate risk of low back pain, having excellent hip mobility significantly decreases the likelihood of experiencing pain.

Inter-rater reliability (IRR) for the FMS video scoring was similar to that reported in previous studies (Chorba et al., 2010; Minick et al., 2010; Schneiders et al., 2011) (Butler et al., 2012 – in press), with both the 21-point and 100-point composite scores achieving excellent IRR ratings. Some of the individual tests showed lower IRR than in previous studies, notably the Trunk Stability Push Up test, which has previously received one of the highest ratings. Butler et al. (2012, in press) actually found the 100-point TSPU to have perfect agreement between expert raters when scored from video, while it had by far the least agreement in this study ($Kappa_{21\text{-point}} = 0.231$, $ICC_{100\text{-point}} = 0.697$). This discrepancy is difficult to explain, but with high ratings of IRR in many other studies as well as excellent composite score IRR in this study, the Functional Movement Screen can still be deemed to have excellent inter-rater reliability overall.

4.4.3 Relationships Between Spike Jump Mechanics and Overuse Pain

The kinematic measures of the volleyball spike jump measured using the 2D Dartfish video analysis system were quite similar to previously reported 3D kinematics of the spike approach (Wagner et al., 2009). One major difference however, was the concentric angular velocity of ankles, knees and hips, which Wagner et al. (2009) reported to be much higher than in our study (1331 vs. 350 degrees/second for ankles, 1207 vs. 413 degrees/second for

knees, 658 vs. 275 degrees/second for hips) (Wagner et al., 2009). The source of this variability is likely due to the frequency at which the 3D and 2D analysis systems are able to take kinematic measures. While the 3D VICON system used by Wagner et al. (2009) has a sampling rate of 250 Hz, the cameras used with our Dartfish system produced a sampling rate of only 55 Hz (Wagner et al., 2009). It is likely that the high angular velocity measurements reported by Wagner et al. (2009) are more accurate than the low values reported in this study, and this is one of the main limitations of the Dartfish video analysis system (Wagner et al., 2009).

Based on the results of a comparison of mean jumping characteristics between participants with and without pain at the shoulder, low back or knee, several mechanical factors appear to have a significant relationship ($p<0.01$) with overuse pain for males, but none for females (Table 4.5). The only spike jump characteristic that was predictive of overall pain (i.e. pain at any location) in the previous 7 days was vertical jump height. Male athletes who had experienced 7-day pain at either the shoulder, low back or knee had a tendency to jump 14 cm higher than healthy counterparts (86.1 cm vs. 72.1 cm). As it is not feasible to deliberately reduce jump height as a means of injury prevention, this is not a practically modifiable risk factor. This finding is in agreement with previous studies that have identified jump height as a risk factor for patellar tendinopathy (Cook et al., 2004; Lian et al., 1996; Lian et al., 2003).

Surprisingly, between athletes with and without a history of knee pain there was only 1 significant difference in spike jump mechanics. Male athletes with knee pain present in the past 7 days (but no pain at the time of testing) demonstrated greater hip excursion from neutral during their takeoff, which translates into greater flexion angles at the hip during

takeoff. This finding has not been previously reported, but it could be related to a jumping style that is more knee and ankle dominant and has incomplete terminal hip extension. Such a pattern could hypothetically place a higher load on the knee extensor mechanism if the hip extensors are not working through a full range of motion.

Our results were not in agreement with previous work by Edwards et al. (2010) who found that male athletes with asymptomatic patellar tendon abnormalities tended to have greater hip flexion at the initial contact point of a stop jump takeoff (Edwards et al., 2010b). These differences are likely because of the vast difference between a stop jump and the asymmetrical, sport-specific volleyball spike jump. Additional differences may be present due to the different populations studied in their study versus ours. While none of their participants had previously experienced pain, nearly half of our athletes who took part in the 2D kinematic analysis had suffered from knee pain in the past.

Among males with a 7-day history of low back pain, the ratio of hip eccentric velocity to knee eccentric velocity tends to be significantly lower than for healthy athletes. This ratio could be modified by either low eccentric hip velocities, or high eccentric knee velocities during the loading phase of the spike approach, and in looking at the results it appears that both cases are true for the males with a history of low back pain. This finding has not been previously observed, but could give insight into an altered pattern of inter-joint jumping coordination for male volleyball players with low back pain.

In contrast to the findings in the low back pain group, male athletes with a history of 7-day shoulder pain exhibited high rates of eccentric hip velocity and an increased ratio of hip to knee eccentric velocities. It is difficult to explain why the hip velocities in the shoulder pain group would be so different from the low back pain group, as it would indicate that the

two types of injury are differently affected by hip mechanics. The relationship between eccentric hip velocity and shoulder pain could be seen as unexpected, however Okada et al. (2011) also reported a significant relationship between shoulder mobility on the right side and overall performance on a battery of tests measuring lower body agility, power and muscle endurance (Okada et al., 2011). Although no mechanisms have been proposed, there appears to be some link between shoulder and hip function, which is directly in line with the theory of regional interdependence. The effect of trunk and core stability as well as spinal mobility should be investigated further, as these factors would have an effect on both the shoulders and the hips.

Inter-rater reliability of the 2D kinematic analysis using Dartfish proved to be excellent, which is encouraging and can pave the way for more studies to be done with larger sample sizes that would be too expensive and time intensive using a lab-based 3D kinematics setup. While the sagittal plane mechanics measured by Dartfish have been found to be very well correlated to the 3D kinematics analyses for lifting tasks (Norris and Olson, 2011), additional research should be conducted to validate this tool for high speed tasks such as the volleyball spike approach.

4.4.4 Relationships Between Fundamental Movement Patterns and Spike Jump Technique

A correlation matrix between 100-point FMS scores (both composite and individual) and spike jump mechanics revealed a number of significant interactions (Table 4.6). As shown in Figure 4.13, a correlate to the In Line Lunge movement pattern was the degree of ankle flexion compared to neutral (excursion) at the time of Second Foot Plant ($R^2 = 0.442$,

p=0.005). The scatterplot shows a trend for males with higher scores on the In Line Lunge test to have more dorsiflexion in the dominant leg as the second foot plants during the takeoff phase. This makes sense as the In Line Lunge requires both mobility and stability at the ankle joint and having a dorsiflexion limitation would reduce both the degree of dorsiflexion available to the ankle during the spike jump as well as the athlete's ability to lower into the full range of a lunge without losing balance. Why this result would show up for only the Second Foot Plant phase of the spike jump is unknown, as is why it is only significant for males. As there is a high degree of inter-subject variability in the ankle flexion measurements, a larger sample size may be useful in elucidating further associations between the In Line Lunge movement and ankle angle throughout the spike jump.

The relationship between Shoulder Mobility and the relative timing of hip and knee flexion (Figure 4.12) is another example of the curious relationship between shoulder function and lower body function, highlighting the theory of regional interdependence. Females with low scores on the Shoulder Mobility test tend to have a greater latency between reaching peak hip flexion and peak knee flexion during the spike jump ($R^2 = 0.560$, p=0.001). This could be a valuable finding as Edwards et al. (2010) reported that male athletes with asymptomatic patellar tendon abnormalities tended to begin hip extension earlier than their healthy counterparts, which would increase the latency between hip and knee peak flexion (Edwards et al., 2010b). While the timing of hip and knee movement was not found to be significantly related to previous injury in this study, the participants in the study by Edwards et al. (2010) were actually all healthy and had no history of overuse injury (Edwards et al., 2010b). Therefore the results presented in Figure 4.12 could be related to an asymptomatic breakdown of the patellar tendon that could progress into patellar

tendinopathy. Certainly further research is warranted to investigate the relationship between shoulder function and lower body mechanics during jumping tasks.

Also for females, the hip angle at initial contact had a tendency to be higher among those with higher Shoulder Mobility scores ($R^2 = 0.478$, $p=0.004$) (Figure 4.13). However, the scatterplot displayed in Figure 4.13 shows that it is mainly 2 athletes with low Shoulder Mobility scores who tend to have very high degrees of hip flexion at IC, while most females have high Shoulder Mobility scores and a wide range of hip flexion at IC. Edwards et al. (2010) identified that male participants with asymptomatic patellar tendon abnormalities tended to have greater hip flexion at IC, indicating that this may be a high risk pattern that could cause microtrauma in the patellar tendon (Edwards et al., 2010b).

4.4.5 Limitations

A major limitation in this study turned out to be the current health of the volleyball players at the time of testing. At mid-season when the testing was conducted, nearly 80% of all participants reported pain during the previous 7 days. With such a high prevalence of pain, the utility of the Functional Movement Screen to detect true measures of fundamental movement was somewhat compromised. The FMS is designed only as a screening tool to identify movement dysfunction, asymmetry or pain among otherwise healthy athletes (Cook et al., 2010). Within the field of fundamental movement assessment, the FMS is simply the first point of contact for athletes to determine if further, more detailed assessment of movement is warranted. As outlined by Cook (2010), athletes who experience pain during the movements that comprise the FMS testing should be referred to a clinician for a thorough assessment (Cook et al., 2010). Therefore, since the FMS is not intended for use with a

population that is already suffering from pain, the results of the testing are not true indications of fundamental movement patterns, but instead a blurred combination of fundamental patterns and patterns that are affected by pain. Use of a more specialized and comprehensive assessment of fundamental movement should be adopted for future studies involving elite volleyball players. Perhaps testing prior to the start of the season would reduce the number of athletes experiencing pain, however between beach volleyball and indoor volleyball very few collegiate volleyball players have true off seasons and it is likely that a high degree of pain is frequently present.

Using a 2D kinematic analysis tool such as Dartfish to analyze a tri-planar movement such as the volleyball spike approach also has many inherent weaknesses. A large source of variation in this study came from the inability to accurately measure and correct for the degree of rotation that each athlete used in his or her spike approach. As a result, the measurements of joint angles that are intended to capture sagittal plane mechanics are not a consistent representation of pure sagittal plane movement, but instead involve an individual level of distortion based on each participant's degree of rotation during the takeoff movement. In an attempt to capture the degree of rotation in each athlete's spike jump, estimates of lead foot external rotation at initial contact and takeoff were recorded for all jumps. Sixty-six percent of participants displayed between 0 and 30 degrees of external rotation as their first foot contacted the ground, with 34% rotating between 30 and 60 degrees. At takeoff, 34% of players retained a 0-30 degree rotation, 28% rotated 30-60 degrees, and 38% of athletes increased their rotation to 60-90 degrees, indicating that a component of rotation was present during the stance phase on the dominant leg. There were

no significant relationships between the degree of rotation during the spike jump and history of overuse pain.

A final limitation of this study is the sample size. With the number of athletes currently experiencing lower body pain at the time of testing, a sample size of only 31 athletes for the spike jump kinematic analysis decreased the power for our statistical measures. After splitting the group of healthy participants into male and female sub-groups, we did not have a sufficient sample size to conduct more advanced statistical measures such as regression analyses. Also, because the intra-subject variability in spike jump mechanics appears to be quite high, a small sample size made it difficult to identify statistically significant relationships since the standard deviation for most measures was quite high. As the 2D Dartfish analysis is much less time consuming than a traditional 3D analysis, future studies should attempt to analyze the spike jump movement in a prospective manor with a much larger cohort.

Chapter 5: Conclusion

The purpose of this chapter is to present the overall conclusions from the thesis study, with specific reference to the literature reviews presented in the introduction. This chapter will also provide practical recommendations based on the results of this study and other impactful studies, and will finish with a description of future research directions.

5.1 Overuse Injuries in Volleyball

The sport of volleyball imposes significant physical and physiological strain on the body, often from a very young age. As a non-contact sport, the incidence of time-loss injuries in volleyball is quite low relative to other sports (Agel et al., 2007; Bahr and Reeser, 2003; Reeser et al., 2006), however the prevalence of pain associated with chronic overuse injuries is remarkably high, particularly in the shoulders, low back and knees. In 2009, Bahr (2009) reported that 64% of elite beach volleyball players experienced pain in the 7 days prior to his interview, while 83% of players had played with pain in the previous 2 months (Bahr, 2009). These findings were supported by the results of this study with 80% of collegiate volleyball players suffering from overuse pain in the 7 days prior to our testing. Similar to the results of previous studies, the males with the highest vertical jump in this study were the most likely to suffer from overuse knee pain. This result was not paralleled for female volleyball players.

Along with an exorbitant rate of pain prevalence, this study added information about non-steroidal anti-inflammatory drug use and medical treatments that were employed as a means of pain control. In our sample of 57 collegiate volleyball players, 60-70% of athletes sought pharmacotherapy or medical treatment regularly, which comes at a great cost to the athletes and/or athletics programs. With such a high rate of overuse injury among collegiate

volleyball players, increased attention should be paid to the primary prevention of these conditions, particularly among male athletes with a high vertical jump. A greater understanding of the aetiology and prevention of overuse shoulder, knee, and low back injuries may help reduce the financial burden associated with frequent medical attention and pharmacotherapy, while prolonging the careers of elite volleyball players.

5.2 The Relationships Between Fundamental Movement Patterns and Overuse Injuries

From the systematic review of the evidence supporting the Functional Movement Screen, it appears that the FMS is a highly reliable tool that has significant ability to predict the occurrence of severe injuries with excellent specificity and moderate sensitivity. FMS scores are also modifiable with training, but it is not yet known if modifying these scores can reduce the risk of injury. Prior to this study, it was unknown if the results of the FMS were in any way related to symptoms of pain or overuse injuries.

Based on the results of this study, it is difficult to provide substantial support for the hypothesis that those collegiate volleyball players with a history of pain in the shoulder, low back, or knees tend to score lower on the Functional Movement Screen than healthy players. No differences in composite 21-point or 100-point scores were evident between healthy and injured groups, and only 2 associations existed between individual FMS test scores and injury history, both related to low back pain. For individuals without a history of low back pain, Active Straight Leg Raise scores tend to be significantly higher ($p=0.022$) than for those athletes with a history of low back pain. This result is in agreement with previous findings connecting hip mobility with low back pain (Mellin, 1988; Sjolie, 2004).

Additionally, volleyball players with a history of low back pain tended to score higher on the Hurdle Step test, which is counterintuitive as the hurdle step requires excellent lumbopelvic control, hip mobility and balance.

A possible explanation for the lack of significant results in the comparison between fundamental movement patterns and overuse injury history lies in the characteristics of collegiate volleyball players. With a 7-day pain prevalence of 80% for both male and female collegiate volleyball players, the ability of the FMS to detect fundamental movement patterns without measuring pain becomes quite limited. As the FMS is designed for use with healthy populations as a means to discover movement dysfunction, asymmetry and the presence of pain, it is ill fitted for the role of fundamental movement assessment among a group of athletes currently experiencing pain. Since the presence of pain on the FMS tests reduces the score of that test to 0 in both the 21-point and 100-point scoring systems, the FMS does not end up giving a true measure of fundamental movement, but rather a combination of fundamental movement and pain.

Future research aimed at investigating fundamental movement patterns among elite volleyball players should employ a different measurement tool, perhaps the clinical counterpart to the FMS, the Selective Functional Movement Assessment (SFMA) (Cook et al., 2010). The SFMA is designed for fundamental movement assessment in populations with known musculoskeletal pain, and as such classifies movements as functional/not painful, functional/painful, dysfunctional/not painful and dysfunctional/painful. This tool would allow a more valid assessment of the fundamental movement patterns of elite volleyball players and could be useful in providing a more concrete answer to the question of how fundamental movement patterns are related to overuse injuries in volleyball.

5.3 The Relationships Between Volleyball Spike Jump Technique and Overuse Injuries

Numerous recent studies have identified the role that spike jump mechanics may play in the aetiology of overuse knee pain (Bisseling et al., 2008; Edwards et al., 2010a; Edwards et al., 2010b). Of particular interest are the mechanics during the takeoff phase, when peak strain is imposed on the patellar tendon (Edwards et al., 2010a; Edwards et al., 2010b). In 2010, Edwards et al. (2010) reported that athletes with an asymptomatic patellar tendon abnormality tended to have greater hip flexion at initial contact of the takeoff phase, and begin hip extension earlier than their healthy counterparts (Edwards et al., 2010b). The authors also noted that this trend was observable using sagittal plane mechanics only. As such, a 2-dimensional kinematic analysis tool may be able to capture the same pattern and provide a more accessible and cost-effective means of detecting high-risk movement patterns during a volleyball spike jump.

Until this study, spike jump kinematics had only been analyzed with a 3-dimensional VICON system (Bisseling et al., 2008; Wagner et al., 2009), but with recent studies validating the use of 2D Dartfish video analysis software for capturing sagittal plane mechanics (Norris and Olson, 2011), a 2D analysis was warranted. Through the use of the Dartfish software for 2D kinematic analysis, this study attempted to determine if there was a relationship between spike jump kinematics and shoulder, low back or knee pain among collegiate volleyball players. In particular, we hypothesized that currently healthy players with a history of knee pain would have an earlier initiation of hip extension than players who have never suffered from knee pain.

While we were not able to provide support for our main hypothesis, significant differences in jump mechanics were present between males with and without shoulder, knee and low back pain. All of these results were in relation to hip mechanics, highlighting the importance of the lumbopelvic complex in the analysis of jumping technique. While our results are not conclusive enough to make firm claims or recommendations based on this study alone, it appears that hip mechanics are an important factor, at least for males, in determining shoulder, low back and knee pain, and future studies should attempt to expand on these results with larger sample sizes and for female volleyball players as well.

The inter-rater reliability of measuring sagittal plane jumping mechanics using Dartfish software was found to be excellent in this study, but due to the inability of the 2D system to capture inter-individual variation in spike approach angle and rotation the accuracy of the measurements generated using this program are unknown. Future studies should look to validate the use of a 2D tool such as Dartfish compared to a gold standard 3D analysis for the volleyball spike jump.

5.4 Interactions Between Fundamental Movement Patterns and Spike Jump Technique

In an attempt to bridge the gap between the study of developmentally based fundamental movement patterns and explosive, sport-specific movement patterns, this study investigated the relationship between FMS scores and measures of sagittal plane spike jump kinematics. One significant association for males and 2 significant associations for females emerged, providing limited support for our hypothesis that fundamental movement patterns would have a strong correlation with spike jump mechanics.

For males, In Line Lunge test scores are related to the degree of ankle dorsiflexion experienced by the dominant leg at the time that the non-dominant leg touches down (second foot plant). Volleyball players with higher scores on the In Line Lunge test, which requires high degrees of dorsiflexion, demonstrated greater degrees of dorsiflexion in the spike jump, an example of a fundamental pattern transferring directly to a sport-specific pattern. However this was the only association found for males, and it is difficult to hypothesize why this would occur for males but not females, and also only during the second foot plant phase of the spike jump and not any other phases such as peak ankle flexion.

For females, the primary associations were between the results on the Shoulder Mobility test and measures of hip angle and coordination throughout the spike jump. These results could be seen as somewhat surprising, but previous work has also found relationships between shoulder mobility and lower body performance testing (Okada et al., 2011). This finding highlights the importance of the regional interdependence model, and while specific conclusions cannot be generated from this study alone, future research should attempt to elucidate the intricacies of the relationship between functional movements at the shoulders and hips.

5.5 Practical Recommendations

Based on the results of this study and in relation to the evidence currently available on the topic of injury prediction/prevention for the sport of volleyball, several practical recommendations are available for sports medicine and strength and conditioning professionals involved with volleyball players.

- *Due to an incredibly high prevalence of pain experienced by elite volleyball players, players, coaches and parents should be educated on the high risk of developing overuse injuries in volleyball and exposed to accessible options for physical training with an injury prevention focus. A particular focus should be placed on hip mobility and stability for developing athletes, as low back pain is directly linked to decreased active hip flexion range.*
- *Athletes with above average vertical jump ability are at greater risk of developing overuse knee pain and as such should be closely monitored. Coaches should also ensure that proper strength and conditioning and injury prevention training are part of their athletes' development.*
- *During pre-season assessments with elite volleyball players, the Functional Movement Screen may be used as a broad screening tool, but for players who are currently experiencing pain a trained clinician should perform a more in depth analysis of fundamental movement patterns. Subsequent medical treatment referrals should be made to not only relieve pain, but also improve function at the beginning of the season, not only when pain forces the athlete to seek medical attention.*
- *Pre-season assessments for volleyball players should include not only an assessment of fundamental movement patterns, but also an analysis of highly demanding sport-specific patterns such as attacking and jumping. General principles of proper kinetic linking and alignment should be applied to training both the spike jump and the attack arm swing, and soft landings should be promoted when landing from a spike or block jump. A particular focus should be placed on hip mechanics during jumping, although specific guidelines are not yet available.*

5.6 Future Directions

In light of the current state of the literature and based on the results of this study, several projects will be necessary to improve the evidence available for sports medicine professionals to effectively treat and prevent overuse injuries in the sport of volleyball.

1) Despite the proposed role that fundamental movement patterns may play in the aetiology of volleyball-related overuse injuries, specific associations have not been described beyond this study. The Functional Movement Screen is not an appropriate tool for use with elite volleyball players during their season as the prevalence of overuse pain is so high, therefore a study involving the Selective Functional Movement Assessment should aim to elucidate the relationships between movement dysfunction and overuse injuries of the shoulder, low back and knees among volleyball players. These associations can pave the way for subsequent studies that investigate the efficacy of corrective exercises guided by movement dysfunction in the management and prevention of overuse injuries.
2) As the presence of pain related to overuse injuries is already extremely high among collegiate volleyball players, studies focused on risk factors for overuse should start with athletes much younger than collegiate age. Studies with youth volleyball players should aim to determine at what age volleyball players tend to develop their first overuse injuries, and prospectively investigate if fundamental and sport-specific movement patterns prior to that age play a role in the aetiology of these conditions.

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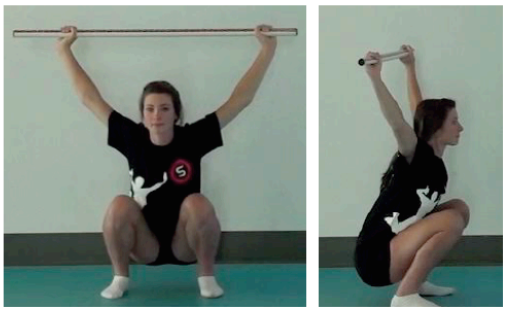
Appendices

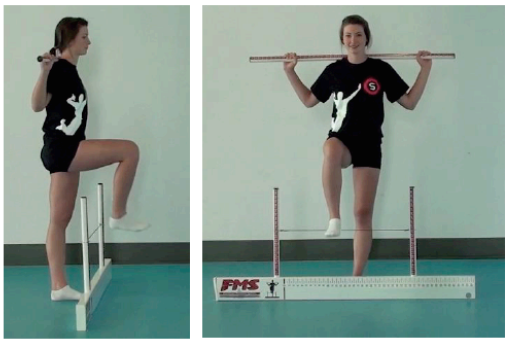
Appendix A - Tests and Scoring Criteria for the Functional Movement Screen

Overhead Deep Squat



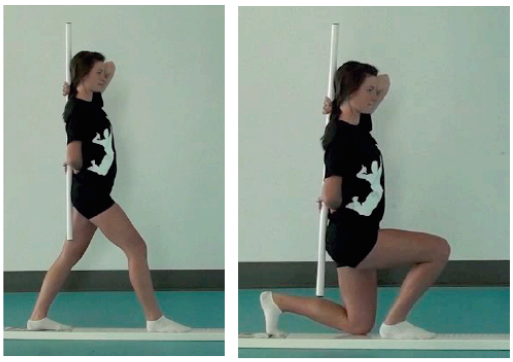
3	2	1
• Upper torso is parallel with tibia or toward vertical • Femur below horizontal • Knees are aligned over feet • Dowel aligned over feet	• 2x6 board required under feet • Upper torso is parallel with tibia or toward vertical • Femur is below horizontal • Knees are aligned over feet • Dowel is aligned over feet	• 2x6 board required under feet • Tibia and upper torso are not parallel • Femur is not below horizontal • Knees are not aligned over feet • Lumbar flexion is noted

Hurdle Step



3	2	1
• Hips, knees and ankles remain aligned in the sagittal plane • Minimal to no movement is noted in lumbar spine • Dowel and string remain parallel	• Alignment is lost between hips, knees, and ankles • Movement is noted in lumbar spine • Dowel and string do not remain parallel	• Contact between foot and string occurs • Loss of balance is noted

In Line Lunge

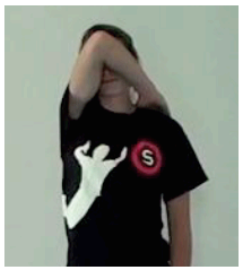


3	2	1
• Dowel contacts remain with lumbar spine extension • No torso movement is noted • Dowel and feet remain in sagittal plane • Knee touches board behind heel of front foot	• Dowel contacts do not remain with lumbar spine extension • Movement is noted in torso • Dowel and feet do not remain in sagittal plane • Knee does not touch behind heel of front foot	• Loss of balance is noted

Shoulder Mobility

3	2	1
• Fists are within one hand length	• Fists are within one and a half hand lengths	• Fists are not within one and a half hand lengths

Shoulder Clearing Test

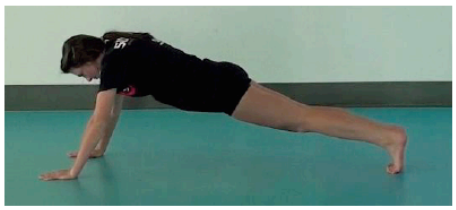


No Pain	Pain
• Clear is passed • No modifications to the Shoulder Mobility score are to be made	• Clear is failed • Shoulder Mobility score is reduced to "0"

Active Straight Leg Raise

3	2	1
• Ankle/Dowel resides between mid-thigh and ASIS	• Ankle/Dowel resides between mid-thigh and mid-patella/joint line	• Ankle/Dowel resides below mid-patella/joint line

Trunk Stability Push Up

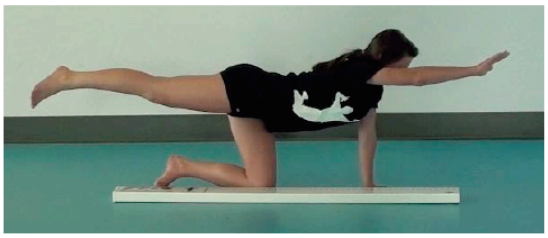


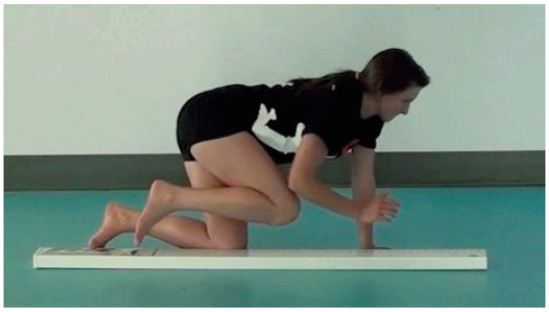
3	2	1
• Males perform one repetition with thumbs aligned with the top of the forehead • Females perform one repetition with thumbs aligned with chin	• Males perform one repetition with thumbs aligned with chin • Females perform one repetition with thumbs aligned with clavicle	• Males are unable to perform one repetition with hands aligned with chin • Females are unable to perform one repetition with thumbs aligned with clavicle

Spinal Extension Clearing Test

No Pain	Pain
• Clear is passed • No modifications to the Trunk Stability Push Up score are to be made	• Clear is failed • Trunk Stability Push Up score is reduced to "0"

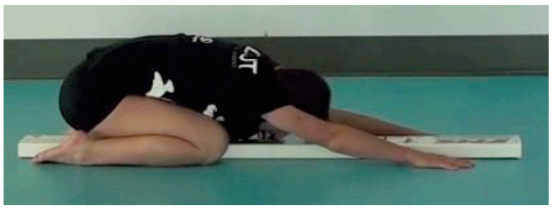
Rotary Stability





3	2	1
• Performs one correct unilateral repetition while keeping spine parallel to surface • Knee and elbow touch	• Performs one correct diagonal repetition while keeping spine parallel to surface • Knee and elbow touch	• Inability to perform diagonal repetitions

Spinal Flexion Clearing Test



No Pain	Pain
• Clear is passed • No modifications to the Rotary Stability score are to be made	• Clear is failed • Rotary Stability score is reduced to "0"

Appendix B - Athlete Information and Injury History Questionnaire

****Administrative purposes only - DO NOT COMPLETE****

Date: Athlete Code (eg/M-UBC-1):

Baseline Athlete Questionnaire:

Functional Movement Patterns and Jump Technique as Injury Predictors Among Collegiate Volleyball Players

Baseline Information

Age:	Gender (circle): Male / Female
Height (m or ft):	Weight (kgs or lbs):
Position:	Dominant Hand (circle): Right / Left

Training History

How many years have you been playing competitive volleyball (club level or higher)? _____

During the previous 12 months, please indicate the average number of ***hours per week*** spent doing each of the following:

Competition:	hours/week
Practice:	hours/week
Strength & Conditioning:	hours/week
Other Sports (please list):	

During your competitive volleyball career, have you ever participated in an injury prevention program or routine? (circle) YES / NO

Time Loss Injury History

Based on your best memory, please describe any injuries that you have experienced during your athletic career, based on the following definition of injury: **"Any injury causing cessation of participation in competition or training for at least 1 day following the onset of injury"**

Injury 1

Location of injury (please circle):

Foot/Ankle	*Lower Leg*	*Knee*	*Upper Leg*	*Hip/Groin*	*Lower Back*
Upper Back	*Neck*	*Head*	*Shoulder*	*Elbow*	*Wrist/Hand*

Diagnosis of injury (please circle):

Concussion	*Contusion*	*Sprain*	*Strain*	*Tendinopathy*	*Dislocation*
Fracture	*Skin Wound*	*Other:*			*Unknown*

During which type of activity did the injury occur? (please circle)

Match	*Warm-Up for a Match*	*Practice*	*Strength & Conditioning*

Other: _____

Please circle whether the injury was an acute injury (sudden onset arising from a particular event) or an overuse injury (with a gradual onset): *Acute / Overuse*

How many days, weeks or months did it take until you were able to fully participate in all activities (matches, practices, strength & conditioning)?_____*Days/Weeks/Months* (circle)

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Injury 2

Location of injury (please circle):

Foot/Ankle	*Lower Leg*	*Knee*	*Upper Leg*	*Hip/Groin*	*Lower Back*
Upper Back	*Neck*	*Head*	*Shoulder*	*Elbow*	*Wrist/Hand*

Diagnosis of injury (please circle):

Concussion	*Contusion*	*Sprain*	*Strain*	*Tendinopathy*	*Dislocation*
Fracture	*Skin Wound*	*Other:*			*Unknown*

During which type of activity did the injury occur? (please circle)

Match	*Warm-Up for a Match*	*Practice*	*Strength & Conditioning*

Other: _____

Please circle whether the injury was an acute injury (sudden onset arising from a particular event) or an overuse injury (with a gradual onset): *Acute / Overuse*

How many days, weeks or months did it take until you were able to fully participate in all activities (matches, practices, strength & conditioning)?_____*Days/Weeks/Months* (circle)

Injury 3

Location of injury (please circle):

Foot/Ankle	*Lower Leg*	*Knee*	*Upper Leg*	*Hip/Groin*	*Lower Back*
Upper Back	*Neck*	*Head*	*Shoulder*	*Elbow*	*Wrist/Hand*

Diagnosis of injury (please circle):

Concussion	*Contusion*	*Sprain*	*Strain*	*Tendinopathy*	*Dislocation*
Fracture	*Skin Wound*	*Other:*			*Unknown*

During which type of activity did the injury occur? (please circle)

Match	*Warm-Up for a Match*	*Practice*	*Strength & Conditioning*

Other: _____

Please circle whether the injury was an acute injury (sudden onset arising from a particular event) or an overuse injury (with a gradual onset): *Acute / Overuse*

How many days, weeks or months did it take until you were able to fully participate in all activities (matches, practices, strength & conditioning)?_____*Days/Weeks/Months* (circle)

Injury 4

Location of injury (please circle):

Foot/Ankle	*Lower Leg*	*Knee*	*Upper Leg*	*Hip/Groin*	*Lower Back*
Upper Back	*Neck*	*Head*	*Shoulder*	*Elbow*	*Wrist/Hand*

Diagnosis of injury (please circle):

Concussion	*Contusion*	*Sprain*	*Strain*	*Tendinopathy*	*Dislocation*
Fracture	*Skin Wound*	*Other:*			*Unknown*

During which type of activity did the injury occur? (please circle)

Match	*Warm-Up for a Match*	*Practice*	*Strength & Conditioning*

Other: _____

Please circle whether the injury was an acute injury (sudden onset arising from a particular event) or an overuse injury (with a gradual onset): *Acute / Overuse*

How many days, weeks or months did it take until you were able to fully participate in all activities (matches, practices, strength & conditioning)?_____*Days/Weeks/Months* (circle)

Pain History

Shoulder

In the past 7 days, have you experienced pain, ache or soreness in the dominant shoulder, with OR without radiating pain to the upper extremity? YES / NO

In the past 12 months, have you experienced pain, ache or soreness in the dominant shoulder, with OR without radiating pain to the upper extremity? YES / NO

In the past 12 months, have you taken pain killers or anti-inflammatory medication because of shoulder pain? YES / NO

In the past 12 months, have you sought medical treatment (physio, chiro, massage, etc.) for management of shoulder pain? YES / NO

In the past 12 months, have you missed training or a competition due to shoulder pain? YES / NO

If you have shoulder pain while playing, how intense is the pain usually? Please indicate by placing X on the line below:

No Pain _____ Worst pain imaginable

If you have shoulder pain while *NOT* playing volleyball, how intense is the pain usually? Please indicate by placing X on the line below:

No Pain _____ Worst pain imaginable

Low Back

In the past 7 days, have you experienced pain, ache or soreness in the low back, with OR without radiating pain to the gluteal area or the lower extremity? YES / NO

In the past 12 months, have you experienced pain, ache or soreness in the low back, with OR without radiating pain to the gluteal area or the lower extremity? YES / NO

In the past 12 months, have you taken pain killers or anti-inflammatory medication because of low back pain? YES / NO

In the past 12 months, have you sought medical treatment (physio, chiro, massage, etc.) for management of low back pain? YES / NO

In the past 12 months, have you missed training or a competition due to low back pain? YES / NO

If you have low back pain while playing, how intense is the pain usually? Please indicate by placing X on the line below:

No Pain _____ Worst pain imaginable

If you have low back pain while *NOT* playing volleyball, how intense is the pain usually? Please indicate by placing X on the line below:

No Pain _____ Worst pain imaginable

Knee

In the past 7 days, have you experienced pain, ache or soreness in the quadriceps and/or patellar tendon of either knee? YES / NO

In the past 12 months, have you experienced pain, ache or soreness in the quadriceps and/or patellar tendon of either knee? YES / NO

In the past 12 months, have you taken pain killers or anti-inflammatory medication because of knee pain? YES / NO

In the past 12 months, have you sought medical treatment (physio, chiro, massage, etc.) for management of knee pain? YES / NO

In the past 12 months, have you missed training or a competition due to knee pain? YES / NO

If you have knee pain while playing, how intense is the pain usually? Please indicate by placing X on the line below:

No Pain _____ Worst pain imaginable

If you have knee pain while *NOT* playing volleyball, how intense is the pain usually? Please indicate by placing X on the line below:

No Pain _____ Worst pain imaginable

Thank You!

Appendix C – 100 Point Scoring System for the Functional Movement Screen

1. Deep Squat (Test without board first, if all test criteria are not met, use board and score as indicated below) 18

Upper torso is parallel with tibia or toward vertical	6	0
Knees are aligned over feet	8	0
Dowel aligned over feet	4	0

With Board

Femur below horizontal	2	0
Upper torso is parallel with tibia or toward vertical	2	0
Knees are aligned over feet	2	0
Dowel aligned over feet	2	0

If subject is unable to perform movement with heels on board, subject receives a total score of 1 for the squat test

2. Hurdle Step 18 (named according to moving leg)

Right

Foot clears cord (does not touch)	5	0
Hips, knees and ankles remain aligned in the sagittal plane	2	0
Minimal to no movement is noted in lumbar spine	1	0
Dowel and hurdle remain parallel	1	0

Left

Foot clears cord (does not touch)	5	0
Hips, knees and ankles remain aligned in the sagittal plane	2	0
Minimal to no movement is noted in lumbar spine	1	0
Dowel and hurdle remain parallel	1	0

3. Lunge 20 (named for forward leg)

Right

Knee touches behind heel	2	0
Dowel and feet remain in sagittal plane	2	0
Dowel contacts maintained	2	0
Dowel remains vertical	2	0
No torso movement noted	2	0

Left

Knee touches behind heel	2	0
Dowel and feet remain in sagittal plane	2	0
Dowel contacts maintained	2	0
Dowel remains vertical	2	0
No torso movement noted	2	0

4. Shoulder 8 (named for top hand)

Right

Fists are within one hand length	4
Fists are within one-and-a-half hand lengths	2
Fists are not within one and half hand lengths	0
Active impingement	+/-

Left

Fists are within one hand length	4
Fists are within one-and-a-half hand lengths	2
Fists are not within one and half hand lengths	0
Active impingement	+/-

5. Active Straight Leg Raise (Knee straight, ankle neutral, opposite knee on board) 12

Right

Malleolus resides between mid-thigh and ASIS	6
Malleolus resides between mid-thigh and joint line	2
Malleolus resides below joint line	0

Left

Malleolus resides between mid-thigh and ASIS	6
Malleolus resides between mid-thigh and joint line	2
Malleolus resides below joint line	0

6. Push-up (Lumbar neutral) 12

Males

Thumbs at forehead level	12
Thumbs at chin level	5
Failure at chin level	0
Extension clearing	+/-

Females

Thumbs at chin level	12
Thumbs at clavicle	5
Failure at clavicle level	0
Extension clearing	+/-

7. Rotary Stability (Lumbar neutral) 12

Right

Unilateral repetition	6
Diagonal repetition	2
Failure of diagonal repetition	0

Left

Unilateral repetition	6
Diagonal repetition	2
Failure of diagonal repetition	0
Flexion clearing	+/-