Preseason Functional Movement Screen™ predicts risk of time-loss injury in experienced male rugby union athletes

By

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B.Sc., University of Victoria, 2012

A thesis submitted in partial fulfillment of the requirements for the degree of

MASTER OF SCIENCE

in the School of Exercise Science, Physical and Health Education

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Supervisory Committee:

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ABSTRACT

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OBJECTIVES: To determine the relationship between composite FMS score and the risk of time-loss injury in experienced male rugby union athletes, and in addition, to determine the relationship between FMS-determined bilateral movement asymmetries and the risk of time-loss injury in these athletes.

DESIGN: Analytical cohort study.

SETTING: Rugby union on-field training and competition, and athletic therapy rooms at the University of Victoria or at Rugby Canada's Center of Excellence, Victoria BC.

PARTICIPANTS: 76 experienced, male rugby union athletes (mean age 21.6±2.7 years).

MEASUREMENTS: Participants completed surveys pertaining to demographic, anthropometric, injury history, and involvement in rugby union information. The main outcome measures were time-loss injury incidence and FMS scores.

RESULTS: Odds ratio analyses revealed that when compared to those scoring at least 14.5, players with FMS scores below 14.5 were 10.42 times (95%CI: 1.28-84.75, Fisher's exact test, one-tailed, p=0.007) more likely to have sustained time-loss injury (+LR=7.08, -LR=0.72*,* specificity=0.95, sensitivity=0.35) in Season One and 4.97 times (95%CI: 1.02-24.19, Fisher's exact test, one-tailed, p=0.029) more likely in Season Two (+LR=3.56, -LR=0.71 specificity=0.90, sensitivity=0.36). Participants scoring below

15.5 on the FMS were also at significantly greater risk of injury, exhibiting a risk of injury 3.37 times (95%CI: 1.12-10.14, Fisher's exact test, one-tailed, p=0.027) greater than players with higher FMS scores in Season Two (+LR=1.84, -LR=0.55, specificity=0.65, sensitivity=0.64), but not in Season One. The presence of bilateral asymmetries was not associated with increased likelihood of time-loss injury.

<u>CONCLUSIONS:</u> Experienced male rugby union athletes with preseason FMS scores below 14.5 are 5-10 times more likely to sustain one or more time-loss injuries in a competitive season when compared to athletes with FMS scores of at least 14.5. The quality of fundamental movement, as assessed by the FMS, is predictive of time-loss injury risk in experienced rugby union athletes and should be considered an important preseason player assessment tool.

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Acknowledgements

I would like to express my utmost gratitude to my graduate supervisor and mentor, Dr. Catherine Gaul, for her consistent support, patience and tolerance throughout this chapter of my academic journey. Working with, and learning from, such an experienced professional was an absolute pleasure. The generosity she has demonstrated in lending her time and expertise over the past 30 months is something I cannot possibly repay her for.

Thanks to Dr. Steve Martin, a practitioner and active promoter of player welfare in Canadian national team rugby, for his enthusiastic support of our research project.

Thanks to Danielle Mah and Traci Vander Byl for their incredible support and cooperation that made this research project possible.

Thank you to the athletes, coaches, and team medical staff for taking the efforts to make this research project become a reality. The degree and quality of participation was phenomenal; I could not have asked for a more willing and supportive group of people.

Dedication

This project is dedicated to my extremely supportive parents, Candace and Neil, my caring and thoughtful sister, Andrea, and my loving girlfriend, Erin. As well, this work is dedicated to the well-being of rugby union athletes, as the global rugby community is ever-striving to make the game more safe. This research project is a small token of gratitude for a game that has created so much meaning in my life.

Chapter 1: Introduction

Rugby union has one of the highest reported injury rates in sport (Brooks et al., 2005). Professional rugby players are reported to sustain 91 injuries per 1000 player-hours, a greater incidence of injury than that of ice hockey or soccer (Brooks et al., 2005). As well, professional rugby union injuries result in a greater number of missed matches than do collegiate American football injuries (Brooks et al., 2005). The incidence of injury in club-level rugby union is similar at 93 injuries per 1000-player hours (Chalmers et al., 2012). Because of the high incidence of injury, it is vital to identify factors that contribute to injury risk in order to develop effective injury prevention strategies. A number of risk factors have been prospectively identified in both club- and elite-level rugby union, including body mass, BMI, previous injury, recent training volume, firmness of playing surface, weather conditions, and age (Brooks et al, 2005; Brooks & Kemp, 2008; Brooks & Kemp, 2010; Chalmers et al., 2012; Quarrie, 2001). Prolonged high-intensity intermittent running ability, chin-up strength, speed and aerobic power have been identified as risk factors for injury in rugby league, a sport with similar physical demands to rugby union (Gabbett & Domrow, 2005; Gabbett, Ullah and Finch, 2012)

Injury prevention in sport focuses on identifying imbalances in strength, flexibility, biomechanics, as well as recognizing the anthropometric and demographic factors that contribute to injury (Gribble et al., 2013). Although the respective impacts of the aforementioned risk factors have been evaluated independently, the multifactorial nature of injury risk warrants the collective evaluation, or interplay, of multiple risk factors in relationship to injury (Kiesel, Plisky & Voight, 2007; Gribble et al., 2013).

In recent years, rehabilitation strategies in sport have opted to focus on more comprehensive evaluations of kinetic chain imbalances, rather than using the traditional method of targeting isolated muscles (Gribble et al., 2013). For example, the regional-interdependence examination model was built on the concept that within the context of musculoskeletal problems, the chief complaint of any given patient may be associated with impairments in a remote anatomical location (Wainner et al., 2007). An example of the regional-interdependence examination model is a physiotherapist treating the thoracic spine of a patient that is experiencing neck pain (Wainner et al., 2007). On the basis of regional interdependence, researchers are currently investigating comprehensive functional movement pattern examinations as a means to predict injury risk (Gribble et al., 2013).

The Functional Movement Screen™ (FMS) is a noninvasive, inexpensive, quick and easily administered tool that assesses multiple functional movement patterns of an individual in order to identify movement limitations and asymmetries, which are suspected to influence risk of injury in sport (Cook, Burton & Hoogenboom, 2006; Kiesel, Plisky & Voight, 2007; Perry & Koehle, 2013). In the context of the FMS, a fundamental movement pattern is a basic movement designed to provide simultaneous observable demonstration of muscular strength, balance, trunk and core stability, coordination, motor control, flexibility, range of motion, and proximal-to-distal kinetic linking (Cook, Burton & Hoogenboom, 2006; Kiesel, Plisky & Voight, 2007; Perry & Koehle, 2013). Through exposing right and left side imbalances (bilateral movement asymmetries) as well as impairments in stability and mobility, the FMS aims to identify programmed altered movement patterns in the kinetic chain (Cook, Burton &

Hoogenboom, 2006). Programmed altered movement patterns arise from the use of compensatory strategies in physical activity, which are in many cases the result of previous injury and pain (Cook, Burton & Hoogenboom, 2006). Programmed altered movement patterns may contribute to further impairments in mobility and stability, which, along with previous injury, are known to be risk factors for injury in sport (Cook, Burton & Hoogenboom, 2006).

The FMS is comprised of seven functional movements, each of which is scored on a scale of 0-3 (Cook, Burton & Hoogenboom, 2006). The effectiveness of the FMS as a predictor of injury risk has previously been demonstrated in a number of physically active populations, such as professional American football players (Kiesel, Plisky & Voight, 2007), NCAA athletes (Chorba et al., 2010; Lehr et al., 2013), recreational athletes (Shoejaedin et al., 2013), Marine Corps officer candidates (Lisman et al., 2013; O'Connor et al., 2011) and firefighters (Butler et al., 2013).

Although similar in nature to other sports for which FMS has been studied, the ability of FMS to predict injury risk in rugby players has yet to be well explored. This study is one of the first to investigate the effectiveness of the FMS as a predictor of injury risk in rugby union players.

1.1 Purpose Statement

The purpose of this study was to determine the relationship between composite FMS score and the risk of time-loss injury in experienced male rugby union athletes. In addition, this study aimed to determine the relationship between FMS-determined bilateral movement asymmetries and the risk of time-loss injury in these athletes.

1.2 Research Questions

The following research questions were addressed in this study:

1) What is the relationship between FMS composite score and the risk of time-loss injury in experienced male rugby union athletes?

2) What is the relationship between bilateral movement asymmetries, as measured by the FMS, and the risk of time-loss injury in male experienced rugby union athletes?

It was hypothesized that low FMS scores and the presence of bilateral movement asymmetries would be associated with greater risk of time-loss injury among male experienced rugby union athletes.

1.3 Assumptions

1) Baseline and follow-up questionnaires were answered honestly.

2) The FMS test is reliable and accurate and that the tester accuracy was high and consistent.

3) All rugby training and match-play injuries experienced by the participants during the period of the study were reported.

4) All injury data were recorded completely and accurately.

1.4 Limitations

1) Recording of injury data, and its accuracy, was limited by quality of communication between participants, team trainers, athletic therapists, physiotherapists, medical doctors, and the researcher.

2) Participants may have had varied experience performing the FMS and although there is little research that supports this, the effect of practice may have been a confounding factor.

3) Convenient nonrandom recruitment of participants could have introduced a selection bias.

1.5 Delimitations

1) Only individuals who competed in the 2013 Vancouver Island Elite and 1st Division Leagues and the 2014 Canadian Direct Insurance Premier and 1st Division Leagues were invited to participate.

2) Participants were living in the Victoria area.

3) Participants were within the ages of 19-30 years.

4) All participants were able to speak English in order to effectively communicate with team medical staff.

1.6 Operational Definitions

1) Injury: "Any physical complaint, which was caused by a transfer of energy that exceeded the body's ability to maintain its structural and/or functional integrity, that was sustained by a player during a rugby match or rugby training, irrespective of the need for medical attention or time-loss from rugby activities" (Fuller et al., 2007, p.329).

2) *Time-loss Injury:* "an injury that results in a player being unable to take a full part in future rugby training or match play" (Fuller et al., 2007. p.329).

3) *Full-fitness:* “Able to take a full part in training activities and available for match selection” (Brooks & Kemp, 2011, p.765).

4) *Injury Severity:* The number of days between the time of the injury and the time at which a player returns to full-fitness (Brooks & Kemp, 2011).

5) *Functional Movement Patterns:* Fundamental, comprehensive movement patterns that, in order to be performed properly, require adequate muscular strength and symmetry, balance, trunk and core stability, coordination, motor control, flexibility, range of motion, and proximal-to-distal kinetic linking (Cook, Burton & Hoogenboom, 2006; Kiesel, Plisky & Voight, 2007; Perry & Koehle, 2013). Significant limitations in any of these requirements result in altered, or compensatory, movement patterns (Cook, Burton and Hoogenboom, 2006).

6) *Functional Movement Screen™:* An evaluation tool that aims to assess the fundamental movement patterns of an individual through providing observable performance of basic locomotor, manipulative, and stabilizing movements (Cook, Burton & Hoogenboom, 2006).

Chapter 2: Review of Literature

2.1 The Incidence of Injury in Rugby Union

Since its birth in 1895, rugby union has become one of the most popular team sports globally, with 6.6 million participants in 119 countries registered with the International Rugby Board (IRB) (Brooks & Kemp, 2008; IRB, 2014). This number is expected to grow, as one of the major goals of the IRB's Strategic Plan for 2010-2020 is to have 205 international unions in membership by 2020 (IRB, 2014. Fueling further growth of the game is the upcoming Olympic debut of rugby union in Rio de Janeiro, 2016. With 1.5 million female players and a reported age range of 6-60 years, rugby union is popular for both men and women of all ages (Brooks & Kemp, 2008; IRB, 2014).

With reported injury rates of 91 injuries per 1000 player-hours at the professional level and 93 injuries per 1000 player-hours at the club-level, rugby union has one of the highest incidences of time-loss injury, exceeding that of ice hockey, soccer, and collegiate American football (Brooks et al., 2005; Chalmers et al., 2012). In elite rugby union, the total impact of training and match-play injury is that 23% of a professional club's squad will not be physically fit and available for selection at any given time during the season (Brooks et al., 2005). This translates to roughly 9 players per team occupying the injured reserve on any given game day (Brooks et al., 2005).

The high incidence of injury in professional and club-level rugby union can be attributed to the body contact and collisions that are integral to the game- characterized by tackles, rucks, mauls and scrums- as well as the lack of protective equipment that can be worn within the rules of the game (Brooks and Kemp, 2008). Since the dawn of professionalism in rugby union in 1995, the anthropometric profile of rugby union athletes has evolved- emphasizing player skill, speed, power, strength, intensity, fitness and body mass (Brooks & Kemp, 2008). This has resulted in more forceful collisions between larger players, as well as an emphasis on the speed of the game and the duration that the ball is in play, posing greater opportunity for players to sustain injury. Brooks and Kemp (2008) recognized that the ball-in-play time per match increased by 25% between the 1995 and 2003 Rugby World Cup events. A comparison in Bledisloe Cup international test matches revealed that the number of tackles and rucks per game increased by 51% and 63%, respectively, between 1972 and 2004 (Brooks and Kemp, 2008). An injuries study on the Australian national rugby union team reported that the incidence of injury in rugby union before (1994-1995) and after (1996-2000) the beginning of the professional era were 47 and 74 injuries per 1000 player-hours, respectively, indicating a 157% increase (Bathgate et al., 2002).

Although the laws of rugby union are constantly updated to reduce the incidence of injury, such as the banning of the “tip tackle” (where the tackled player is driven into the ground head-first) in an attempt to reduce the incidence of catastrophic injury, a number of laws have been recently employed that may actually promote injury. One such law, employed in 2007, allows quick line-outs (a method of continuing the game after the ball or player in possession of the ball travels outside the sideline) to be thrown backwards to another player without a stoppage in play. This serves to increase ball-in-play time per match and subsequently provides more opportunity for injury. Another law introduced in 2007 requires the defensive team to stand behind an offside line 5 meters behind the scrum, creating a larger run-up between opposing players as they race for the gain-line and thereby promoting larger collisions.

The safety equipment that may legally be worn in rugby union is typically limited to mouthguards; athletic tape; grease; and padded headgear, shoulder pads, and chest pads that are no thicker than 1 cm when uncompressed and no denser than 45 kg per cubic meter (Brooks & Kemp, 2008; Kaplan et al., 2008). In fact, field and laboratory research investigating rugby union safety equipment revealed that padded headgear does not reduce the incidence of concussion and shoulder pads do not reduce the incidence of shoulder injury (Brooks & Kemp, 2008). According to Brooks and Kemp (2008), most IRB-approved headgear does not meet the standard impact-testing criteria that would typically prevent a sport-related concussion.

A recent consensus statement established by the IRB defines an injury as “any physical complaint, which was caused by a transfer of energy that exceeded the body’s ability to maintain its structural and/or functional integrity, that was sustained by a player during a rugby match or rugby training, irrespective of the need for medical attention or time-loss from rugby activities” (Fuller et al., 2007, p.329). A time-loss injury is defined as any “injury that results in a player being unable to take a full part in future rugby training or match play” (Fuller et al., 2007, p.329).

A recent review of epidemiological studies on professional and amateur rugby union players revealed that match injuries typically account for 80-90% of all injuries; however, it should be noted that it is more difficult for researchers to gather accurate injury data and exposure data- especially at the amateur level- for training injuries when compared to match injuries (Brooks & Kemp, 2008). Through epidemiological research, the lower limb was determined to be the most common site of injury in rugby union, accounting for 41-55% of all injuries, with the knee, thigh and ankle being the most frequently injured lower limb sites (Brooks & Kemp, 2008). In addition, lower limb injuries were revealed to be disproportionately severe, especially those affecting the knee joint (Brooks & Kemp, 2008). Injuries to the anterior cruciate ligament and medial collateral ligament proved to be the most severe knee injuries, accounting for the greatest proportion of time-loss (Brooks & Kemp, 2008). Hematomas and hamstring strains were the most common injuries to the thigh, while lateral ankle ligament injury was the most common injury to the ankle (Brooks & Kemp, 2008). The head and neck were frequently the next most common reported sites of injury in epidemiological studies, ranging from 12-33% of all injuries, with concussions and lacerations being the most common injury types (Brooks & Kemp, 2008). Upper limb injuries contributed 15-24% of all injuries and appeared to be disproportionately severe, with rotator cuff and acromioclavicular injuries being most frequently reported (Brooks & Kemp, 2008).

In reviewing epidemiological studies involving large cohorts of players, there were negligible difference in the incidence of injury between forwards and backs, while the individual position with the highest incidence of injury has widely varied (Brooks & Kemp, 2008).

An epidemiological study by Brooks et al. (2005) on 546 English Premiership rugby union players over the course of two seasons revealed that the tackle was the area responsible for the greatest number of injuries in professional rugby. This is in agreement with other epidemiological studies, which report that the tackle area accounts for approximately half of all match injuries in rugby union (Brooks & Kemp, 2008). Brooks et al. (2005) reported that head-on tackles caused the most injuries to players while tackling, while side-on tackles cause most injuries to players while being tackled. The most common injuries sustained when tackling head-on were concussion and cervical nerve root injuries, though shoulder dislocation/instability caused the greatest number of days of absent. Thigh hematoma was the most common injury sustained while being tackled side-on; however, anterior cruciate ligament injuries caused the greatest number of days absent for forwards and medial collateral ligament injuries caused the greatest number of days absent for backs. Injuries incurred via contact mechanisms- including tackles, rucks, mauls, scrums, and collisions- was responsible for 72% of all injuries, while only 6% of all injuries were sustained during an act of foul play. This demonstrates the inherent danger involved within the rules of the sport.

Brooks et al. (2005) demonstrated a match-play injury incidence of 91 injuries per 1000 player-hours at the professional level, with injuries causing an average time-loss of 18 days. Recurrences accounted for 18% of all injuries and were on average more severe (27 days) when compared to new injuries (16 days), indicating a major risk factor for rugby union athletes. Among the most common injuries were thigh hematomas, hamstring strains, concussions, calf strains and lateral ankle ligament strains, while the most severe injury was anterior cruciate ligament injury (258 days). The injuries causing the greatest total number of days absent among forwards and backs, respectively, were anterior cruciate ligament injuries and hamstring injuries.

Chalmers et al. (2012) prospectively investigated the impact of a number of potential risk factors for injury in 704 male, amateur club-level rugby players over the course of one season. Similar to the results of Brooks et al. (2005), 93 injuries/1000 player-hours were observed during match-play, indicating that similar injury rates occur in both club-level and professional rugby union. Despite this finding, several epidemiological studies have reported an increase in the incidence of injury as level of play increases (Brooks & Kemp, 2008). Brooks and Kemp (2008), in reviewing the recent trends in rugby union injuries, reported match-play injury incidence ranges of 15-74 injuries/1000 player hours at the senior amateur level and 68-218 injuries/1000 player hours at the professional level. The broad ranges of injury incidences reported within each cohort are largely due to variations in the injury definition used in each investigation. Chalmers et al. (2012) reported that the most common types of injury at the club-level were sprains/strains (42%) and contusions (23%), while the most common injury sites were the lower limb (35%), the face/head/neck (30%) and the torso (23%). Those at an elevated risk of injury included athletes of Pacific Island descent, those with BMI above 25 kg/m^2, those participating in over 40 hours of strenuous activity per week, and those that were playing while nursing an injury that did not prevent their participation in the sport. An increasing risk of injury with age was also observed. The results from this investigation suggest the need for special considerations to be taken for those at an elevated risk, such as reducing weekly hours of strenuous activity and ensuring that players are completely rehabilitated from previous injury as return-to-play criteria.

A number of other risk factors have been prospectively identified through epidemiological investigations in club- and elite-level rugby union as well as rugby league, a sport with similar physical demands to rugby union. Intrinsic risk factors include previous injury, ligament laxity, lumbo-pelvic stability, physique, body mass, body mass index, previous injury, recent training volume, cigarette smoking status, years of rugby experience, stress, aerobic and anaerobic performance, chin-up strength, push-up performance, speed, aerobic power, high-intensity intermittent running ability and position, while extrinsic risk factors include level of play, firmness of playing surface, ground and weather conditions, time of season and being the victim of foul play (Brooks et al, 2005; Brooks & Kemp, 2008; Brooks & Kemp, 2010; Chalmers et al., 2012; Gabbett & Domrow, 2005; Gabbett, Ullah and Finch, 2012; Quarrie, 2001). Rugby union epidemiological research to date has provided an abundance of data, particularly in the identification of risk factors for injury, serving as a foundation for the development of effective preventative and therapeutic interventions (Brooks & Kemp, 2008). This has been demonstrated through rugby union injury-specific investigations on injury-prone sites, such as the head, spine, shoulder, hamstring, knee and ankle (Brooks & Kemp, 2008).

The consequences of injury in rugby union can be devastating, with 1 in 10,000 rugby players per season reported to sustain a catastrophic non-fatal spinal injury, defined as a brain or spinal cord injury that results in severe functional disability (Brooks & Kemp, 2008). The most commonly reported catastrophic spinal injury is fracture dislocation at C4-C5 or C5-C6 due to hyperflexion of the cervical spine, in very rare cases causing death (Quarrie, Cantu & Chalmers, 2002). The vast majority of these injuries have been reported to occur within the tackle or scrum areas of the game, with hookers and props being the most at-risk positions primarily due to their particular role in the scrum (Quarrie, Cantu & Chalmers, 2002).

The long-term consequences of injury in rugby union are not well documented, indicating a gap in the current research (Brooks & Kemp, 2008). Because the vast majority of rugby injuries involve muscles, ligaments and joints, subsequent neurodegenerative disease may pose future health issues for rugby union players (Lee et al., 2001). Lee et al. (2001) conducted an investigation on the consequences of rugby injuries sustained four years prior. Participants involved 911 amateur rugby players that participated in an original epidemiological study throughout the course of the 1993-1994 season (Lee & Garraway, 1996). Results indicated that 26% of the retired players had done so because of rugby injury, with sprains, strains and dislocations being the most common types of injury (80%), and the knee (35%), back (14%) and shoulder (9%) being the most common sites of injury. This was the largest category of retired players (from 566 categories, each representing a unique reason to retire), greater than work (25%) and family (10%) commitments. Of the injured players, 35% reported temporary or significant negative effects on education, employment, family life, or health and general fitness from their injuries.

An effective injury prevention strategy in rugby union is to ameliorate intrinsic modifiable risk factors for injury. Of particular importance is to reduce the likelihood of common, severe injuries, as the impact of injuries is best indicated by the product of injury incidence and severity (Brooks & Kemp, 2008). One of the strongest predictors of injury in rugby union and other sports is previous injury, as it consistently reported in injuries studies (Brooks & Kemp, 2008; Chalmers et al., 2012; Kiesel, Butler & Plisky, 2014; Quarrie et al., 2001; Van Mechelen et al., 1996). Although injury history cannot be modified, the consistent reporting of injury history as a risk factor in injury research can be largely explained by the lingering effects of injury, such as changes in motor control (Kiesel, Butler & Plisky, 2014). Changes in motor control, such as movement limitations and asymmetries can be improved upon or overcome with proper rehabilitation in many cases, indicating their modifiable nature.

A potential modifiable risk factor for injury is the quality of functional movement. Although a gold standard for measuring quality of functional movement does not exist, a number of potential risk factors for injury in sport can be assessed simultaneously through the analysis of basic movements (Cook, Burton & Hoogenboom, 2006). Some of these potential risk factors include: trunk and core strength and stability, muscular strength, balance, motor control, range of motion, neuromuscular coordination, asymmetry in movement, static and dynamic flexibility and the presence of programmed altered or compensatory movement patterns (Perry & Koehle, 2013). The FMS also has the ability to identify programmed altered movement patterns that perpetuate from movement limitations associated with pain (Cook, Burton & Hoogenboom, 2006; Kiesel, Butler & Plisky, 2014). This assesses injury-related alterations in motor control, a potentially modifiable risk factor. Additionally, left and right side movement tasks involved in the FMS can identify bilateral movement asymmetries, a form of programmed altered movement pattern that poses a potential risk factor for injury in sport through its association with previous injury and pain (Kiesel, Butler & Plisky, 2014). Further investigation on this subject may lead to improvements in injury prevention strategies within the sport of rugby union, as the quality of fundamental movement patterns poses a potential risk factor that is modifiable in nature itself.

In addition to assessing injury risk, fundamental movement quality may translate to on-field performance in some sports (Cook, Burton & Hoogenboom, 2006). In fact, a recent study by Chapman, Laymon and Arnold (2013) revealed a significant relationship between functional movement quality, as measured by the FMS, and longitudinal competitive performance outcomes in elite track and field athletes.

The high incidence of injury in rugby union demonstrates the need for injury prevention strategies. Though a number of risk factors for injury have been identified in rugby union investigations, incorporating pre-screening tools that simultaneously assess multiple risk factors to pre-screening protocols may be more useful in assessing the risk of injury in rugby athletes.

2.2 The Functional Movement Screen™

2.2.1 Development of the Functional Movement Screen™

The traditional sports medicine model focuses on specific isolated, objective testing for joints and muscles, rather than general functional movement, as rehabilitation professionals often perform specific sports performance and skill assessments in the absence of comprehensive functional movement assessments (Cook, Burton & Hoogenboom, 2006). Traditionally, pre-participation screening exams for athletes involve a pre-participation medical examination followed by specific performance assessments that commonly include: sit-ups, push-ups, endurance runs, sprints, and agility activities (ACSM, 2000; Cook, Burton & Hoogenboom, 2006). These performance assessments are objective in nature and do not take into consideration the quality of human movement, which plays a role in the risk of athletic injury (Cook, Burton & Hoogenboom, 2006). Without the assessment of common fundamental aspects of human movement, it seems that the traditional pre-participation screening model does not provide enough baseline information to accurately determine whether or not an individual is prepared for activity (Cook, Burton & Hoogenboom, 2006. Since pre-participation and performance screenings have the common goal of decreasing injuries, enhancing performance, and improving quality of life, it is necessary that fundamental movement assessments be conducted alongside medical exams and specific performance assessments (Cook, Burton & Hoogenboom, 2006)

The FMS was developed by Cook, Burton and Hoogenboom (2006) in an attempt to create a standardized pre-screening tool that provided observable analysis of an individual's functional movements. The FMS was designed to be quick, noninvasive, inexpensive and easily administered (Perry & Koehle, 2013). In utilizing the FMS, administrators can simultaneously assess an individual's muscular strength, balance, trunk and core stability, coordination, motor control, flexibility, range of motion and proximal-to-distal kinetic linking (Cook, Burton & Hoogenboom, 2006; Kiesel, Plisky & Voight, 2007; Perry & Koehle, 2013). As well, the FMS exposes the use of programmed altered or compensatory movement patterns and the presence of bilateral movement asymmetries, which have the potential to lead to further mobility and stability imbalances (Cook, Burton & Hoogenboom, 2006).

In the development of a fundamental movement assessment tool, Cook, Burton and Hoogenboom (2006) aimed to bridge the gap in the traditional pre-participation and performance screening model. The development of the FMS revolved around the idea that common fundamental aspects of human movement are inherently involved in athletic activities and applications, and the quality of fundamental movement patterns affects performance and the injury risk. Descriptions and scoring criteria of the seven FMS tests can be found in Appendix A.

2.2.2 Rationale for the Individual Functional Movement Screen™ Tests

The FMS is comprised of seven functional movement patterns: the deep squat, hurdle step, in-line lunge, shoulder mobility, active straight leg raise, trunk stability push-up and rotary stability. These components will be discussed individually. Detailed descriptions and scoring criteria of the seven FMS tests can be found in Appendix A.

2.2.2.1 Deep Squat

The squat is an integral part of sport, as it is involved in most athletic movements for the generation of power in the lower extremities (Cook, Burton & Hoogenboom, 2006). When performed properly, the deep squat challenges total body mechanics, providing an observable assessment of bilateral, symmetrical, functional mobility of the hips, knees and ankles (Cook, Burton & Hoogenboom, 2006). The deep squat requires a dowel to be held overhead, providing an observable assessment of bilateral, symmetrical mobility of the shoulders and thoracic spine. (Cook, Burton & Hoogenboom, 2006).

2.2.2.2 Hurdle Step

The hurdle step challenges the body to perform proper stride mechanics that are involved during running (Cook, Burton & Hoogenboom, 2006). The task involves a high stepping motion, challenging single-leg stance stability as well as proper coordination and dynamic stability between the hips and torso (Cook, Burton & Hoogenboom, 2006). This test provides observable assessment of bilateral functional mobility and stability of the hips, knees, and ankles (Cook, Burton & Hoogenboom, 2006).

2.2.2.3 In-line Lunge

In an attempt to mimic the stresses placed on the body during rotational, decelerating, or lateral-type movements, the in-line lunge involves placing the lower extremities in a scissor-like arrangement (Cook, Burton & Hoogenboom, 2006). In testing the ability of the trunk and upper extremities to resist rotation and maintain alignment, the in-line lunge provides observable assessment of hip and ankle mobility and stability, quadriceps flexibility, and knee stability (Cook, Burton & Hoogenboom, 2006).

2.2.2.4 Shoulder Mobility

The shoulder mobility component of the FMS aims to evaluate bilateral active shoulder range of motion through combining internal rotation with adduction and external rotation with abduction (Cook, Burton & Hoogenboom, 2006). This test also assesses whether or not normal scapular mobility and thoracic spine extension are present (Cook, Burton & Hoogenboom, 2006).

2.2.2.5 Active Straight Leg Raise

The active straight leg raise challenges the body’s ability to flex the lower extremity from a prone position while maintaining proper trunk stability (Cook, Burton & Hoogenboom, 2006). This straight leg raise provides observable assessment of hamstring and gastoc-soleus flexibility during an attempt to maintain pelvic stability (Cook, Burton & Hoogenboom, 2006).

2.2.2.6 Trunk Stability Push-up

This component of the FMS challenges the body to maintain spinal stability while performing a symmetrical upper extremity pressing action, providing observable assessment of trunk stability during a challenging upper body movement (Cook, Burton & Hoogenboom, 2006).

2.2.2.7 Rotary Stability

The rotary stability component of the FMS involves a complex lower and upper extremity movement that is designed to test neuromuscular coordination, providing observable assessment of multi-plane trunk stability (Cook, Burton & Hoogenboom, 2006).

2.2.3 Scoring the Functional Movement Screen™

According to Cook, Burton and Hoogenboom (2006), the FMS is comprised of seven tests, each of which is scored from 0-3 to yield a composite score out of 21. For a particular test, an individual is assigned a score of 0 if pain is felt anywhere in the body during the movement task (the painful area is noted). If an individual is unable to complete the functional movement task for a particular test, but does not feel any pain, the score assigned for that test is 1. If an individual is able to complete the movement task, but demonstrates an altered or compensatory movement pattern (outlined by the FMS guidelines), the scored assigned is 2. An individual is assigned a score of 3 if the movement task is completed properly, as outlined by the FMS guidelines.

For each of the 7 FMS tests, individuals are permitted up to three attempts to demonstrate the movement task; bilateral tests allow up to three attempts bilaterally. The highest score of the three attempts is recorded.

Most of the FMS tests require both left and right side assessment; however only the side scoring lowest should be included in the composite score. Nonetheless, scores for both sides are recorded in order to identify asymmetries.

Three of the FMS tests involve a clearing test, which is scored as either positive or negative. If an individual feels any pain during a clearing test, he/she is assigned a positive score and is automatically given a score of 0 for the particular test the clearing test is associated with.

2.2.4 Reliability of the Functional Movement Screen™

A handful of studies have investigated both the intra- and interrater reliabilities of the FMS.

Smith et al. (2013) investigated the inter- and intrarater reliabilities of the FMS with real-time administration by four raters of varying educational backgrounds and levels of experience with the FMS. Twenty healthy, injury-free men and women volunteered to perform the FMS. The raters consisted of an entry-level physical therapy student with prior FMS experience (over 100 FMS tests), but no FMS certification; a certified FMS administrator; a faculty member in Athletic Training who had completed a PhD in Biomechanics and Movement Science but was without FMS experience; and an entry-level physical therapy student without prior FMS experience. Each rater attended a 2-hour FMS training session, which covered the 7 functional movements, the three clearing tests, verbal instructions, and scoring criteria as outlined by the FMS developers. To evaluate interrater reliability, the four raters simultaneously scored each participant using real-time administration while following the FMS guidelines outlined by Cook, Burton and Hoogenboom (2006). To evaluate intrarater reliability, raters scored the same participants one week later using the same procedure as in session 1. Scores from both sessions were used to assess interrater reliability. Results revealed that interrater reliability was good for session 1 (ICC = 0.89; 95% confidence interval [CI]: 0.80–0.95) and for session 2 (ICC = 0.87; 95% CI: 0.76–0.94). All raters demonstrated 100% agreement on the three clearing tests for all participants. Intrarater reliability was also found to be good, ranging from ICC's of 0.91 (95% CI: 0.78–0.96) to 0.81 (95% CI: 0.57–0.92). Contrary to their hypothesis, Smith et al. (2013) revealed that FMS certification did not translate to higher intrarater reliability.

Minick et al. (2010) aimed to determine the interrater reliability of the FMS through the use of videotaped FMS sessions. Four raters consisted of two FMS experts, who instructed courses on FMS administration, and two novice raters, who had completed a standardized training course on the FMS. Each rater independently scored the videotaped FMS sessions, which featured front-on and side-on views for 40 healthy participants. Novice raters demonstrated substantial to excellent agreement (≥87.2% agreement) on 14 of the 17 tests (several of the 7 functional movements that comprise the FMS involve both bilateral and overall scores, summing to 17 different tests), while the expert raters did the same (≥79.5% agreement) for 13 of the 17 tests. When comparing novice raters to expert raters, raters demonstrated substantial to excellent agreement (≥83.4% agreement) on all 17 tests. Minick et al. (2010) concluded that the FMS can confidently be applied by trained individuals.

Onate et al. (2012) aimed to determine the real-time intra- and interrater reliabilities of the FMS through the involvement of one FMS certified rater and one novice rater with little FMS experience. To evaluate intrarater reliability, raters scored 19 healthy and physically active volunteers on the FMS in accordance to the FMS guidelines. The same protocol was then repeated one week later involving the same participants. To assess interrater reliability, raters administered the FMS on a subset of 16 participants from the intrarater reliability sessions. Results indicated that the FMS demonstrated fair to high intra-and interrater reliabilities (ICC ≥0.70) on 6 of the 7 FMS components; however, the Hurdle Step component of the FMS demonstrated poor intra- and interrater reliability (ICC = 0.00-0.69). The intra- and interrater reliabilities of composite FMS scores were found to be high (ICC=0.92 and 0.98, respectively). Onate et al. (2012) reported that possessing the FMS certification did not have an impact on the interrater reliability of a real-time FMS assessment; however only two raters were assessed.

Gribble et al. (2013) investigated the intrarater reliability of the FMS through the use of videotaped FMS sessions. Three healthy volunteers were the subjects of the video footage, performing the FMS according to FMS guidelines. Thirty-eight volunteer raters of varying FMS experience and clinical background were involved in the study. Each rater belonged to one of three groups: (1) athletic training students with no FMS experience, (2) athletic trainers with no FMS experience and (3) athletic trainers with at least 6 months of FMS experience in either research or clinical settings. Each rater independently scored the videotaped FMS sessions according to FMS guidelines, then repeated the same process (the order of videotaped FMS sessions was randomized) one week later. All raters demonstrated moderate reliability (ICC: 0.754; 95% CI: 0.526–

0.872). The athletic trainers with FMS experience demonstrated high intrarater reliability (ICC: 0.946; 95% CI: 0.684–0.991), while the athletic trainers demonstrated moderate intrarater reliability (ICC: 0.771; 95% CI: 0.317–0.923). The athletic training students demonstrated poor intrarater reliability (ICC: 0.372; 95% CI: 20.798 - 0.780). Gribble et al. (2013) concluded that certified athletic trainers, regardless of FMS experience, demonstrated moderate to strong intrarater reliability, thus supporting the FMS as a reliable assessment tool of functional movement in a healthy population.

Teyhen et al. (2012) investigated the intra- and interrater reliability of the FMS through real-time administration of 64 young, healthy, active-duty service members by 8 novice raters. The group of novice raters consisted of physical therapy students who underwent 20 hours of FMS training led by physical therapists. Intrarater reliability was evaluated through the raters scoring participants twice within 72 hours, while interrater reliability was evaluated through the simultaneous scoring of participants. Intrarater reliability demonstrated substantial agreement for each of the components with the exceptions of the hurdle step and rotary stability components, which demonstrated moderate and poor agreement, respectively. Intrarater reliability of the composite FMS score was found to be moderate (ICC: 0.74; 95% CI: 0.60-0.83). Interrater reliability ranged from moderate to excellent for each of the 7 components, while interrater reliability of the composite FMS score was determined to be good (ICC: 0.76; 95% CI: 0.63-0.85). Teyhen et al. (2012) concluded that the FMS had adequate reliability when applied to young, healthy, active-duty service members by novice raters.

Frost et al. (2013) discovered that performers' knowledge of the FMS grading criteria significantly changed their scores, threatening the ability of the movement screen to solely reflect dysfunction when administered improperly. The mean composite score from 21 firefighters significantly improved ($p<0.001$) from 14.1, when performing the FMS using standard protocol as indicated by Cook, Burton and Hoogenboom (2006) (i.e. standardized verbal instructions without coaching or feedback), to 16.7 when performing the FMS immediately after being provided with knowledge pertaining to specific grading criteria. Improvements were observed in all but one of the 21 firefighters. Specifically, significant improvements ($p<0.05$) were observed in the Deep Squat, Hurdle Step, In-line Lunge, and Shoulder Mobility tests. Although Frost et al. (2013) recognized that the effect of practice as well as motivation to improve upon a previous score could have played a role in the improvement of FMS scores, they concluded that the utility of whole-body movement screens such as the FMS to predict musculoskeletal injury risk or to guide recommendations for training is compromised when performers are given knowledge of the grading criteria. Frost et al. (2013) also recognized that the purpose of movement screens is to evaluate the engrained movements of the performers. By administering the FMS using standard protocol- using standardized verbal instructions without coaching or feedback- the movement screen promotes observation of engrained movement patterns, rather than temporary movement patterns that reflect the performers interpretation of specific instructions or criteria (i.e. Hawthorne Effect).

Based on prior investigations of intra- and interrater reliabilities, the FMS can be administered with confidence by both novice and experienced FMS raters, regardless of whether or not they possess the FMS certification or not. The findings of Frost et al. (2013) indicate that the utility of the FMS to predict musculoskeletal injury risk is lost when information pertaining to specific grading criteria is provided to performers in supplement to the standardized verbal instructions as indicated by Cook, Burton and Hoogenboom (2006).

2.3 The Relationship Between Functional Movement Screen™ Score and Injury in Sport and Occupation

A limited number of studies have investigated the relationship between the incidence of injury and FMS score in sport and occupation; however the FMS is a relatively new assessment tool that is gaining popularity in sport and clinical settings (Minick et al, 2010).

2.3.1 Professional American Football

Kiesel, Plisky and Voight (2007) investigated the relationship between professional American football players' (n=46) composite FMS scores and the likelihood of "serious injury", defined as "membership on the injured reserve and time-loss of 3 weeks", over the course of one competitive season (p.149). The mean FMS score for athletes who sustained serious injuries was 14.3±2.3, while the mean score for athletes without serious injury was 17.4±3.1. These means were significantly different (df = 44; t = 5.62; $p<0.05$). A receiver-operator characteristic curve was created in order to determine the FMS cut-off score that maximized sensitivity and specificity of the test. This identified a composite cut-off score of 14 on the FMS. The incidence of serious injury was found to be 51% for players who scored ≤14 on the FMS at the beginning of the season. An odds ratio of 11.67 (95%CI: 2.47-54.52) revealed that players scoring ≤14 on the FMS had an eleven-fold increased risk of sustaining a serious injury when compared to players scoring >14 on the FMS at the beginning of the season. Only composite FMS scores were available to the researchers, preventing the analysis of the individual components of the FMS and their influence on injury risk. Participants were selected from only one professional American football team, reflecting a small sample size and suggesting a selection bias. Finally, the definition of serious injury used prevented potentially meaningful injuries that did not result in players being placed on the injury reserve for three or more weeks from being included in the study. The researchers suggested that dysfunctional movement patterns, as measured by the FMS, are associated with serious injury in professional American football players; however they reported that their findings cannot be used to establish a cause-and-effect relationship.

In follow-up to the work of Kiesel, Plisky and Voight (2007), Kiesel, Butler and Plisky (2014) designed an investigation that considered bilateral asymmetry (as indicated by the FMS) as a potential risk factor for injury in professional American football, in addition to composite score. This study involved a larger sample size and a less conservative injury definition than the definition used in Kiesel, Plisky and Voight's (2007) investigation. The purpose of the investigation was to determine whether motor control of fundamental movement patterns and pattern asymmetry, as measured by the FMS, had a relationship with time-loss injury in professional American football players participating in pre-season training. Participants included 238 professional American Football players, while the main outcome measure was time-loss musculoskeletal injury, defined as "any time-loss from practice or competition due to musculoskeletal injury" (Kiesel, Butler & Plisky, 2014, p.89). Using a predetermined FMS composite cut-off score of 14, as determined by Kiesel, Plisky and Voight (2007), participants with scores

≤14 at the beginning of preseason exhibited a relative risk related to injury of 1.87 (95% CI: 1.20-2.96) when compared to those with scores >14. Participants with at least one asymmetry on the FMS exhibited a relative risk related to injury of 1.80 (95% CI: 1.11–2.74) when compared to those without asymmetry. Exhibiting one or more asymmetries in combination to scoring ≤14 was highly specific for injury, with a specificity of 0.87 (95% CI: 0.84–0.90). The researchers concluded that fundamental movement patterns and pattern asymmetry are identifiable risk factors for time-loss injury in professional American football players during the preseason.

2.3.2 NCAA Sports

Similar to the work of Kiesel, Plisky and Voight (2007), Chorba et al. (2010) used a retrospective design to investigate the ability of the FMS to predict the incidence of injury in one competitive season. Participants included 38 female NCAA athletes that were involved in regular season soccer, basketball or volleyball. The definition of injury that was used was "any musculoskeletal injury that occurred as a result of participation in an organized intercollegiate practice or competition setting that required medical attention or advice from a certified athletic trainer" (Chorba et al., 2010, p.49). The mean FMS score for athletes who sustained serious injuries was 13.9 ± 2.12, while the mean score for athletes without serious injury was 14.7 ±1.29. Directed by the findings of Kiesel, Burton and Hoogenboom, the FMS composite cut-off score of 14 was used to determine relationships between low FMS score and injury. Those scoring ≤14 on the FMS were found to be significantly more likely to suffer an injury (p=0.0496). Of the athletes scoring ≤14 on the FMS, 69% suffered an injury within their respective season, experiencing a four-fold increase in injury risk when compared to those scoring >14 on the FMS. Moreover, 82% of athletes scoring ≤13 on the FMS suffered an injury within their respective season. Chorba et al. (2007) reported that a strong correlation existed between composite FMS score and the incidence of injury (r=0.761, P=0.021). An even stronger correlation existed between lower body injury and composite FMS score (r=0.952, P=0.0028) when the shoulder mobility component of the FMS was excluded (yielding a maximum composite FMS score of 18). Linear regression was able to establish a predictive relationship between composite FMS score and injury risk (p=0.0450); however this was only true for subjects without ACL repair surgery. The small sample size used was likely responsible for the lack of statistical power necessary to establish a significant relationship between composite FMS score and injury risk when all subjects were included.

Lehr et al. (2013) aimed to evaluate the utility of an algorithm to predict the likelihood of noncontact lower extremity injury in American collegiate athletes. Participants included 183 male and female athletes from ten different NCAA Division III varsity sports at one institution. The algorithm, designed by two of the authors to categorize athletes into groups defined by injury risk, was comprised of scores from the FMS, the Lower Quartile Y-Balance Test™, and also included demographic and injury history information. Participants were either categorized as low risk or high risk. Those grouped into the low risk category had scores above the predetermined cut-off scores for both the FMS (14) and Lower Quartile Y-Balance Test™, no positive clearing tests on the FMS, no asymmetries on either test, no injuries in the past year, and no pain at the time of testing. Those with one or more risk factors as described in the former sentence, besides injury in the past year, were grouped in the high risk category. Injury data was collected for all non-contact lower extremity injuries throughout the course of one season. Using relative risk measures, those grouped into the high risk category were 3.4 times more likely to be injured (95% CI: 2.0-6.0) than those in the low risk category.

2.3.3 Basketball

McGill, Anderson and Horne (2012) investigated whether specific tests of fitness and movement quality could predict injury resilience and performance in male NCAA basketball players over the course of two competitive seasons. Participants were 14 varsity basketball players at a major American university. Movement quality was assessed through use of the FMS in addition to several other tasks often used by clinicians or Kinesiologists to evaluate injury risk or return to work status, such as gait and posture analysis. Physical fitness was assessed through several tasks that are featured in the National Basketball Association (NBA) combine, while performance indicators involved statistics from NCAA games such as minutes played, points scored, assists, rebounds, steals, and blocks per game. No conclusive relationship between movement quality and injury resilience emerged; however, better performance was linked to having a stiffer torso, more mobile hips, weaker left grip strength, longer standing long jump and quicker agility. A limitation to the interpretation of results included the small sample size used in the investigation. Links between movement quality and injury were not robustly supported due to only five occurrences of injury within the two-year data collection period.

Sorenson (2009) investigated the ability of the FMS to predict injury in high school basketball players. Participants (n=112) included 52 male and 60 female high school basketball players- ranging from freshmen to seniors- in two distinct school districts in Oregon. Participants completed the FMS prior to the start of the regular season and their non-contact neuromusculoskeletal injuries were tracked over the period of one competitive season. Using the predetermined FMS composite cut-off score of 14, as established by Kiesel, Plisky and Voight (2007), Sorenson (2009) found no significant relationship between FMS score and the likelihood of injury. Moreover, no significant relationship between individual FMS component scores or asymmetry scores and the likelihood of injury emerged. Subsequently, Sorenson (2009) concluded that the FMS does not appear to be a valid tool in predicting injury risk in high school basketball players over the period of one season.

2.3.4 Recreational Sports

Shoejaedin et al. (2013) aimed to test the ability of the FMS to predict lower extremity injury in a young, active, healthy population over the course of one season. Participants included 50 male and 50 female university students who had participated in recreational or competitive soccer, handball, or basketball for the past five years. Similar to the work of Kiesel, Plisky and Voight (2007), Shoejaedin et al. (2013) used a receiver-operator characteristic curve in order to determine the FMS composite cut-off score that maximized sensitivity and specificity. This identified a cut-off score of 16.5 on the FMS. Use of the odds ratio revealed that those scoring below 16.5 on the FMS were 4.7 times more likely to suffer a lower extremity injury than those scoring above 17.5. Confidence intervals in support of the odds ratio value of 4.7 were not reported. A statistical difference (p=0.005) was observed between the mean of the injured athletes and that of the non-injured athletes; however, these means were not reported.

2.3.5 Military Training

O'Connor et al. (2011) aimed to document the distribution of FMS scores as well as determine if FMS scores could be used to predict injury in a large military cohort. Participants were 874 male Marine officer candidates between the ages of 18-30. FMS scores were collected immediately prior to the beginning of officer training camp. Injury data was collected daily throughout the physically demanding officer training camp, which was classified as long-cycle (68 days; n = 427), or short-cycle (38 days; n = 447). The mean FMS score for all candidates was 16.6 ±1.7. For short-cycle candidates, those with FMS scores ≤14 were 1.91 times (95%CI: 1.21–3.01, p<0.01) more likely to have sustained injury than those with FMS scores >14. For long-cycle candidates, those with low FMS scores were 1.65 times (95% CI = 1.05– 2.59, P = 0.03) more likely to suffer an injury when compared to those with FMS™ scores >14. Among all candidates, approximately 10% of all candidates demonstrated FMS scores of ≤14.

Lisman et al. (2013) investigated the associations between injury and individual components of the Marine Corps physical fitness test (PFT), self-reported level of physical activity, previous injury history, and FMS score through the use of a retrospective design. Participants were 874 men that were enrolled in Marine Corps officer candidate training. Injury data was collected over the course of the 6-week (n=447) or 10-week (n=427) training periods, while all other data was collected within the first week of training. Mulivariate analysis revealed that odds ratios for high 3-mile run times (OR: 1.72, 95%CI: 1.29-2.31, p<0.001) and low FMS scores (OR: 2.04, 95%CI: 1.32-3.15, p=0.001) were independent risk factors, suggesting that these measures had independent predictive values for injury. A composite cut-off score of 14 was used to define low FMS scores, while a cut-off time of 20.5 minutes was used to define high 3-mile run times. Participants with low FMS scores (≤14) in combination with high 3-mile run times (under 20.5 minutes) were 4.2 times more likely to sustain an injury (95%CI: 2.33-7.53, p<0.001).

2.3.6 Firefighters

Peate et al. (2007) aimed to describe the relationship between FMS score and injury history in 433 male (n=408) and female (n=25) firefighters. All participants had full duty status, with ages ranging from 21-60. The mean age of males was 41.8, while the mean age of females was 37.4. Injury data were collected from the fire department database. FMS scores were observed to decrease with increasing age, tenure and rank. Linear regression revealed that previous injury lowered composite FMS score by 3.44 points. After dichotomizing the outcome variable to either pass (>16) or fail (≤16) and controlling for age, multiple logistic regression revealed that participants with a history of injury were 1.68 times (95% CI: 1.04–2.71) more likely to fail the FMS than those without previous injury (p = 0.033). This exemplifies the significant effect that injury history has on FMS score in a high-risk occupation.

As a secondary objective, the effectiveness of a core strength and flexibility intervention was prospectively assessed over the period of 12 months. The two-month intervention included 21 three-hour seminars that emphasized functional movement by training core strength, flexibility and proper body mechanics. After the intervention and 12-month injury data collection period, overall injuries were reduced by 44% and lost time due to injury was reduced by 62% when compared to the historical control group. This was indicative of the effectiveness of the intervention. Although FMS scores were not collected post-intervention, improvements in functional movement quality that were made during the intervention may have contributed to higher FMS scores. The lower incidence of injury post-intervention likely supported the ability of FMS to predict injury in firefighters.

Burton (2013) evaluated the ability of the FMS to predict occupational injury and performance in 23 firefighters entering a 16-week fire academy course. Outcome measures for performance included VO2 max, 1.5-mile run time and scores for the Firefighter Physical Conditioning Course. A total of 8 injuries were sustained over the 16-week course. The investigation failed to reveal a conclusive relationship between injury and composite FMS scores or the presence of one or more asymmetries as measured by the FMS. Likewise, no clear relationship was found to exist between FMS score and the performance indicators. Burton (2006) confessed that the small sample size used in the investigation may not have allowed for an appropriate representation of firefighters, as members from only one in-coming firefighter candidate class participated in the study.

Butler et al. (2013) investigated whether measures of physiologic function and functional movement quality could predict injury in 108 firefighters involved in academy training. Physiologic function was assessed through five tests: the sit-and-reach test, pull-up test, push-up test, 1.5 mile run and a firefighter-specific performance test known as the "tower test". The quality of functional movement was evaluated through use of the FMS. Injuries, defined as "any episode that caused the recruit to miss 3 consecutive days of training in the academy due to musculoskeletal pain (excluding burns)" were tracked over the 16-week academy training period. In accordance to Kiesel, Plisky and Voight (2007) and Shoejaedin (2013), Butler et al., plotted a receiver-operator characteristic curve to pinpoint an FMS composite cut-off score that maximized sensitivity and specificity. This produced a cut-off score of 14, equal to the cut-off score determined by Kiesel, Plisky and Voight (2007). Diagnostic odds ratio calculation revealed that those scoring ≤14 on the FMS were 8.31 times more likely to suffer an injury (95%CI: 3.2–21.6) than those scoring >14. Moreover, both the deep squat (OR: 1.21, 95% CI: 1.01–1.42) and trunk stability push-up (OR: 1.30, 95% CI: 1.07–1.53), individual components of the FMS, were significant predictors of injury. The only measure of physiologic function that was significantly linked to injury was the sit-and-reach test OR: 1.24 (95% CI: 1.06–1.42). Information regarding the specific types of injuries sustained was not recorded, preventing the certain risk factors that emerged from being associated with specific injuries. Not only did this study determine that composite FMS score is predictive of injury in a population of firefighters, it also identified specific components of the FMS as modifiable risk factors for injury.

2.4 Summary of the Literature

Despite its global popularity, rugby union- characterized by forceful body contact in the absence of ample protective equipment- has one of the highest reported injury incidences in sport (Brooks et al., 2005). This high injury rate, combined with the often severe consequences of injury, warrants the identification of factors that contribute to injury risk in order to develop effective preventative interventions.

The FMS is a noninvasive, inexpensive, quick and easily administered tool that assesses multiple functional movement patterns of an individual in order to identify movement limitations and asymmetries, which are suspected to influence risk of injury in sport (Cook, Burton & Hoogenboom, 2006; Kiesel, Plisky & Voight, 2007; Perry & Koehle, 2013). The effectiveness of the FMS as a tool for injury-risk assessment has been demonstrated in professional American football players (Kiesel, Plisky & Voight, 2007), NCAA athletes (Chorba et al., 2010; Lehr et al., 2013), recreational athletes (Shoejaedin et al., 2013), Marine Corps officer candidates (Lisman et al., 2013; O'Connor et al., 2011) and firefighters (Butler et al., 2013). Additionally, the FMS has demonstrated high intra- and interrater reliability among trained raters (Gribble et al., 2013; Onate et al., 2012). Though a growing number of investigations are assessing the effectiveness of the FMS as a primary tool for injury risk assessment in athletic populations, little research has attempted to evaluate the relationship between FMS score and the likelihood of injury in rugby union players.

Chapter 3: Methodology

3.1 Experimental Design

Although this small-scale study is not epidemiological in nature, it follows an analytical cohort design similar to those employed in epidemiological research. Cohort studies typically compare outcome measures between two groups, those bearing some exposure or potential risk factor thought to influence the outcome measure, and those without the exposure or potential risk factor. In this investigation, the outcome measure was the likelihood of time-loss injury, and the exposure or potential risk factor being investigated was FMS score below the experimentally derived FMS composite cut-off score. The FMS composite cut-off score that was used to separate the two cohorts was established using a receiver-operator characteristic (ROC) curve after all FMS and injury data had been collected.

The surveillance time for this study was two full, consecutive seasons. Season One, the 2013 Vancouver Island Elite/1st Division League (September-December 2013) involved 8 regular season games and one postseason match for the two top-ranked teams, while Season Two, the 2014 Canadian Direct Insurance Premier/1st Division League (January-April 2014) involved 8 regular season matches from which injury data were collected. Participants that sustained time-loss injury and returned to play were not excluded from further time-loss injury data collection.

FMS data were collected prior to the start of Season One and Season Two, representing the exposure characteristics (i.e. impairments in stability and mobility, bilateral asymmetries and programmed altered movement patterns) hypothesized to affect the primary outcome measure, likelihood of time-loss injury. Demographic and injury history questionnaires were administered prior to the beginning of Season One. Injury data were collected prospectively throughout the course of the two 4-month club-level rugby union seasons. Statistical analyses were conducted separately for Season One and Season Two on the basis of comparing the risk of time-loss injury between the two cohorts. A follow-up questionnaire was administered at the end of Season Two.

3.2 Participants

3.2.1 Recruitment

International-, provincial- and club-level rugby union players from the Victoria area that were participating in the 2013 Vancouver Island Elite and/or 1st Division Leagues and the 2014 Canadian Direct Insurance Premier and 1st Division Leagues were recruited to volunteer to participate in this study. Recruitment occurred in the Victoria area due to proximity to the researcher. Recruitment involved convenience sampling through connections between the researcher and rugby union clubs and coaches in the Victoria area. After club-team coaches granted their permission for players to be invited to participate, and provided the researcher with contact information for their players, the researcher contacted athletes directly via email.

3.2.2 Inclusion and Exclusion Criteria

Eligible participants were English-speaking males ages 19-30 years with the capacity to communicate effectively with athletic therapy students, athletic therapists, physiotherapists, physicians and the researcher. As well, eligible participants were insured through the British Columbia Rugby Union (BCRU), as it is a requirement for participation in British Columbia league rugby. In order to participate, participants were deemed healthy by self-report and by assessment from team medical staff before the first regular season game. In addition, participants must have been free from any "injury sustained within the 30 days preceding testing that excluded the athlete from participating in practice and/or competition, or recent surgical intervention that limited the athlete's participation in sport due to physician-imposed restriction" in order to participate (Chorba et al., 2010, p.48).

In summary, participants who met the following inclusion criteria were included in the study:

1) Apparently healthy
2) Participating in the 2013 Vancouver Island Elite/1st Division leagues and/or the 2014 Canadian Direct Insurance Premier/1st Division Leagues
3) English speaking
4) Ages 19-30
5) Insured to play league rugby in British Columbia through the British Columbia Rugby Union

Participants were excluded from one or both of Season One and Season Two if they met one or more of the following exclusion criteria: were absent for more than 3 games during one season for reasons other than rugby-related injury or representative rugby union competition; participated in new, regular mobility interventions during the regular season; experienced dramatic changes in training status; ceased to play rugby; or moved away from the Victoria region.

This study was conducted with the approval of the University of Victoria Human Research Ethics Board (refer to Appendix H). Participants signed informed consent forms ensuring that they fully understood the rationale for the research and the intended use of the results.

3.2.3 Sample Size

The intended number of participants was 60 athletes, as recruiting this many participants was thought to be a feasible given the availability of experienced, male rugby union athletes in the Victoria area. Given the high incidence of injury associated with rugby union, it was thought that a sample size of 60 athletes would sustain a substantial number of time-loss injuries to be involved in statistical analyses. Additionally, this sample size is similar to those in previous FMS and athletic injury studies (Chorba et al., 2010 and Kiesel, Plisky & Voight, 2007). This number of participants was expected to effectively address the research questions of the current study.

A total of 76 participants (age 21.6±2.7 years) were involved in the research project, all of whom competed the 2013 Vancouver Island Elite/1st Division Leagues and/or the 2014 Canadian Direct Insurance Premier /1st Division Leagues. Injury data were collected from all competitions the participants took part in, including club-, representative- and international-level rugby.

Rugby union players living in the Victoria area typically compete in both the Vancouver Island Elite/1st Division league and the Canadian Direct Insurance Premier/1st Division League seasons. The number of participants competing in Season One for whom data were included in the statistical analyses was 68, while the number of participants included in the analyses for Season Two was 65. A total of 57 players participated in both seasons. Data from 11 players were included in the statistical analyses for Season One, but were excluded for Season Two for meeting one or more of the exclusion criteria described above. A group of 8 players was introduced to the research project in Season Two in order to account for the loss of players from Season

One. The Follow-up Questionnaire (Appendix D) was used to collect information regarding participant involvement in new, regular mobility interventions (e.g. yoga), resulting in the exclusion of three athletes from the statistical analyses in the season during which the intervention took place.

3.3 Procedure

3.3.1 Functional Movement Screen™ Testing

Potential participants were informed of the purpose and procedures of the study when first contacted by the researcher. Those who were informed and willing to participate were asked to arrange an appointment for FMS testing and demographic and injury history data collection. During testing appointments, participants were provided with an informed consent form. They then completed demographic and injury history questionnaires. Upon completion of the questionnaires, a certified FMS rater administered the FMS in accordance to the standard protocol outlined by Cook, Burton & Hoogenboom (2006), which took roughly 10 minutes per individual to complete. This involved providing participants with a brief explanation of the assessment. Participants performed the FMS in a private quiet space, one at one time. Assessment of the 7 functional movement tasks involved in the FMS were scored (0-3) to yield a composite score out of 21. See Appendix A for the individual FMS component descriptions and scoring criteria. This process was completed prior to the first regular game in Season One. The participants' FMS data were once again obtained by the FMS rater prior to the first game in Season Two. All FMS assessments were performed in the athletic therapy rooms at the University of Victoria or at Rugby Canada's Center of Excellence, Victoria BC.

3.3.2 Functional Movement Screen™ Interrater Reliability

To confirm the reliability and accuracy of the FMS data, the FMS rater (author), alongside another experienced, certified FMS rater, scored ten athletes on the FMS in parallel tests following which inter-rater reliability was computed.

3.3.3 Injury Reporting

Rugby-related injury data, including injury type, mechanism of injury, injured body part and severity (time lost between injury and return to play) were prospectively collected over the two seasons. All injuries were recorded on the injury report form developed by the International Rugby Board (Fuller et al., 2007). Participants were repeatedly encouraged to not only report to and be assessed by their team trainers, athletic therapists, physiotherapists, and if necessary, doctors, but to also report to the researcher in the event of any athletic injury sustained during training or match-play. Lines of communication between team trainers, athletic therapists, physiotherapists, doctors, the researcher, and players themselves aided in the injury data collection process. Specifically, team trainers were in weekly contact with the researcher in ensuring that all time-loss injuries were reported, while team medical staff provided information regarding the diagnoses of injuries. At the end of Season Two, participants completed a Follow-up Questionnaire to provide information regarding training status and their involvement throughout both Seasons.

3.4 Instrumentation

Five instruments were used to collect information from the participants: the FMS, a demographic questionnaire, an injury history questionnaire, a follow-up questionnaire, and an injury report form. All instruments were used to collect data in the presence of the researcher.

3.4.1 The Functional Movement Screen™

A single certified rater with previous experience collected all FMS data. Administration of the FMS occurred in accordance to the FMS guidelines, as outlined by Cook, Burton and Hoogenboom (2006). Individual FMS component descriptions and scoring criteria are presented in Appendix A.

3.4.2 Demographic Questionnaire

This instrument (see Appendix B) was used to collect personal characteristic information about each participant. Participants completed this questionnaire prior to competing in regular season rugby during which injury data were collected. The information obtained included the following:

- Name
- Date of birth
- Age
- Height
- Weight
- Handedness
- Dominant foot
- Number of years involved in rugby union
- Date last participated in rugby union training
- Current injury status

3.4.3 Injury History Questionnaire

Information regarding previous injury sustained by participants was collected using the Injury History Questionnaire (see Appendix C). Participants completed this questionnaire prior to competing in regular season rugby during which injury data were collected. The information collected included the following:

- Musculoskeletal surgery history – date, operation type, site and side of body affected.
- Most recent injury – date, type of injury, whether or not it was a time-loss injury, site and side of body affected.
- Non-surgical time-loss injuries – date, diagnosis, site and side of body affected.

3.4.4 Follow-up Questionnaire

This questionnaire (see Appendix D) was completed after Season Two ended in order to identify athletes that met one or more of the exclusion criteria explained above. The information collected included the following:

- Training status – Whether or not it significantly changed over the 8-month surveillance period and if so, how it changed.
- Regular participation in any mobility interventions (e.g. yoga or stretching interventions) that an individual did not regularly participate in prior to pre-season data collection – type of intervention, duration of the intervention, number of sessions per week, duration of each session.
- The number of weeks of team training missed during the regular season.
- The number of matches an individual missed during the regular season.
- The number of matches an individual missed in the regular season due to injury.

3.4.5 Injury Report Form

Team medical staff and participants provided information to the researcher in order to complete injury report forms (see Appendix E) upon assessing injuries. These forms were completed throughout both seasons. This form was a modified version of the injury report form provided in the IRB's consensus statement on injury definitions and data collection procedures for studies of injuries in rugby union (Fuller et al., 2007). The information collected included the following:

- Date of injury
- Date of return to full participation (indicating injury severity)
- Position played when the injury occurred
- Injured area and side of body
- Type of injury
- Diagnosis (as assessed by an athletic therapist, physiotherapist, or physician)
- Cause of injury (overuse versus trauma)
- If the injury resulted from foul play
- If the injury resulted from a contact mechanism
- If the injury occurred during training or match-play
- If the injury occurred during rugby 7s or 15s

3.5 Statistical Analyses

The software package IBM SPSS Statistics for Windows, Version 22.0 (2013, IBM Corp., Armonk, NY) was used for all statistical analyses with significance set at the $p<0.05$ level. Descriptive statistics were determined in order to summarize FMS and injury data.

3.5.1 Functional Movement Screen™ Composite Score

To determine if a significant difference in composite FMS scores existed in those who sustained a time-loss injury and those who did not, a dependent t-test was conducted.

A receiver-operator characteristic (ROC) curve was plotted for each season in order to determine the FMS composite cut-off score that maximized sensitivity and specificity of the FMS as a screening test for time-loss injury. An ROC curve is a plot of the sensitivity (true positive rate) versus 1-specificity (false positive rate) of a screening test such as the FMS (Fawcett, 2006). Each point on an ROC curve corresponds to a different cut-off value (FMS composite cut-off score) used to identify whether a test value (FMS composite score) is considered positive or negative (Fawcett, 2006). Since cut-off values are meant to categorize test values as either positive or negative, cut-offs typically correspond to unobtainable test values that are equidistant between actual test values. For example, given that obtainable test values for the FMS include whole numbers from 0 to 21, a suitable cut-off value for the FMS could be 9.5, 10.5, 11.5 and so on. The cut-off value that maximizes sensitivity and specificity of a screening test, thereby maximizing true positive tests while minimizing false positive tests, is found at the upper left portion of the ROC curve (Fawcett, 2006). In this context, this cut-off value would most effectively discriminate between those participants who are at greater risk and those who are at lower risk of time-loss injury on the basis of FMS score.

Once the FMS composite cut-off score was identified, it was used to evaluate the relationship between lower and higher FMS composite scores and time-loss injury risk within each season. A 2x2 contingency table was made for each season, dichotomizing those with FMS scores above the cut-off from those at or below the cut-off FMS score, and those who suffered a time-loss injury from those who did not. Sensitivity, specificity, diagnostic odds ratios with confidence intervals set at 95% and likelihood ratios (-LR, +LR) were calculated. Fisher's exact tests with one-tailed p value of <0.05 were used to determine if those with low FMS scores were significantly more likely to suffer a time-loss injury than those above the cut-off score. The Fisher's exact test was chosen for its ability to calculate a more exact p value for small sample sizes when compared to the Chi-square test (Chorba et al., 2010).

Independent t-tests were used to compare the mean incidence of injury and mean severity of time-loss injury across cohorts above and below the FMS composite cut-off score for both seasons. Pearson correlation analysis was used to determine the relationship between composite FMS score and the incidence of injury among participants. Linear regression was used to determine the association between FMS score and injury incidence. Binomial logistic regression analysis was used to determine the association between time-loss injury status (binomial dependent variable) and the independent variables: FMS composite score; the number of bilateral asymmetries, as assessed by the FMS; and scores for each of the 7 individual FMS components.

3.5.2 Bilateral Movement Asymmetries

Additionally, ROC curves were plotted in order to determine the cut-off value for number of bilateral movement asymmetries (as indicated by the FMS) that discriminated between those at significantly higher risk of injury from those at lower risk. Subsequently, a 2x2 contingency table was made for each season, dichotomizing those above the cut-off value of asymmetries from those below the cut-off value, and those who sustained time-loss injury from those uninjured. A Fisher's exact test with a one-tailed p value of <0.05 was performed to determine if those above the cut-off value for asymmetries were significantly more likely to suffer a time-loss injury than those below the cut-off value. Pearson correlation and linear regression analyses were used to determine the relationship between number of bilateral asymmetries present and the incidence of time-loss injury among participants.

3.5.3 Interrater Reliability

Inter-rater reliability of composite FMS scores was evaluated through an Intra-class Correlation Coefficient (ICC), while inter-rater reliabilities of the individual components of the FMS were evaluated through Cohen's kappa statistic.

3.6 Study Timeline

Recruitment of Participants	August - September 12, 2013
Demographic and Injury History Questionnaires, Informed Consent and FMS testing (n=68)	September 1-12, 2013
Injury Surveillance (n=68)	September 13 - December 8, 2013
Demographic and Injury History Questionnaires, Informed Consent for 8 new participants; FMS testing for all participants (n=65)	January 3-18, 2014
Injury Surveillance (n=65)	January 17 - April 19, 2014
Follow-Up Questionnaire (n=76)	April 19-28, 2014
Statistical Analyses	May - June 2014

Chapter 4: Results

4.1 Participant Characteristics

A total of 76 male, experienced rugby union athletes (mean age = 21.6 ± 2.7 years) voluntarily participated in this study, 57 of which were involved in both Season One and Season Two. Of the remaining 19 athletes that only participated in the study for one season, 11 participated during Season One, while 8 participated in Season Two. Participants' age, years of rugby union experience and anthropometric characteristics are shown in Table 1. All participants had sustained previous time-loss injury history. Information regarding participant involvement in international and representative rugby union competitions (in addition to club-level rugby) during the surveillance time are shown in Appendix F.

Table 1. Age, Years of Rugby Union Playing Experience and Anthropometric Characteristics of the Study Population (n=76)

Variable	Mean ± SD	Range
Age (yrs)	21.6 ± 2.7	18-29
Playing Experience (yrs)	8.85 ± 2.88	3-17
Height (cm)	183 ± 7	163-201
Weight (kg)	94.9 ±11.6	73-133

4.2 Injury Incidence

A total of 79 time-loss injuries were sustained in Season One (n=68), while 59 injuries were sustained in Season Two (n=65). This corresponded to an incidence of 1.16 (1.05) injuries per player in Season one and 0.91 (0.74) injuries per participant in Season

Two. A total of 48 participants (out of 68) were injured in Season One, while 47 participants (out of 65) were injured in Season Two.

With regards to injury severity, participants that sustained one or more injuries in Season One experienced an average time-loss of 47.17 (79.23) days due to injury, while participants that were injured in Season Two experienced an average time-loss of 35.20 (48.21) days. The average time-loss per injury in Season One and Two was 28.66 and 26.85 days, respectively. The majority of time-loss injuries were experienced during match play, as opposed to during training, in both Season One (67%) and Season Two (75%). Contact mechanisms were the most common cause of injuries in both Seasons (i.e. rucks, mauls, scrums, tackles, and collisions) and were responsible for 61% and 71% of the injuries sustained in Season One and Two respectfully. Non-contact events such as running, jumping or side-stepping were responsible for the remaining injuries. Being tackled was the most frequently recorded contact mechanism of injury in both seasons. Recurring injuries, injuries of the same type and site of previous injury, accounted for 37% of injuries in Season One and 36% of injuries sustained in Season Two.

The most common injury type in Season One was muscle rupture/strain/tear/cramp (29%), while the most common injury type in Season Two was ligament injury/sprain (39%). The most frequent sites of injury for both Seasons can be found in Appendix G.

4.3 Functional Movement Screen™

Mean FMS scores for Season One and Season Two were similar at15.2±1.94 and 15.4±2.05, respectively. In both seasons, mean FMS scores did not differ significantly between injured (15.04±2.15 and 15.15±2.30 in Season One and Two, respectively) and uninjured (15.55±1.27 and 15.90±1.21 in Season One and Two, respectively) players. The distribution of FMS scores for both injured and uninjured athletes in Season One and Season Two are illustrated in Figure 1 and Figure 2, respectively.

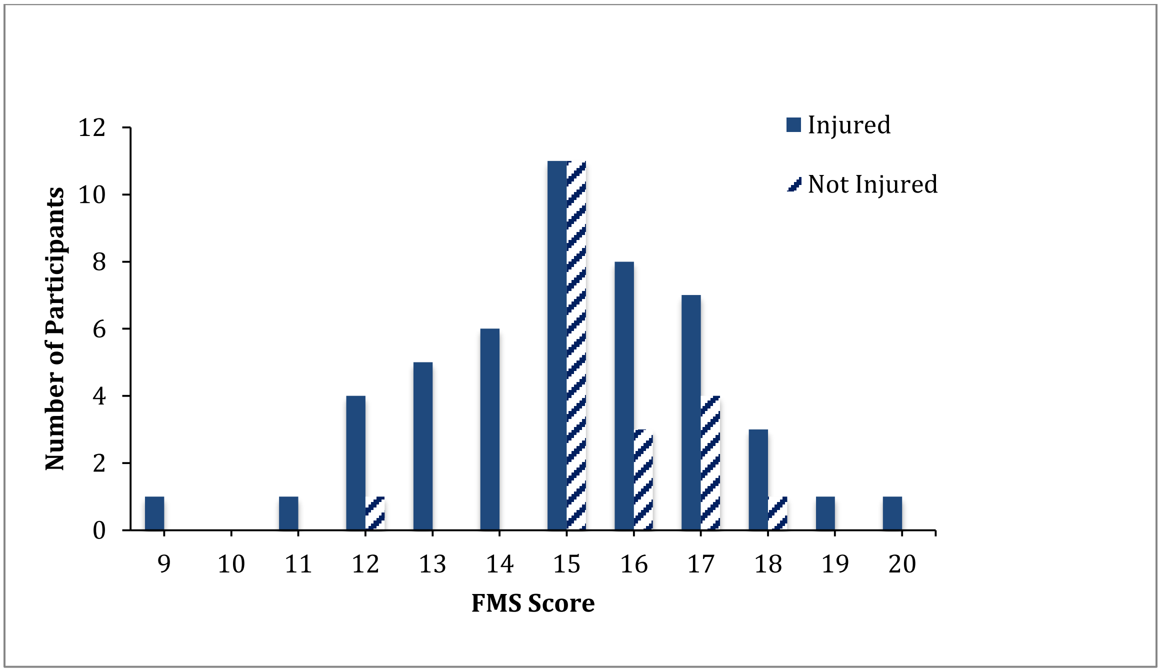


Figure 1. Season One distribution of composite FMS scores, indicating those who sustained injury and those who remained uninjured.

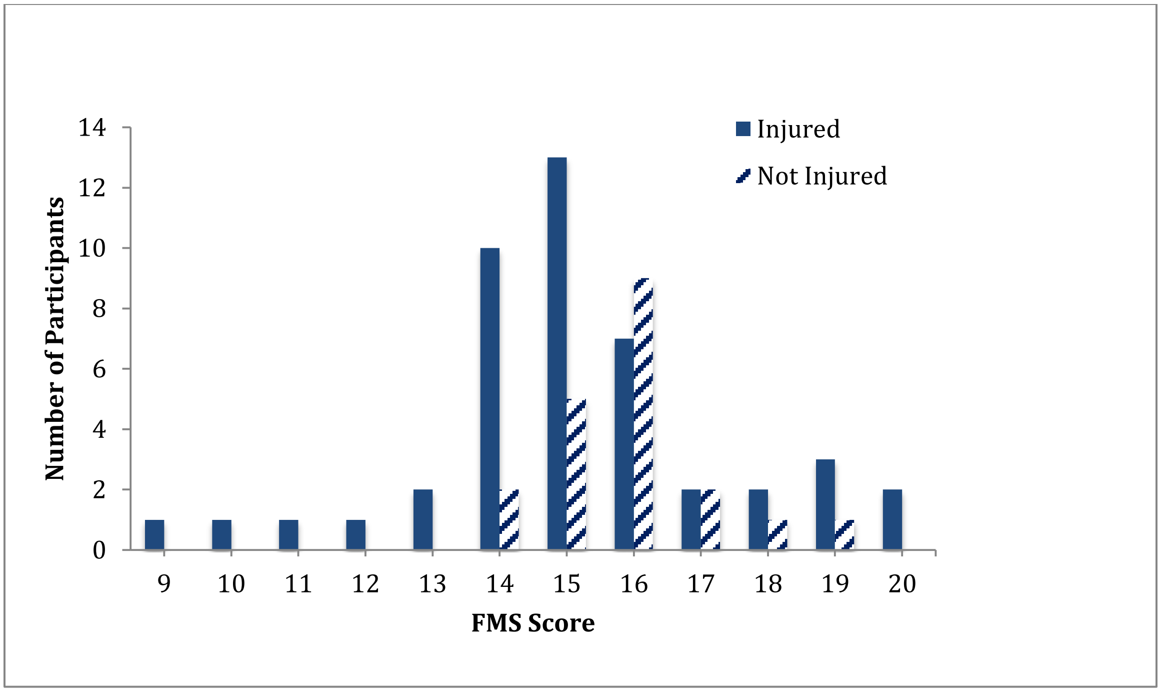
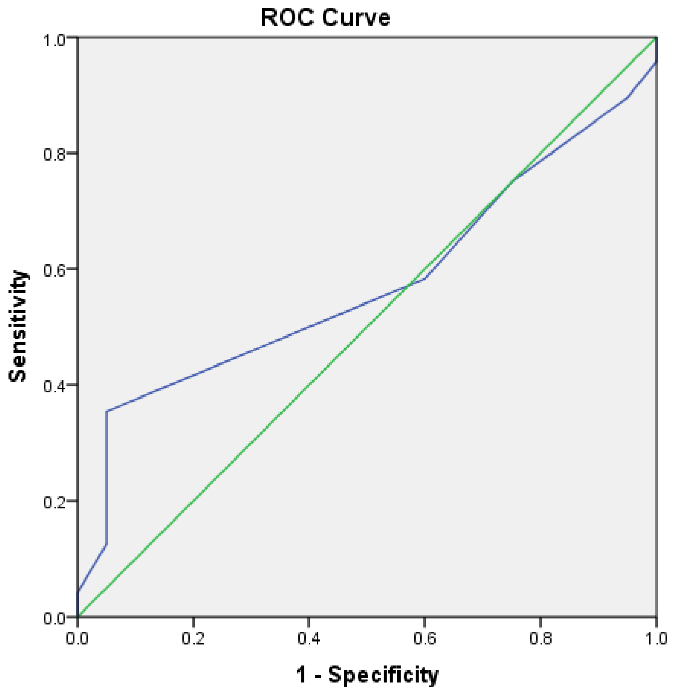


Figure 2. Season Two distribution of composite FMS scores, indicating those who sustained injury and those who remained uninjured.

ROC curves were used to determine an FMS cutoff score that discriminated between those participants at greater risk of injury. In Season One, the ROC curve and corresponding sensitivity and specificity data indicated that an FMS cut-off score of 14.5 maximized sensitivity and specificity of the FMS (Figure 3). ROC curve analysis for Season Two (Figure 4) indicated that FMS cutoff score values of 14.5 and 15.5 both maximized sensitivity and specificity. FMS composite cut-off scores were chosen for their correspondence to the point on the ROC curve that maximized the number of true positives (participants with relatively lower FMS scores that sustained injury) and minimized false positives (participants with relatively higher FMS scores that sustained injury). These points were found nearest to the upper left corner of the 1-specificity versus sensitivity graph.



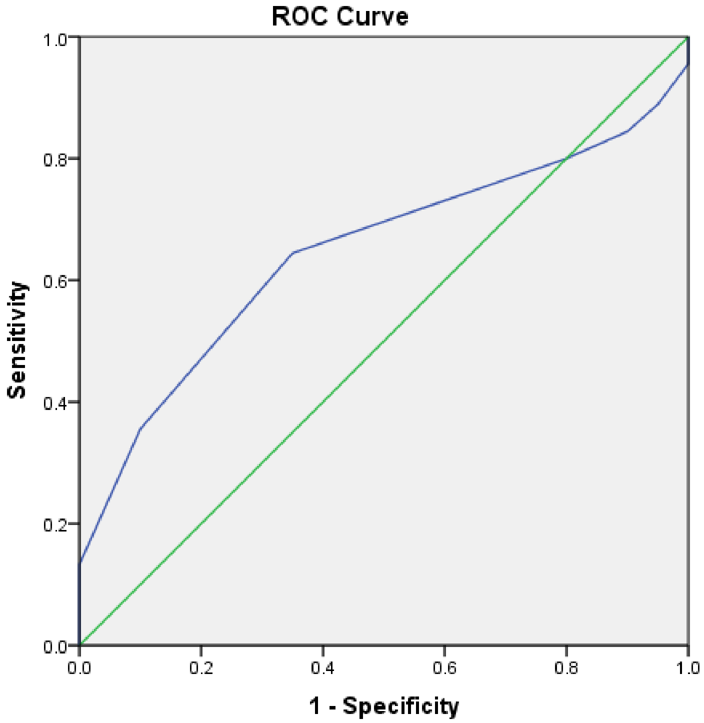
Diagonal segments are produced by ties.

Coordinates of the ROC Curve

Test Result Variable(s): FMS

Positive if Less Than or Equal To[a]	Sensitivity	1 - Specificity
8.0000	.000	.000
10.0000	.021	.000
11.5000	.042	.000
12.5000	.125	.050
13.5000	.229	.050
14.5000	**.354**	**.050**
15.5000	.583	.600
16.5000	.750	.750
17.5000	.896	.950
18.5000	.958	1.000
19.5000	.979	1.000
21.0000	1.000	1.000

Figure 3. Receiver-operator characteristic (ROC) curve for FMS composite score and injury status in Season One. Coordinates of the ROC curve indicate that the FMS composite score value that lies nearest to the upper left corner of the 1-specificity versus sensitivity graph is 14.5, justifying its determination as the FMS composite cut-off score (Fawcett, 2006). Cutoff values are the averages of two consecutive ordered observed test values.



Diagonal segments are produced by ties.

Coordinates of the ROC Curve

Test Result Variable(s): FMS

Positive if Less Than or Equal To[a]	Sensitivity	1 - Specificity
8.0000	.000	.000
9.5000	.022	.000
10.5000	.044	.000
11.5000	.067	.000
12.5000	.089	.000
13.5000	.133	.000
14.5000	**.356**	**.100**
15.5000	**.644**	**.350**
16.5000	.800	.800
17.5000	.844	.900
18.5000	.889	.950
19.5000	.956	1.000
21.0000	1.000	1.000

Figure 4. Receiver-operator characteristic (ROC) curve for FMS composite score and injury status in Season Two. Coordinates of the ROC curve indicate that the FMS composite score values of 14.5 and 15.5 lie near to the upper left corner of the 1-specificity versus sensitivity graph. Because of the presence of two potential FMS composite cut-off scores that maximized sensitivity and specificity, statistical analyses were conducted for both scores (Fawcett, 2006).

The FMS cutoff score of 14.5 was applied to the injury data from both Seasons to evaluate the risk of injury associated with participants exhibiting FMS composite scores below and above the cut-off value. The proportion of participants exhibiting FMS scores below the experimentally determined FMS composite cut-off score of 14.5, deemed the level of exposure, was 26% and 28% for Season One and Season Two, respectively. Additionally, since two cut-off values were indicated by ROC curve analysis in Season Two, the FMS cut-off score of 15.5 was used to evaluate the risk of injury for participants above and below this cutoff score in Season Two. A 2x2 contingency table was created for both Season One (Table 2) and Season Two (Table 3), dichotomizing those with FMS scores above the cutoff score of 14.5 from those below the cutoff score, as well as those that sustained injury from those that were uninjured. An additional 2x2 contingency table using the cutoff score of 15.5 was created for Season Two (Table 4).

Table 2. Season One 2x2 contingency table dichotomizing those above from those below the cut-off FMS score of 14.5, and those who suffered a time-loss injury from those who did not.

Season One		Time-Loss Injury?		Total
		yes	no	
FMS score <14.5?	yes	17	1	18
	no	31	19	50
Total		48	20	68

Table 3. Season Two 2x2 contingency table dichotomizing those above from those below the cut-off FMS score of 14.5, and those who suffered a time-loss injury from those who did not.

Season Two		Time-Loss Injury?		Total
		yes	no	
FMS score <14.5?	yes	16	2	18
	no	29	18	47
Total		45	20	65

Table 4. Season Two 2x2 contingency table dichotomizing those above from those below the cut-off FMS score of 15.5, and those who suffered a time-loss injury from those who did not.

Season Two		Time-Loss Injury?		Total
		yes	no	
FMS score <15.5?	yes	29	7	36
	no	16	13	29
Total		35	20	65

Diagnostic odds ratio analyses revealed that participants who scored below 14.5, were 10.42 times (95%CI: 1.28-84.75) more likely to have sustained injury (+LR=7.08, -LR=0.72, specificity=0.95, sensitivity=0.35) in Season One and 4.97 times (95%CI: 1.02-24.19) in Season Two (+LR=3.56, -LR=0.71 specificity=0.90, sensitivity=0.36) compared with those with higher FMS scores. Fisher's exact tests confirmed that participants with FMS scores below 14.5 were significantly more likely to sustain injury in both Season One (one-tailed, p=0.007) and Season Two (one-tailed, p=0.029). A large majority of players with FMS scores below 14.5 sustained one or more injuries in both Season One (94.44%) and Season Two (88.89%). Additionally, a significant proportion of players with FMS scores >14 sustained injury in Season One (62.00%) and Season Two (61.70%).

Participants scoring below 15.5 on the FMS were also at significantly greater risk of injury, exhibiting a risk of injury 3.37 times (95%CI: 1.12-10.14, Fisher's exact test, one-tailed, p=0.027) greater than players with higher FMS scores in Season Two (+LR=1.84, -LR=0.55, specificity=0.65, sensitivity=0.64), but not in Season One.

Correlation and linear regression analyses demonstrated no significant relationship between composite FMS score and the incidence of injury. Binomial logistic regression did not identify any of the independent variables (FMS score, the number of bilateral asymmetries and scores from the 7 individual FMS components) as being significantly predictive of injury status.

In Season One, participants with FMS scores below 14.5 sustained significantly more injuries (1.72±1.72 injuries per participant) compared with those scoring above 14.5 (0.96±0.95). In Season Two, again participants with FMS scores below 14.5 sustained significantly more injuries (1.22±0.65 injuries per participant), than those with FMS scores >14 (0.79±0.75 injuries).

4.4 Bilateral Movement Asymmetries

The maximum number of possible bilateral asymmetries per participant that could be identified by the FMS was 5, as there are 5 FMS components that involve bilateral assessment. The average number of bilateral movement asymmetries among participants was 1.44±0.92 in Season One and 1.03±0.90 in Season Two. Only 11 participants in Season One and 21 participants in Season Two were without any asymmetries. No participants exhibited greater than 4 asymmetries on the FMS. The distribution of bilateral asymmetries among participants grouped by injury status is depicted in Figures 5 and 6 for Seasons One and Two, respectively. ROC curves were unable to determine a clear cutoff number of asymmetries that discriminated between those at significantly elevated risk of injury from those at lower risk. For this reason, 2x2 contingency tables were made for each theoretical cutoff number of asymmetries (0.5, 1.5, 2.5, 3.5 and 4.5) to dichotomize those above the theoretical cutoffs from those below the theoretical cutoffs, and those who sustained time-loss injury from those uninjured. Fisher's exact tests determined that no theoretical cutoff number of asymmetries was able to adequately distinguish between those at significantly greater risk of time-loss injury than those at lower risk. For this reason, diagnostic odds ratios are not reported. Correlation and linear regression analysis did not identify a relationship between bilateral movement asymmetries and the incidence of time-loss injury.

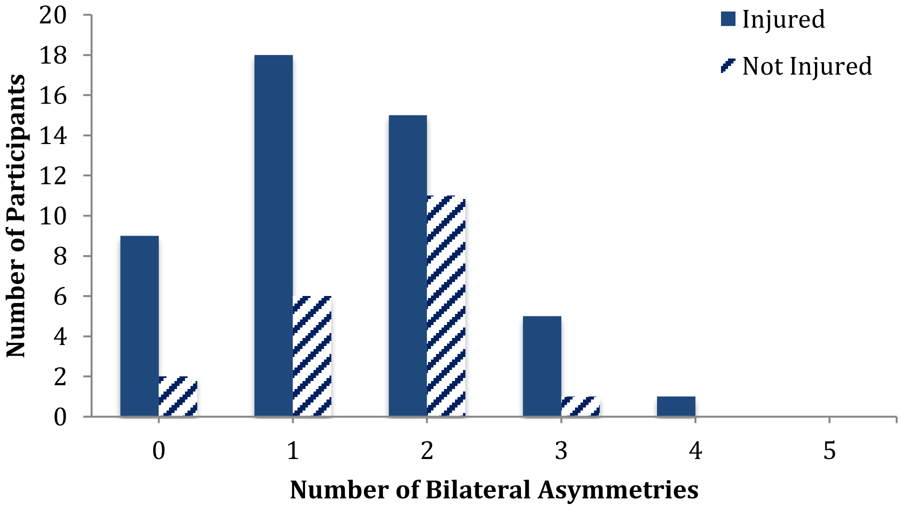


Figure 5. Season One distribution of bilateral asymmetries, grouped according to injury status.

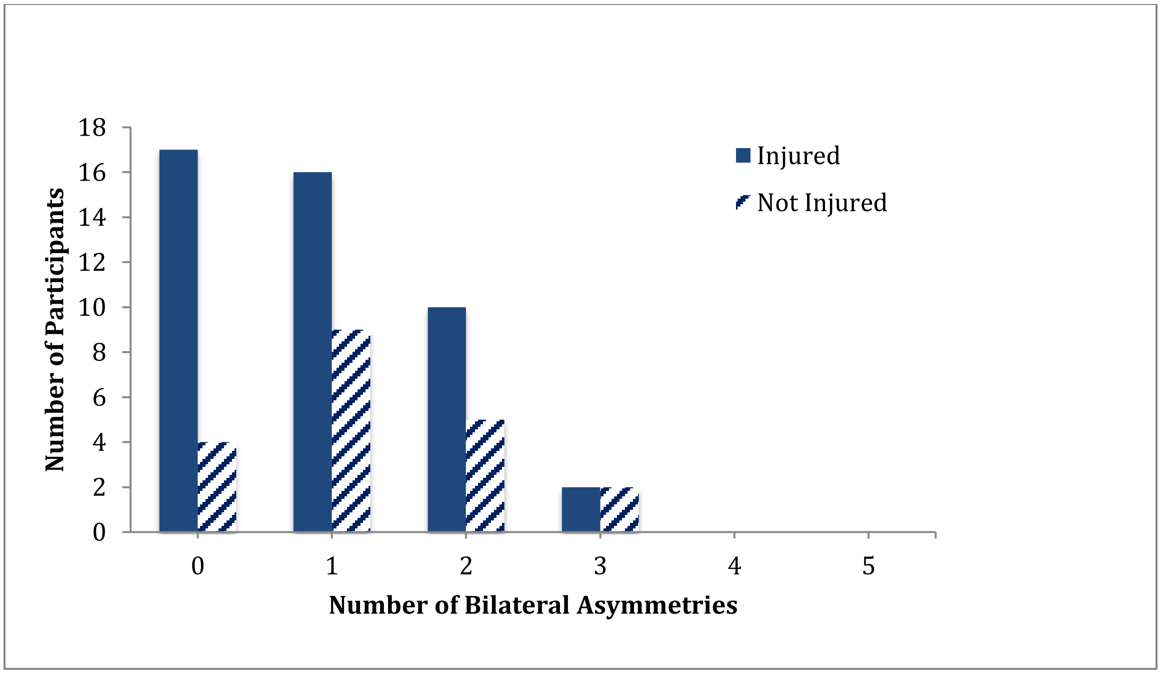


Figure 6. Season Two distribution of bilateral asymmetries, grouped according to injury status.

4.5 Non-contact Injuries

Since some injuries are unlikely to be related to the quality of movement, for example, concussions and haematomas, the relationship between FMS score and time-loss injuries sustained by non-contact mechanisms was investigated. This excluded all injuries sustained via tackling, being tackled, rucks, mauls, scrums and collisions. In agreement to the above, ROC curve analysis found the FMS composite cut-off score of 14.5 to maximize both the specificity and sensitivity of the test as a predictor of non-contact time-loss injury risk. However, Fisher's exact tests revealed that those with FMS scores below 14.5 were not more likely to sustain non-contact injury when compared to those scoring above 14.5 in either season.

4.6 Strictly Club-level Group

In order to control for the heterogeneity of level of play and with the aim of describing the relationship between FMS score and injury risk in solely club-level rugby union athletes, statistical procedures were conducted with the exclusion of athletes that were involved in international competition. This resulted in the inclusion of 48 and 45 strictly club-level participants in the statistical analyses for Season One and Two, respectively. Consistent with the aforementioned findings, ROC curve analysis found the FMS composite cut-off score of 14.5 to maximize both the specificity and sensitivity of the test as a predictor of time-loss injury risk in the strictly club-level group. Fisher's exact tests revealed that those with FMS scores below 14.5 were significantly more likely to sustain injury than those with FMS scores above 14.5 in Season One (one-tailed, p=0.026), but not in Season Two. Sensitivity and specificity values corresponding to the FMS composite cut-off score of 14.5 in Season One were 0.33 and 0.94, respectively. Odds ratios revealed that when compared to club-level athletes with FMS scores above 14.5, those with FMS scores below 14.5 were 8.50 (95%CI: 0.985-73.33) times more likely to be injured in Season One. Statistical procedures for the group that was involved in international rugby, excluding the participants that only participated in club-level rugby, were not performed as the group was considered to be too small (n=20).

4.7 Interrater Reliability

The experienced, certified FMS rater involved in this study rated ten individuals alongside another experienced, certified FMS rater. In the context of real-time simultaneous testing, the FMS composite score demonstrated an ICC value of 0.930

(95%CI: 0.752-0.982), while, as seen in Table 5, kappa values for the individual FMS components ranged from 0.614 to 1.0, demonstrating substantial to perfect agreement (Landis & Koch, 1977).

Table 5. Interrater reliability for each of the individual FMS components.

FMS Component	% Agreement	Kappa	Level of Agreement*
Deep Squat	90	0.756	substantial
Hurdle Step	90	0.615	substantial
In-line Lunge	80	0.677	substantial
Shoulder Mobility	100	1.00	perfect
Active Straight-leg Raise	90	0.944	almost perfect
Trunk Stability Push-up	100	1.00	perfect
Rotary Stability Quadruped	100	1.00	perfect

*Landis & Koch (1977)

Chapter 5: Discussion

The FMS is a non-invasive, easily administered, quick and reliable assessment tool that evaluates the quality of functional movement, a proposed risk factor for injury in sport (Cook, Burton & Hoogenboom, 2006).

Rugby union, characterized by frequent, high-impact collisions between players in the absence of ample protective equipment, has one of the highest reported injury rates in sport (Brooks et al., 2005; Brooks & Kemp, 2008). The consequences of injury can be not only long-lasting, but devastating, as 1 in 10,000 athletes are reported to suffer a catastrophic non-fatal spinal injury per season (Brooks & Kemp, 2008). The most frequently reported cause for professional rugby athletes to retire is injury, of whom 35% report significant adverse effects on education, employment, family life or health from injury (Lee et al., 2001). For these reasons, it is imperative that contemporary research investigate potential risk factors for injury in order to develop effective injury prevention and therapeutic strategies. Investigating the utility of pre-season screening tools that simultaneously assess multiple potential risk factors for injury, such as the FMS, can lend to the development of these strategies.

Previous investigations have revealed that lower composite FMS scores and the presence of bilateral asymmetries (Kiesel, Butler & Plisky, 2014) are associated with significantly greater risk of injury in a number of sports and occupations (Butler et al., 2013; Chorba et al., 2010; Kiesel, Plisky & Voight, 2007; Lehr et al., 2013; Lisman et al., 2013; O'Connor et al., 2011; Shoejaedin et al., 2013). This was one of the first investigations to determine the relationship between both composite FMS score and bilateral asymmetries, as assessed by the FMS, and the risk of time-loss injury in experienced male rugby union athletes. The primary finding was that club- and international-level rugby union athletes with FMS scores less than 14.5 were at significantly greater risk of sustaining time-loss injuries than those with FMS scores greater than 14.5.

5.1 Experimental Design

This analytical study was based on the comparison of an outcome measure, the incidence of time-loss injury, between two groups: (1) those exhibiting FMS scores below the experimentally determined cut-off, and (2) those exhibiting FMS scores above the cut-off.

In many cohort studies, participants are separated prior to outcome measure data collection; however, the two cohorts in this investigation were not separated until all the outcome measures were obtained. Only after determining the FMS composite cut-off score through ROC curve analysis were the two cohorts statistically identified and compared. This was necessary in order to experimentally determine a FMS composite cut-off score that was associated with an increased risk of time-loss injury in rugby union.

Prior investigations of the relationship between FMS score and injury in sport have applied pre-determined FMS composite scores as predictors of injury risk. In several cases, the pre-determined FMS composite cut-off scores were demonstrated as predictive of injury in separate previous studies that investigated other, distinct sports. For example, in maintaining consistency with the findings of Kiesel, Plisky and Voight, who used ROC curve analysis to derive the FMS composite cut-off score of 14 in professional American football athletes, Chorba et al., (2010) used the FMS composite cut-off score of 14 to evaluate the ability of the FMS to predict injury in female NCAA soccer, basketball and volleyball athletes. Likely, the FMS cut-off score that best predicts injury risk for one sport may be distinct from that of another sport, especially when considering contact sports versus non-contact sports. The diversity of injury risk and profile across different sports should be considered in investigating a screening tool that serves the purpose of predicting injury risk in sport. Since this study was one of the first to investigate the relationship between both FMS composite score and bilateral asymmetries, and the risk of time-loss injuries in rugby union, receiver-operator characteristic curves were plotted in order to determine appropriate FMS composite cut-off scores. This ensured that the cut-off scores presented in this study effectively maximized sensitivity and specificity of the FMS, and were consequently best suited for classifying injury risk.

Previous investigations of FMS score and sport-related injury have employed the use of ROC curves in experimentally determining FMS composite cut-off scores (Kiesel, Plisky & Voight, 2007; Shoejaedin et al., 2013). Several other investigations that have explored FMS score and sport-related injury risk have separated cohorts prior to data collection on the basis of employing an FMS composite cut-off score established by prior research (Chorba et al., 2010; Lehr et al., 2013; Sorensen, 2009). These studies did not use ROC curves to derive an appropriate FMS composite cut-off score for their study population. This investigation set out to experimentally determine the most accurate FMS cut-off score through ROC curve analysis because limited research had investigated the ability of the FMS to predict the likelihood of time-loss injury in rugby union.

The surveillance time of this study spanned two competitive club-level rugby seasons. Participants performed the FMS prior to each of two consecutive competitive seasons, during which injury data were collected prospectively. The majority of FMS and injury studies have investigated the relationship between FMS score and likelihood of injury over the course of a single competitive season (i.e. Kiesel, Plisky & Voight, 2007; Chorba et al., 2010). Studies that collect data over the course of two competitive seasons, such as the design employed in the current study, produce more robust findings when compared to studies that collect data from only one competitive season. The inclusion of a second season of rugby union data collection allowed for the testing of the utility of the FMS composite cut-off score identified in Season One to an additional set of injury data.

This study evaluated the interrater reliability of the FMS measurements prior to preseason data collection. The ICC and kappa values for the FMS composite score and the individual FMS components, respectively, provide evidence that measurement error in administering the FMS was minimal, contributing to the reliability of the FMS measures.

5.2 Sample Size Evaluation

Cohort studies typically require large sample sizes when the prevalence of exposure is rare and/or the relative risk of the outcome occurring in exposed participants is small (Blettner, Heuer & Razum, 2000). Because of the substantial proportion of exposed participants and the high likelihood of injury associated with exposure, it was determined that the sample size was adequate in addressing the research questions posed in this investigation. Studies investigating the relationship between FMS composite score and injury in other athletic populations have used comparable, if not smaller, sample sizes (Chorba et al., 2010; Kiesel, Plisky & Voight, 2007; Shoejaedin et al., 2013; Sorenson, 2009).

5.3 The FMS Composite Score

5.3.1 Identification of an FMS Cut-off Score

5.3.1.1 ROC Curve Analyses and Diagnostic Odds Ratios

Receiver-operator characteristic curve analysis from Season One revealed that an FMS composite cut-off score of 14.5 maximized sensitivity and sensitivity of the screening test, effectively separating the participant pool into two cohorts with significantly distinct risks of injury. In comparing the likelihood of time-loss injury between cohorts in Season One, diagnostic odds ratio analyses indicated that participants with FMS scores less than 14.5 demonstrated a significant ten-fold increased likelihood of time-loss injury when compared to those scoring less than 14.5 on the FMS.

The ROC curve obtained from Season Two data indicated two potential FMS composite cut-off scores, confirming the appropriateness of the FMS composite cut-off score of 14.5 found in Season One and introducing an additional secondary cut-off score of 15.5 that was associated with meaningful differences in injury risk between cohorts. In Season Two, participants scoring less than 14.5 on the FMS demonstrated a significant a five-fold increased likelihood of time-loss injury, while those scoring less than 15.5 demonstrated a significant three-fold increased likelihood of time-loss injury. Reasons for the determination of the secondary FMS composite cut-off score of 15.5 in Season Two, but not Season One, are unclear. A greater proportion of participants scoring 15 on the FMS sustained time-loss injury in Season Two (72%) when compared to those sustaining time-loss injury in Season One (50%). Although the difference in proportions of participants scoring 15 and sustaining time-loss injury between Seasons was likely coincidental, it served to provide an additional secondary cut-off score that was able to classify participants into different risk categories in Season Two. Previous studies of athletes in any type of sport have not determined the FMS composite cut-off score 15.5 to effectively separate cohorts with significantly distinct likelihoods of injury (Kiesel, Plisky & Voight, 2007; Shoejaedin et al., 2013).

The difference in diagnostic odds ratio values associated with the primary FMS cutoff score of 14.5 between Season One and Season Two can be explained in part by the number of injuries observed in each season. The odds ratio for Season One, where 79 injuries were sustained, was found to be 10.42, while the odds ratio for Season Two, where 59 injuries were sustained was 4.97. According to team medical staff, an unusually high number of injuries took place during Season One. The greater incidence of injury in Season One could have amplified the trend that athletes with FMS scores below 14.5 were more likely to sustain injury.

The results from this investigation are very similar to those of Kiesel, Plisky and Voight (2007), who found a FMS composite cut-off score of 14 to predict the likelihood of “serious injury”, defined as “membership on the injured reserve and time-loss of three weeks”, in professional American football players when using ROC curve analysis (p.149). The participants were separated in the same way, as statistical analyses were performed on the basis of comparing the likelihood of injury between two cohorts: (1)

Those that exhibited FMS composite scores less than 14.5 and (2) those that exhibited FMS composite scores greater than 14.5.

The current findings provide additional evidence of the utility of the FMS composite cut-off score of 14.5 in identifying athletes at risk of injury, extending the generalizability of this FMS composite cut-off score from professional American football athletes (Kiesel, Plisky & Voight, 2007); female NCAA soccer, basketball and volleyball athletes (Chorba et al., 2010); Marine Corps officer candidates (Lisman et al., 2013; O'Connor et al., 2011); and firefighter candidates (Butler et al., 2013) to experienced rugby union athletes.

5.3.1.2 Specificity of the Cut-off Score

In order for the FMS to be deemed an effective tool for predicting injury risk in rugby union athletes its ability to accurately identify the potential disorder or condition of interest in exposed athletes is critical. In this case, the potential disorder or condition of interest was time-loss injury and the "exposed" athletes were those that exhibited FMS scores below the experimentally determined FMS composite cut-off score of 14.5. The ability to correctly identify athletes at risk of injury reflects the specificity of the test; highly specific tests are able to accurately recognize at-risk players with very few false positive results. When using the FMS composite cut-off score of 14.5, the specificity of the FMS was relatively high for both seasons. During Season One, all but one of the 18 athletes identified to be at significantly greater risk of injury by this FMS composite cut-off sustained time-loss injury, indicating a specificity of 0.95. Using the cut off of 14.5 with the Season Two results, all but two of the 18 athletes identified to be at significantly greater risk of injury sustained time-loss injury, indicating a specificity of 0.90. The presence of just one false positive result in Season One (6%) and two false positive results in Season Two (11%) indicates that the FMS composite cut-off score of 14.5 is conservative in its time-loss injury risk classification, as it minimizes false positive errors by making positive classifications only with strong evidence (Fawcett, 2006). The false positive in Season One and two false positives in Season Two were three different athletes, each of whom participated fully in club-level training and match-play. Their low FMS composite score and lack of time-loss injury status can simply be attributed to coincidence.

The high specificity values observed in this study are supported by the positive likelihood ratios values observed in Season One (+LR= 7.08) and Season Two (+LR=3.56).

The findings from this study confirm the findings of Kiesel, Plisky and Voight (2005), who, while investigating the relationship between composite FMS score and the likelihood of injury in American Football players, used ROC curve analysis to determine an FMS cut-off score of 14 that was associated with a specificity value of 0.91. Although Kiesel, Plisky and Voight (2005) reported an FMS cut-off value of 14, this value was used to separate the participants into two cohorts in the same way the cut-off value of 14.5 separated the participants in the current study: (1) Those with FMS scores below 14.5 (or less than or equal to 14) and (2) Those with FMS scores above 14.5 (or above 14). The specificity and positive likelihood ratio values observed in both seasons of this investigation indicate that the FMS, when using the composite cut-off score of 14.5, can be confidently used to rule in the condition of interest, time-loss injury, in male experienced rugby union athletes.

Less certain, however, was the likelihood of sustaining injury for athletes scoring below the secondary composite cut-off score of 15.5, as a specificity value of 0.65 was found in Season Two. This finding can be explained by the significant proportion of false positives (19%), players with FMS scores below 15.5 that remained uninjured, in Season Two. This finding further supports the utility of the FMS cut-off score of 14.5 to identify rugby union athletes at risk of time-loss injury.

5.3.1.3 Sensitivity of the Cut-of Score

While specificity was strong, when employing the FMS composite cut-off score of 14.5, the sensitivity of the FMS as a predictor of injury risk was weak. Weak sensitivity values in both seasons indicated that the test showed limited capability of recognizing players that were classified under low risk of time-loss injury. This was indicated by the high proportion of athletes who scored above 14.5 on the FMS and sustained time-loss injury. In Season One, 19 of the 50 (38%) athletes who scored above 14.5 on the FMS were uninjured, indicating a sensitivity of 0.35. Similarly, in Season Two, 18 of the 47 (38%) athletes who scored above 14.5 were uninjured, indicating a sensitivity of 0.36.

Despite the ability of the FMS composite cut-off score of 14.5 to accurately rule in the condition of time-loss injury in rugby athletes identified as being at high risk of injury, it offers limited capability in ruling out the condition in athletes identified as being at low risk of injury. Kiesel, Plisky and Voight (2005) also found that the FMS offered limited sensitivity when using a cut-off score that separated their American football athletes with FMS scores less than, or equal to 14 from those with scores greater than14. The sensitivity value associated with the FMS composite cut-off score of 15.5 in Season Two was similarly limited (0.64).

The limited sensitivity of the FMS when applied as a predictor of time-loss injury risk in rugby union can be explained by the inherent danger involved in the sport. Regardless of FMS score, during both seasons only 30% of players were uninjured. The inability of the FMS to rule out the likelihood of injury in rugby union athletes is confirmed by the negative likelihood ratios observed in Season One (-LR=0.72) and Season Two (-LR=0.71). These values indicate that those athletes with FMS scores above 14.5 are only marginally less likely to sustain injury than those with lower FMS scores. Low sensitivity and negative likelihood ratios that approach the value 1 can be explained by the high risk of injury that is inherent to the sport, regardless of athletes' functional movement quality.

Epidemiological studies of rugby union have not only revealed high injury rates, but have prospectively identified numerous intrinsic and extrinsic risk factors for injury (refer to section 2.1). Surely, depending on mechanism of injury and injury type, the incidence of certain injuries common in rugby union are likely unrelated to the quality of functional movement. For example, the likelihood of sustaining a concussion, one of the most common match injury diagnoses in rugby union, seems unlikely to be related to FMS score at all (Brooks & Kemp, 2008). The multifactorial nature of injury risk in rugby union makes it difficult to accurately determine the impact of the quality of functional movement, as assessed by the FMS, on time-loss injury risk in comparison to other risk factors for injury. Although the FMS can be used to accurately rule in the likelihood of injury in certain rugby union athletes, the various contributors to injury risk that have been identified by previous research (Brooks & Kemp, 2008; Chalmers et al., 2012) can explain for the low sensitivity values of the test observed in this study.

5.3.1.4 Factors Influencing Time-loss Injury

The relationship between FMS scores below 14.5 and time-loss injury risk in rugby union athletes can be explained by the FMS's ability to quantify the various potential and confirmed risk factors for injury that are observable during the functional movement evaluation (Cook, Burton & Hoogenboom, 2006). An important independent risk factor for injury in rugby union is previous injury (Brooks & Kemp, 2008; Chalmers et al., 2012; Quarrie et al., 2001). Rugby union athletes with low FMS scores are likely to have sustained previous injuries, as programmed altered movement patterns, often the result of previous injury, are conducive to poor FMS performance (Cook, Burton & Hoogenboom, 2006). Since previous injury remains one of the most important risk factors for injury, not only in rugby union (Brooks & Kemp, 2008; Chalmers et al., 2012; Quarrie et al., 2001), but in general sport (Van Mechelen et al., 1996), these individuals are likely at greater risk of injury because they have extensive injury histories underlying low FMS scores.

In addition to previous injury, a number of other potential risk factors for injury in rugby union are relevant to FMS performance and are likely contributors to low FMS scores. Such potential factors include bilateral movement asymmetry, the presence of programmed altered movement patterns and limitations to the following: functional movement quality, trunk and core strength and stability, muscular strength, balance, motor control, range of motion, neuromuscular coordination, and static and dynamic flexibility (Cook, Burton & Hoogenboom, 2006; Perry & Koehle, 2013). It is likely that the association between FMS scores below 14.5 and time-loss injury in rugby union athletes of this study is explained by the on-field interplay of not only previous injury, but also a number of these other potential risk factors for injury.

5.3.2 Limitations of Using Pearson Correlation, Linear Regression and Binomial Logistic Regression

Despite odds ratio analyses revealing significantly greater likelihood of time-loss injury in participants with FMS scores less than 14.5 when compared to those scoring greater than 14.5 on the FMS, Pearson correlation and linear regression were unable to establish any significant relationships between FMS composite score and the incidence of injury. Additionally, neither FMS composite score, nor any of the individual 7 FMS components were found to be significantly predictive of time-loss injury status. This is likely due to the substantial proportion of athletes that sustained time-loss injury (71% and 69% in Season One and Season Two, respectively), irrespective of their FMS score, during the data collection period. A multitude of risk factors for injury that are unrelated to functional movement status have been identified through epidemiological research in rugby union such as ground and weather conditions, physical fitness, and experience (Brooks & Kemp, 2008) and may explain the lack of a clear statistical relationship between FMS composite score and the likelihood of time-loss injury. Likely, the high rate of injury observed in this investigation for all participants, influenced by a number of risk factors that are unrelated to functional movement status, inhibited the potential for any of the independent variables (FMS composite score and FMS components) to reach significance in the Pearson correlation or linear regression procedures or the logistic regression injury prediction model. The lack of significant findings when employing Pearson correlation, linear regression and binomial logistic regression indicates that FMS composite score, as a continuous variable, is unable to predict the likelihood of time-loss injury in rugby union athletes.

This warranted the need for a higher order of analysis to take place in identifying the relationship between FMS composite score and the risk of time-loss injury, such as dichotomizing FMS scores through use of a cut-off score. In the current study, only when FMS composite scores were grouped into two ranges (i.e. less than 14.5 and greater than 14.5) did a clear relationship exist between FMS composite score and the likelihood of time-loss injury. These findings underscore the importance of employing appropriate statistical procedures when exploring the prediction of injury risk.

5.3.3 Non-Contact Time-loss Injuries

Since a significant proportion of time-loss injuries in rugby union are unlikely to be related to the quality of functional movement, the relationship between FMS score and time-loss injuries sustained by non-contact mechanisms was investigated. This involved analyses of the data with all injuries sustained via tackling, being tackled, rucks, mauls, scrums and collisions excluded. In agreement to the ROC curve findings when using the FMS to predict overall time-loss injury likelihood, ROC curve analysis of the non-contact injury data, exclusively, revealed that the FMS composite cut-off score of 14.5

maximized sensitivity and specificity of the test when predicting non-contact time-loss injuries. However, when using the FMS composite cut-off score of 14.5, diagnostic odds ratios and corresponding Fisher's exact tests were unable to demonstrate a significant relationship between FMS composite score and the likelihood of time-loss injury sustained by a non-contact mechanism.

There are no clear explanations justifying the lack of association between non-contact injury risk and composite FMS score when odds ratios reveal a significant association between overall time-loss injury risk and FMS score. One might predict that FMS score would be more predictive of non-contact injuries than overall injuries, since functional movement quality is likely more closely related to the incidence of the muscle strains and tendinopathies associated with non-contact injuries, rather than incidence of the haematomas, lacerations, concussions and fractures associated with contact injuries. It is possible that when investigating the relationship between the risk of non-contact injury and FMS composite score, the exclusion of injuries sustained via contact mechanisms effectively reduced the total number of injured players to a value lower than what was necessary to reach statistical significance. In Season One, only 56% of those players who sustained time-loss injuries (n=48) had non-contact injuries. Even fewer were observed in Season Two (n-65), where only 15 of 45 injured players had non-contact time-loss injuries. The non-contact injury incidence, much smaller in comparison to the overall injury incidence, may have effectively reduced the potential for the association between non-contact injury and FMS composite score to reach statistical significance. In support of this finding, previous research has demonstrated that the majority of injuries in rugby union are sustained via contact mechanisms (Brooks & Kemp, 2008).

5.3.4 Club-level Rugby Union

Since some rugby union research has demonstrated that injury rate increases with level of play (Brooks & Kemp, 2008), and a significant proportion of the participant pool in the current study were members of representative and international teams, statistical analyses were performed for the proportion of athletes that exclusively participated in club-level rugby in the absence of any other level of competition.

When ROC curve analyses and subsequent statistical procedures were applied to the data from participants who were exclusive to club-level play, those with FMS scores below 14.5 were 8.5 times (95%CI: 0.985-73.33) more likely to sustain time-loss injury than those with FMS >14 in Season One, but not in Season Two. However, since the 95% confidence interval for the odds ratio estimate in Season One spanned across the number 1.0, it cannot be determined with certainty that the club-level athletes with FMS scores less than 14.5 were more likely to be injured than those with scores greater than 14.5.

A possible explanation for the limited ability of the FMS to predict time-loss injury risk in club-level athletes when compared to the entire participant pool is the lack of participants when excluding the athletes that played international-level rugby during the surveillance period. It is possible that the club-level participant pool of 48 athletes in Season One and 45 athletes in Season Two did not provide for enough FMS and time-loss injury data in order for the statistical procedures to demonstrate a consistent, meaningful relationship between FMS score and the likelihood of time-loss injury. For this reason, the findings of this study do not provide evidence of player status (elite vs club) influencing the ability of FMS to predict the risk of time-loss injury.

5.4 Bilateral Asymmetries

The majority of FMS research to date has only considered the composite FMS score as a risk factor for injury, despite the fact that a major goal of the FMS is to assess the quality of functional movement for both left and right sides during bilateral movement tasks (Cook, Burton & Hoogenboom, 2006). Kiesel, Butler and Plisky (2014) demonstrated the ability of bilateral movement asymmetries, as identified by the FMS, to predict the likelihood of injury in professional American football athletes (see 2.3.1). Additionally, in their study, the presence of one or more bilateral asymmetries in combination with FMS scores below, or equal to, 14 was associated with an even greater risk of injury.

In the current investigation, no clear association between the presence of bilateral movement asymmetries and time-loss injury was demonstrated through extensive statistical testing including the use of ROC curves, 2x2 contingency tables with corresponding odds ratios, Fisher's exact tests, binomial logistic regression analysis, linear regression analysis and Pearson correlation analysis.

Reasons underlying the lack of an association between bilateral asymmetries, as measured by the FMS, and injury risk are unclear. One proposed explanation is that the presence of bilateral asymmetries, as identified by the FMS, is simply not a strong enough predictor of injury risk to be statistically associated with time-loss injury likelihood, particularly in a sport with a very high injury incidence. It is likely that a stronger predictor of injury risk is the overall quantification of an individual's functional movement quality, indicated by the FMS composite score, rather than the quantification of bilateral asymmetries- just one feature of that the FMS offers. Despite finding a meaningful relationship between FMS composite score (as a dichotomous variable separated by a cut-off value) and time-loss injury, the influence of bilateral asymmetries (as both a continuous and dichotomous variable) on time-loss injury risk, if any, was too subtle to reach statistical significance in this study.

5.5 Pre-season Injury Risk Assessment and Injury Prevention

Based on the findings of this study, the FMS composite score should be a considered a valuable component of a comprehensive preseason injury risk assessment protocol for its ability to accurately and rapidly identify at-risk rugby union athletes when using the FMS composite cut-off value of 14.5. Specifically, the FMS could lend itself to comprehensive pre-screening protocols that consider other risk factors for injury in rugby union, such as injury history, measures of physiologic function, and demographic information such as playing experience and anthropometric details. Few studies have examined the utility of comprehensive preseason injury risk assessments that involve the FMS in addition to other potential indicators of injury risk. Lehr et al. (2013) investigated the utility of an injury risk prediction algorithm comprised of FMS score, Lower Quartile Y-Balance Test™ score, injury history and demographic information in collegiate football, basketball, soccer, baseball, softball, field hockey, ice hockey and volleyball athletes. Collegiate athletes who were grouped in the "high risk" category by the injury prediction algorithm were at significantly greater risk than their “low risk” counterparts (RR: 3.4, 95%CI: 2.0-6.0). In light of the findings of Lehr et al. (2013), future investigations should focus on comprehensive preseason screening tools. Research on the topic of comprehensive injury risk assessment protocols could inform athletic medical personnel in developing injury prevention programs for athletes participating in inherently dangerous sports such as rugby union.

The finding of a secondary FMS cut-off score (15.5) in Season Two suggests that multiple FMS cut-off scores can lend themselves to a risk classification system that involves more than two injury risk categories. Results from this investigation indicate that not only rugby union athletes scoring below 14.5 on the FMS are at significantly greater risk of injury than their higher scoring counterparts, but athletes scoring below 15.5 on the FMS are also at significantly greater risk of sustaining injury when compared to those scoring above 15.5. Team medical staff should pay special attention to players that are identified by the FMS as being at an elevated risk of injury, as efforts to improve the FMS scores of individuals who score below 15.5, and especially those who score below 14.5, are likely to reduce the injury rates of a given rugby union team. One such intervention known to improve functional movement quality, as assessed by the FMS, is yoga (Cowen, 2010). In an investigation of 108 firefighters, Cowen (2010) revealed that participating in 4 yoga sessions significantly improved FMS scores from a mean score of 13.3±2.3 to 16.5 ±2.2. Additionally, Kiesel, Plisky and Butler (2011), revealed that a 7-week individualized intervention involving self- and partner stretching, self-administered trigger point treatment and corrective mobility exercises resulted in improved FMS composite scores in professional American football athletes. Injury prevention efforts in rugby union athletes should focus on improving FMS composite score, rather than focus on a specific FMS movement, as binomial logistic regression did not identify any particular FMS components to be predictive of time-loss injury.

5.6 Limitations

A number of limitations must be considered when interpreting the findings from this study.

5.6.1 Injury History Data

Although injury history data were collected from all participants, it was only used as a method of identifying players that did not meet the inclusion criteria. Specifically, only players free of "injury sustained within the 30 days preceding testing that excluded the athlete from participating in practice and/or competition, or recent surgical intervention that limited the athlete's participation in sport due to physician-imposed restriction" were included in the study. As previous injury is frequently reported as a risk factor for injury in not only rugby union (Brooks & Kemp, 2008; Chalmers et al., 2012; Quarrie et al., 2001), but in general sport (Van Mechelen et al., 1996), injury history data could lend itself to developing an algorithm with FMS and previous injury components. Such algorithms may evaluate injury risk in sports such as rugby union on a more comprehensive, holistic basis. An algorithm with these features has the potential to offer greater sensitivity and specificity for injury than the FMS alone, demonstrating an increased ability to rule-in the likelihood of injury in suspected at-risk athletes and rule-out the likelihood of injury in athletes not suspected to sustain injury. This investigation did not attempt to incorporate a previous injury history component into such an algorithm due to the very high proportion of participants that had sustained previous injury (100%).

5.6.2 Proportion of Previously Injured Participants

Injury history questionnaires revealed that every participant had sustained previous injury prior to their involvement in the study. As previous injury is one of the most frequently cited risk factors for injury in rugby union, it can be argued that the participant pool involved in this study was at high risk of injury, irrespective of functional movement status (Brooks & Kemp, 2008; Chalmers et al., 2012; Quarrie et al., 2001). It was expected that very few athletes would be without rugby-related injury history prior to their involvement in the study, since participants were experienced athletes in a contact sport with very high reported injury rates (Brooks et al., 2005).

5.6.3 Inflation of the Odds Ratio

The same sets of FMS and injury data in Season One and Season Two were used to identify an appropriate FMS composite cut-off score as well as evaluate the ability of the cut-off score to predict injury risk. In using the same data to both determine and evaluate the cut-off score as predictive, the likelihood of finding a significant relationship between FMS score and injury risk is greater than when using a cut-off score that was determined by a separate, unrelated data set. Preferably, the cut-off score would have been identified through a separate, preliminary prospective investigation. The predictive ability of this cut-off score would then be evaluated by an additional investigation that prospectively collected injury data. This would prevent the inflation of the odds ratios that may occur when using the same data set to both determine and evaluate the cutoff score. Given the time-line of this investigation, and the recruitment of all available experienced rugby union players in the geographic region for the initial season, performing two prospective studies was simply not feasible. Still, FMS and injury data were collected over the course of two competitive seasons. Although the participant pools changed very little between the two seasons, the study was able to test the utility of the FMS cut-off score identified in Season One as a predictor of injury risk in Season Two.

5.6.4 Functional Movement Status

Since the collection of FMS data only occurred prior to each 4-month season, the functional movement status of a given participant at the time of injury during the competitive season may have changed from his preseason status. Injuries are known to affect fundamental movement patterns in compensation of the injury-associated pain (Cook, Burton & Hoogenboom, 2006). It is possible that the FMS scores of participants injured mid-season could have changed after injury and consequently may have facilitated some systematic measurement error. Nonetheless, each injury in Season One was associated with the FMS score achieved in the preseason data collection period prior to Season One, while injuries in Season Two were associated with FMS scores achieved in the Season Two preseason.

5.6.5 Sample Size

Despite reaching significance when comparing the injury rates of athletes above and below the FMS cutoff of 14.5, indicating a nonrandom association between FMS composite scores below 14.5 and injury, wide confidence intervals indicated a large breadth of uncertainty around the odds ratio estimates for Season One (OR: 10.42, 95%CI: 1.28-84.75) and Season Two (OR: 4.97 95%CI: 1.02-24.19). Studying a larger group of rugby union athletes would have produced more certain odds ratio estimates indicated by more precise confidence intervals.

5.6.6 Heterogeneity of the Participant Pool

Although all of the participants were active competitors in the 2013 Vancouver Island Elite or 1st Division leagues and/or the 2014 Canadian Direct Insurance Premier or 1st Division Leagues, a substantial number of athletes also played for international, provincial, or other elite competitive representative sides during the regular season. Data were collected for injuries sustained during all possible competitions, so long as they took place during the Vancouver Island League (September 2013- December 2013) and Canadian Direct Insurance League (January 2014- April 2014) regular seasons. The participant pool was heterogeneous to level of play and experience. Details of the representative and international involvements of the study participants (i.e. team and level of competition) can be found in Appendix F. Since some rugby union research has demonstrated that injury rate increases with level of play, it is possible that some participants involved in the study were at a greater risk of injury due to their participation in representative or international rugby union (Brooks & Kemp, 2008). Nonetheless, all eligible participants were included in the statistical analyses in order to encourage robust findings that were generalizable to the population of experienced, male, rugby union athletes.

In an attempt to control for the effect of level of play on the risk of time-loss injury, statistical analyses were performed for the proportion of athletes that participated in strictly club-level rugby union throughout the surveillance period. The results from these procedures are interpreted in section 5.3.5.

Along with the majority of the 119 nations registered with the International Rugby Board, Canadian rugby does not host a professional league (IRB, 2014). For this reason, the Vancouver Island club-level rugby competition features both Canadian national team athletes and strictly club-level athletes. Studying a group heterogenous to level of play produces findings that are more robust and generalizable to experienced rugby union athletes in Canada and the majority of the 119 rugby nations when compared to findings produced from studying a more defined population.

5.7 Recommendations for Future Research

Separate, prospective preliminary investigations should be conducted in order to determine appropriate FMS composite cut-off scores for various sports before additional investigations explore the relationship between injury risk and FMS composite scores above and below the predetermined cut-off scores. Evaluating the utility of injury prediction algorithms incorporating other risk factors for injury, such as injury history, demographic information and scores from standardized tests of physiologic function in addition to the FMS will provide for superior injury risk assessments at a more comprehensive level. Evaluating such algorithms in rugby union and other high contact sports will lead to the development of more sensitive and specific preseason assessments that have the ability to accurately rule in and rule out the likelihood of injury in athletes, thereby informing effective injury prevention programs. The multifactorial nature of injury risk in sport, particularly in that of rugby union, warrants holistic injury risk assessments and injury prevention strategies that ameliorate multiple risk factors for injury. This is made evident by the low sensitivity for injury associated with the FMS in this study as well as in the work of Kiesel, Plisky and Voight (2007), preventing the FMS from standing alone as an accurate predictor of sport-related injury risk. Additionally, the inclusion of female athletes in future research would provide an important step in rugby union injury prevention, as female participation in rugby union is rapidly growing.

5.8 Conclusions

This study was one of the first to investigate the relationship between composite FMS score and the presence of bilateral movement asymmetries on the risk of injury in male rugby union athletes. The findings of this study add to the body of research investigating the utility of the FMS as an injury risk predictor in sport. The results suggest that experienced male rugby union athletes with preseason FMS scores below 14.5 are 5-10 times more likely to sustain time-loss injury in a competitive season when compared to athletes with FMS scores above 14.5. The elevated risk of injury for rugby union athletes scoring below 14.5 on the FMS in the current study supports the findings of previous investigations on professional American football athletes (Kiesel, Plisky &

Voight, 2007); female NCAA soccer, basketball and volleyball athletes (Chorba et al., 2010); Marine Corps officer candidates (Lisman et al., 2013; O'Connor et al., 2011); and firefighter candidates (Butler et al., 2013) despite the relatively high injury incidence reported in rugby union (Brooks et al., 2005). No significant association was found between the presence of bilateral movement asymmetries and the risk of time-loss injury.

The findings indicate that the quality of fundamental movement, as assessed by the FMS, is predictive of time-loss injury risk in experienced rugby union athletes and should be considered an important preseason player assessment tool. The FMS is highly specific and can confidently be used to quickly and accurately rule in the likelihood of injury in athletes scoring below 14.5; however, low sensitivity for injury values indicate that the screen cannot be used to rule out the risk of injury in rugby union athletes. This prevents the test from standing alone as a complete injury risk assessment tool in rugby union. The FMS should be used in conjunction with other means of injury-risk assessment because of the low sensitivity of the screen, as injury in rugby union and other sports is determined by many factors other than fundamental movement quality.

It should be noted that athletes exhibiting high FMS scores are still at substantial risk of injury due to the inherent danger involved in the sport. Ultimately, the risk of injury in rugby union is so multifactorial in nature that no single screening tool is likely to accurately predict the likelihood of injury with high sensitivity and specificity values. Since rugby union, characterized by forceful collisions in the absence of effective protective equipment, stands out from other popular team sports with regards to inherent danger, it burdens a unique injury risk on its athletes. Because of the exceptionally high injury rate in rugby union when compared to other sports, findings from this study are primarily generalizable to experienced, male rugby union athletes.

The significant association between FMS composite scores below 14.5 and rugby-related time-loss injury implies that rugby union athletes with FMS scores below 14.5 should participate in interventions that aim to improve stability, mobility and functional movement quality in order to reduce their injury risk (e.g. yoga). Special attention should also be paid to athletes scoring below 15.5 on the FMS, as a significantly elevated risk of injury was observed for athletes scoring below 15.5 in Season Two. Since binomial logistic regression did not identify any specific FMS components as predictive of time-loss injury, injury prevention efforts in rugby union athletes should focus on improving all aspects reflected in the 7 movements in the FMS leading to the composite FMS score. Results from this investigation provide important insight that could direct development of effective injury prevention strategies in rugby union. Future research on the topic of comprehensive pre-screening protocols that include FMS performance, injury history, demographic and physiologic components for all rugby athletes, including female players, is warranted.

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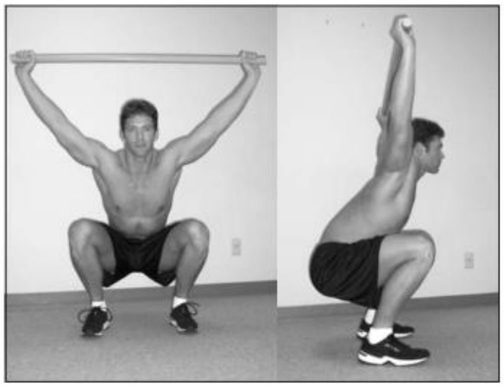
Appendix A: FMS Test Descriptions and Scoring Criteria

It should be noted that for each of the 7 FMS tests, participants are permitted up to 3 attempts to demonstrate the movement task. Bilateral tests allow up to 3 attempts bilaterally. The highest score of the three attempts is then recorded. If scores differ bilaterally, the lowest of the 2 scores is recorded; however the presence of asymmetry is noted. Finally, for every test, an individual is given a score of 0 if pain is felt anywhere in the body during the movement task and the painful area is recorded.



III

II

I

(Kiesel, Plisky & Voight, 2007)

A.1 Deep Squat

The starting position for this test involves the participant placing his/her feet in line with the sagital plane at shoulder width apart. A well, the dowel provided in the FMS testing kit will be held overhead with the shoulders flexed and abducted and the elbows extended. Next, the participant performs a complete squat, maintaining contact between the floor and the heels, with the head and chest facing forward. If this is achieved, a score of III is assigned. If a score of III is not achieved, the participant will perform the same movement with a 2x6 board under the heels. If the participant is able to do a complete squat while maintaining heel contact with the board, a score of II is assigned. If the participant cannot complete the movement with the board a score of I is assigned.

III

II

I

(Kiesel, Plisky & Voight, 2007)

A.2 Hurdle Step

The starting position for this test involves the participant aligning his/her feet together with the toes making contact with the base of the hurdle. The hurdle will be adjusted to the height of the participant’s tibial tuberosity. As well, the dowel will be held across the shoulders. The movement involves the participant slowly stepping over the hurdle and touching his/her foot while maintaining extension of the stance foot. Next, the swing foot is returned to the starting position. If one repetition is completed bilaterally, a score of III is awarded. If the participant uses a compensatory strategy, such as by twisting, leaning or moving the spine, a score of II is assigned. If loss of balance occurs or the participant makes contact with the hurdle a score of I is assigned. The lowest score of the bilateral test is recorded, though it is noted when asymmetry (difference in right and left side scores) is present.

III

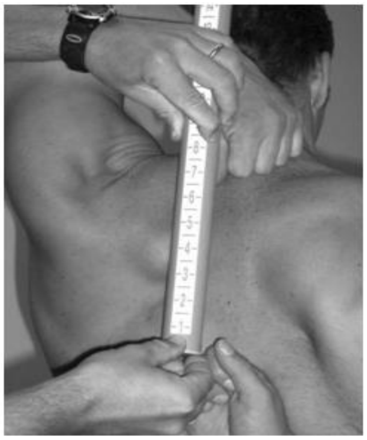
II

I

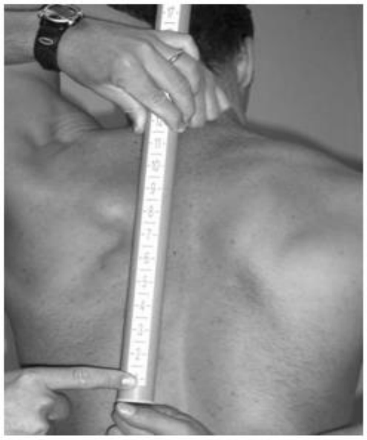
(Kiesel, Plisky & Voight, 2007)

A.3 In-line lunge

First, the length of the participant’s tibia is measured from the floor to the tibial tuberosity. The starting position for this test involves the participant placing the end of his/her heel on the end of the 2x6 board. Using tibial length, a mark on the 2x6 board is made from the end of the participant’s toes. The participant then places the heel of the opposite foot on the mark on the board. The dowel is held behind the back with the hand opposite the front foot grasping the dowel at the cervical spine, while the other hand grasps the dowel at the lumbar spine. The dowel should make contact with the head, thoracic spine, and sacrum. The movement involves the participant lowering his/her back knee to make contact with the board. A score of III is assigned if one successful repetition (out of up to 3 attempts) is completed, a score of II is assigned if a compensatory strategy is used, and a score if I is assigned if a loss of balance or an incomplete rep is demonstrated. The movement is performed bilaterally, and the lowest score is recorded. The presence of asymmetry is also recorded.



III



II

I

Clearing Exam

(Kiesel, Plisky & Voight, 2007)

A.4 Shoulder Mobility

First, the participant's hand is measured from the distal wrist crease to the end of the third digit. Next, the participant is instructed to make a fist with each hand. The movement involves the participant to demonstrate a maximally adducted, extended and internally rotated position with one shoulder, and a maximally abducted, flexed and externally rotated position with the other shoulder so that the fists are arranged on the back. The distance between the two fists on the back, using the closest two points of the fists, is then measured. This motion is repeated bilaterally. A score of II is assigned if the fists are within one of the participant's measured hand length, a score of II is assigned if the fists are within 1.5 hand lengths, and a score of I is assigned if the fists fall outside 1.5 hand lengths. The lowest score of the bilateral test is recorded, though it is noted when asymmetry is present. Following this test, a clearing test is administered. This involves the participant placing his/her hand on the opposite shoulder and attempting to point the elbow upward. If pain occurs from performing this movement with either shoulder, a score of 0 is assigned for the shoulder mobility test.

III

II

I

(Kiesel, Plisky & Voight, 2007)

A.5 Active Straight Leg Raise

The starting position for this test involves the participant lying supine with the arms in the anatomical position and the head making contact with the floor. The 2x6 board is placed under the knees. The anterior superior iliac spine and mid-point of the patella are marked. By using these marks, a third mark is made identifying a mid-point of the thigh. The dowel is then placed vertically on the ground at the mid-point of the thigh. The movement involves the subject lifting the unmarked leg with a dorsiflexed ankle and extended knee while maintaining contact between the knee of the opposite leg and the board. A score of II is assigned if the malleolus of the raised leg is able to move past the dowel. If the malleolus does not pass the dowel, then the dowel is placed vertically on the ground in line with the end range of the malleolus. In this case, if the placement of the dowel lies between the thigh mid-point and the patella, a score of II is assigned. If the placement of the dowel lies distal to the knee, a score of 1 is assigned. This test is repeated for the opposite leg, and the lowest score is recorded. The presence of asymmetry is also recorded.

III

II

I

Clearing Exam

(Kiesel, Plisky & Voight, 2007)

A.6 Trunk Stability Push-up

The participant will begin in a prone position with both feet together and hands placed shoulder width apart with the thumbs at forehead height for males or chin height for females. With fully extended knees and dorsiflexed ankles, the participant attempts to perform one push-up without lag in the lumbar spine. Completion of this task earns a score of III. If the participant cannot correctly perform this movement, the hands are lowered with thumbs aligned with the chin for males and the clavicles for females. If the push-up can be performed correctly from this position, a score of II is assigned. A score of 1 is assigned if this movement cannot be performed correctly from this position. Following performance of this test, a clearing test is administered. This involves the participant performing a press-up in the push-up position into spinal extension. If pain occurs, a score of 0 is assigned for the trunk stability push-up test.

Figure 12. *Rotary Stab Start III*

Figure 13. *Rotary Stab Finish III*

III

Figure 14. *Rotary Stab Start II*

Figure 15. *Rotary Stab Finish II*

II

Figure 16. *Rotary Stab Start I*

I

Figure 17. *Spinal Flexion Clearing Test*

(Cook, Burton & Hoogenboom, 2006)

A.7 Rotary Stability

The starting position for this test involves the participant in quadruped, with shoulders and hips at 90 degrees to the torso. Knees are arranged at 90 degrees, with ankles in dorsiflexion. The movement involves the participant flexing the shoulder and extending the same side hip and knee. The leg and hand are only required to clear the floor by roughly 6 inches. Next, the same shoulder is extended and the same knee flexed so that the elbow and knee make contact before returning to the starting position. This is performed bilaterally for up to 3 repetitions. A score of III is given for completing this movement as described. If this movement cannot be achieved, the participant is instructed to perform the movement as described, but in a diagonal pattern using the opposite hip and shoulder. If this diagonal movement cannot be completed, a score of 1 is given. In the case of differing scores bilaterally, asymmetry is noted and the lowest score of the bilateral test is recorded. Following this test, a clearing exam is performed. This involves the participant assuming a quadruped position, then rocking backward and touching the buttocks to the heels and the chest to the thighs. The hands should remain on the floor, reaching out in font of the body as far as possible. If pain occurs, a score of 0 is given for the rotary stability test.

Appendix B: Demographic Questionnaire

Demographic Questionnaire

Name:_______________________________ **ID:**_____________________

Birth date:	____/		____/	____/	
	(m)		(d)	(y)	
Age:___________________					
Height:________________	m				
Weight:__________________	kg				
Handedness	R		☐	L	☐
Dominant Foot	R		☐	L	☐

# of years playing rugby union:__________________________

Date last participated in rugby union training:______________

Current Injury Status: ____________________________________

Appendix C: Injury History Questionnaire

Injury History Questionnaire

Name:______________________________ ID:____________________

Musculoskeletal surgery history (if multiple use reverse):

Date ____/ ____/ ____/

(m) (d) (y)

Type of surgery:___________________

Injured body part:___________________

Side of body injured: R L

Most recent injury:

Date ____/ ____/ ____/

(m) (d) (y) ☐

Type of injury

Injured body part:_________________________ ☐

Side of body injured: R L

Did this injury prevent you from full participation at training/games?

Y N

Previous non-surgical time-loss injuries (include date, type of injury, injured body part and side of body injured):

Use reverse if more room is needed.

Appendix D: Follow-up Questionnaire

Follow-Up Questionnaire

Name:______________________________ ID:______________________

Did your training status significantly change over the season?

Y N

If so, how did it change?

Did you regularly participate in any mobility interventions (e.g. Yoga) that you were not participating in prior to the first FMS™ testing session?

Y N

If so,

Type of intervention:____________________________________

Length of participation:__________________________________

Duration of each session:_________________________________

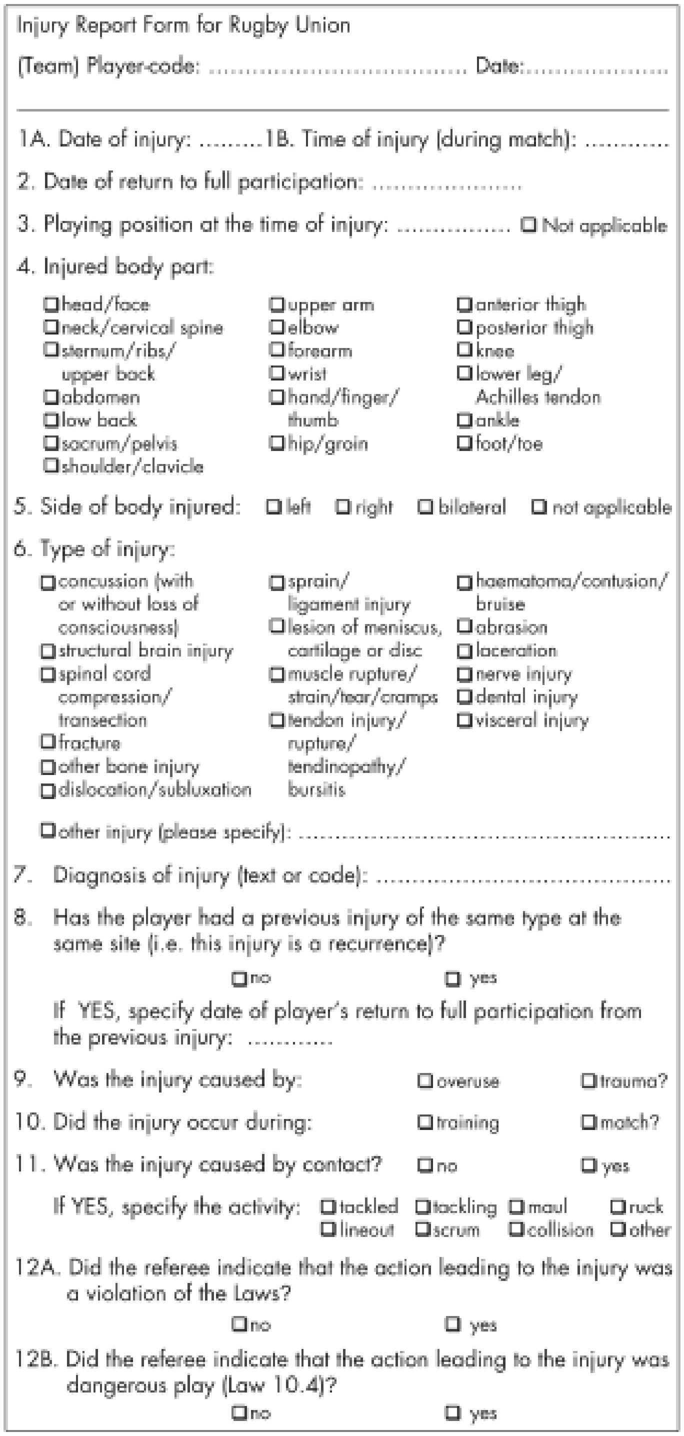
# of sessions per week:☐__________________________________

# of weeks of team training missed during the regular season:____________

# of matches missed in the regular season:_________________

# of matches missed in the regular season due to rugby-related injury:_______________________

Appendix E: Injury Report Form for Rugby Union



Injury Report Form for Rugby Union

(Team) Player-code: .... Date:.....................

1A. Date of injury: ....1B. Time of injury (during match): ....

2. Date of return to full participation: ....

3. Playing position at the time of injury: .... ☐ Not applicable

4. Injured body part:

- ☐ head/face
- ☐ neck/cervical spine
- ☐ sternum/ribs/ upper back
- ☐ abdomen
- ☐ low back
- ☐ sacrum/pelvis
- ☐ shoulder/clavicle
- ☐ upper arm
- ☐ elbow
- ☐ forearm
- ☐ wrist
- ☐ hand/finger/ thumb
- ☐ hip/groin
- ☐ anterior thigh
- ☐ posterior thigh
- ☐ knee
- ☐ lower leg/ Achilles tendon
- ☐ ankle
- ☐ foot/toe

5. Side of body injured: ☐ left ☐ right ☐ bilateral ☐ not applicable

6. Type of injury:

- ☐ concussion (with or without loss of consciousness)
- ☐ structural brain injury
- ☐ spinal cord compression/ transection
- ☐ fracture
- ☐ other bone injury
- ☐ dislocation/subluxation
- ☐ sprain/ ligament injury
- ☐ lesion of meniscus, cartilage or disc
- ☐ muscle rupture/ strain/tear/cramps
- ☐ tendon injury/ rupture/ tendinopathy/ bursitis
- ☐ haematoma/contusion/ bruise
- ☐ abrasion
- ☐ laceration
- ☐ nerve injury
- ☐ dental injury
- ☐ visceral injury

☐ other injury (please specify): ....

7. Diagnosis of injury (text or code): ....

8. Has the player had a previous injury of the same type at the same site (i.e. this injury is a recurrence)?

☐ no ☐ yes

If YES, specify date of player's return to full participation from the previous injury: ....

9. Was the injury caused by: ☐ overuse ☐ trauma?

10. Did the injury occur during: ☐ training ☐ match?

11. Was the injury caused by contact? ☐ no ☐ yes

If YES, specify the activity: ☐ tackled ☐ tackling ☐ maul ☐ ruck ☐ lineout ☐ scrum ☐ collision ☐ other

12A. Did the referee indicate that the action leading to the injury was a violation of the Laws?

☐ no ☐ yes

12B. Did the referee indicate that the action leading to the injury was dangerous play (Law 10.4)?

☐ no ☐ yes

(Fuller et al., 2007)

<u>Additional Question:</u> *During which form of rugby union (7s or 15s) did the injury occur?*

Appendix F: Representative and International Involvements of the Study Population

Table F1. Representative and International Involvements of the Study Population (n=76)

Competition	# of Participants*
HSBC 7s World Series (National Rugby 7s Team)	18
International Matches (National and "A" Rugby 15s Team)	15
Sport Canada Carded Athletes (National Team training environment)	19
Las Vegas International 7s Tournament (UVIC** 7s Team)	22
National University 7s National Championship (UVIC 7s Team)	21
Under-20 International Matches (National Under-20 Team)	8

* Competing as a member of one representative team did not exclude the availability to play for other Canadian National Teams or representative teams.

**University of Victoria

Appendix G: The Most Frequently Injured Sites Among Participants

Table G1. The Most Frequently Injured Sites Among Participants in Season One

Injury Site	# of Injuries
Head/neck/face	12
Posterior Thigh	11
Ankle	10

Table G2. The Most Frequently Injured Sites Among Participants in Season Two

Injury Site	# of Injuries
Shoulder/clavicle	13
Knee	8
Ankle	7
Head/neck/face	7

Appendix H: Certificate of Approval- Human Research Ethics Board

Human Research Ethics Board
Office of Research Services
Administrative Services Building
PO Box 1700 STN CSC
Victoria British Columbia V8W 2Y2 Canada
Tel 250-472-4545, Fax 250-721-8960
Email ethics@uvic.ca Web www.research.uvic.ca

University of Victoria

Certificate of Approval

PRINCIPAL INVESTIGATOR:	Sean Duke
UVic STATUS:	Master's Student
UVic DEPARTMENT:	EPHE
SUPERVISOR:	Dr. Kathy Gaul

ETHICS PROTOCOL NUMBER Minimal Risk - Delegated	13-272
ORIGINAL APPROVAL DATE:	06-Sep-13
APPROVED ON:	06-Sep-13
APPROVAL EXPIRY DATE:	05-Sep-14

PROJECT TITLE: **The relationship Between Functional Movement Screen TM Score and Time-loss Injury Rate in Club-Level Rugby Union Players**

RESEARCH TEAM MEMBERS:
Committee Member: Dr. Steve Martin (UVic)
Athletic Therapists: Traci Van der Byl (UVic)
Physiotherapist: Danielle Mah (Rugby Canada)
Physiotherapist and Athletic Therapist: Isabel Grondin (Camosun College)
Research Assistant: Emily Medd (UVic)

DECLARED PROJECT FUNDING: **None**

CONDITIONS OF APPROVAL

This Certificate of Approval is valid for the above term provided there is no change in the protocol.

Modifications
To make any changes to the approved research procedures in your study, please submit a "Request for Modification" form. You must receive ethics approval before proceeding with your modified protocol.

Renewals
Your ethics approval must be current for the period during which you are recruiting participants or collecting data. To renew your protocol, please submit a "Request for Renewal" form before the expiry date on your certificate. You will be sent an emailed reminder prompting you to renew your protocol about six weeks before your expiry date.

Project Closures
When you have completed all data collection activities and will have no further contact with participants, please notify the Human Research Ethics Board by submitting a "Notice of Project Completion" form.

Certification

This certifies that the UVic Human Research Ethics Board has examined this research protocol and concluded that, in all respects, the proposed research meets the appropriate standards of ethics as outlined by the University of Victoria Research Regulations Involving Human Participants.

[redacted]

[redacted]
Associate Vice-President Research Operations

Certificate Issued On: 13-Feb-14

13-272 Duke, Sean