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Functional Motor Competence, Health-Related Fitness, and Injury in Youth Sport

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DEDICATION

I dedicate this dissertation to my parents who are always there for me. Thank you for everything you do. Thank you for the love, encouragement, and support you have given me. I also dedicate this to Ashley for all of her love, support, and patience through everything that has come our way.

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ABSTRACT

In the United States there millions of youth who participate in sport.[1-3] Unfortunately there is also a high rate of musculoskeletal injury in sport,[4,5] accompanied by millions of dollar in medical cost.[6] The development of functional motor competence and health-related fitness (HRF) is important as these two constructs are related to health, performance, and injury incidence in youth sport.[7,8] It is assumed that children develop their movement ability and physical fitness as they age, however recent evidence suggests that youth functional motor competence and HRF decrease across childhood.[9-13] An evaluation of functional motor competence gaining popularity among health and strength and conditioning professionals, is the Functional Movement Screen (FMS™). The FMS™ has been utilized as a screening tool to evaluate individuals at risk from dysfunctional movement.[14-16] The evaluation and modification of risk factors and mechanisms for injury incidence in youth sport is critical to aid in the reduction of injury. Therefore, the following three studies were conducted.

The first study evaluated the mean and distribution of the FMS™ in youth sport (age 11-18), and if there was a composite FMS™ score which was predictive of increased injury risk. Results indicated that youth sport participants have a mean composite FMS™ score of 13.54 $\pm$ 2.66, revealing that these individuals demonstrated some level of dysfunctional movement. There were two composite FMS™ scores which were predictive of increased risk of injury (FMS™ $\leq$ 14, $\leq$ 15), however when adjusting for

sport, there were no significant composite FMS™ scores that were predictive of increased risk of injury.

The second study evaluated the HRF of youth sport participants (age 11-18), and provided a comparison between Canadian youth normative data and youth in sport. The results revealed that HRF in youth sport participants needs improvement, and that on several measures of HRF there were no differences between the Canadian youth normative data and youth in sport. Furthermore, this study highlights the need to evaluate and address HRF in youth as these measures may related to future health, sport performance, and risk of injury.

The final study evaluated the relationship between HRF and the FMS™ in youth sport (age 11-18), and evaluated if the combination of both HRF and the FMS™ has utility for prediction of injury in youth sport. Results indicated that there are variable relationships between the FMS™ tasks and multiple measures of HRF, with not overall relationship noted. The combination of the FMS™ and HRF for the prediction of injury in sport revealed that the three salient factors for increased odds of injury risk an individual's sex, cardiorespiratory endurance, and muscular power. The relationship between the inline lunge task of the FMS™ and HRF variables may provide insight for strength and conditioning professionals to re-evaluation their selection of training tasks based on the importance of developing both functional motor coordination and HRF.

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CHAPTER 1

INTRODUCTION

Over 50% of high school students in the United States participate in at least one extramural sport, demonstrating that sport provides opportunities for millions of youth to be active and healthy.[1-3] Unfortunately, musculoskeletal injury incidence in youth sport is increasing as more youth participate each year.[4,5] Mitigating injury Incidence in youth sport is critical not only for the health-benefits that participation in sport may promote (i.e., physical activity & fitness),[7,17,18] but also due to medical costs to families.[6] In 2013-2014, the National High School Sports-Related Injury Surveillance Study estimated there were over 1.4 million injuries nationwide with an injury rate of 2.18 (per 1,000 exposures),[4] and the cost of sport related emergency room visits in 2013 alone was in excess of 935 million dollars.[6] Thus, identifying mechanisms relating to injury Incidence in youth sport needs to be addressed.

Sport not only provides an opportunity for youth to be active, but also provides an environment which may aid in the development of positive healthy behaviors. Students who participated in sport (both male and female) were less likely to report behaviors such as, not eating fruits and vegetables the previous day, cigarette smoking, and using marijuana or cocaine when compared to students not participating in sport.[19] Overall, students who participate in sport at some level have a higher tendency toward positive health behaviors.[19] While participation itself may promote healthy behaviors, those youth participating in sport who have decreased levels of physical fitness compared to their peers (muscular strength & endurance) demonstrate higher rates of injury.[20]

Functional Motor Competence

There are multiple terms used to describe movement ability, such as coordination, motor function, motor proficiency, motor coordination and motor competence. The term functional motor competence (FMC) is one that will be utilized as an encompassing name for all of these terms. Functional motor competence can be defined as the ability of a person to coordinate and control one's center of mass and extremities in a gravity based environment in response to perturbations to effectively attain a goal. This concept describes movement in almost any sport. While there are many different assessments that evaluate various aspects of FMC, one has been created for evaluation of an individual's risk related to their movement.

The Functional Movement Screen (FMS™) is an assessment which is used to evaluate the quality of an individual's movement in seven different movements. The FMS™ is a tool which also is used in sports medicine to identify an individual's physical or functional limitation or asymmetries.[16] This tool is also used by strength and conditioning specialists as a baseline of movement, to improve from with training. The FMS™ utilizes movement such as a deep squat and an inline lunge in order to assess FMC. The utilization of FMS™ is increasing in sport as many of the movements are foundational to movements in sport.[14,15] Adequate reliability has been demonstrated for the FMS™, which is the chosen measure of FMC for the purposed of these studies.[21,22]

Linked to the development of FMC, and also important for youth sport performance and injury Incidence, is the development of multiple aspects of physical fitness (i.e., muscular strength, muscular endurance, cardiorespiratory endurance, and weight status).[7,8] While it is generally assumed that all children develop FMC and physical fitness across childhood and adolescence, recent evidence suggests that many children (both boys and girls) actually show a decrease in their level of FMC (as assessed by various movement assessments) and fitness across childhood.[9] To compound the issue, secular data also indicate FMC and physical fitness have been declining in youth[10-13]; with 34.5% of the nation's youth (12-19 years) being obese (2011-2012).[23]

Reviews of risk factors for injury in youth sport indicate increases in injury rates may be related to decreases in individuals' endurance & strength.[20] Twitchett *et al.* also demonstrated that decreased levels of physical fitness in adults is associated with an increased number of injuries sustained during participation in sport activities.[24] In addition, youth with an increased body weight status (BMI) are at an increased risk of sustaining injury associated with sport.[25] Thus, in addition to FMC, the development of multiple aspects of physical fitness in youth also may be an important predictor of injury Incidence in youth.

FMC and injury

The development of FMC, or lack thereof, has been linked to injury Incidence in college and professional sports.[26-29] Overall, individuals with less advanced FMC (as assessed using the Functional Movement Screen) are up to 11.7 times likely (OR= 4.58 to 11.67) to sustain an injury during sport participation than their more advanced peers.[26-

[29] However, no studies have addressed the potential impact that FMC may have on injury Incidence in youth sports. Recent evidence suggests that FMC levels also are directly associated with participation rates in youth sports, although many children who have low FMC still participate in sports.[30]

Relationship between FMC and Fitness

Strong evidence demonstrates the development of FMC across childhood and into adolescence is positively associated with physical activity levels,[31-33] multiple aspects of health-related physical fitness (i.e., muscular strength, muscular endurance, and cardiorespiratory endurance) and inversely related to unhealthy body weight status.[8,34-36] In line with the developmental model proposed by Stodden *et al.* (Figure 1),[8] the strength of the association between FMC and health-related physical fitness increases across childhood and into adulthood.[8] The development of FMC and health-related fitness may open opportunities for participation in multiple modes of physical activity and sport.[8,35]

Overall, the demand for adequate FMC and health-related fitness increases as competition levels increase through adolescence,[34,35,37] and it is important to understand if youth sport participants meet this demand. Unfortunately, little data is available on FMC or health-related fitness levels in youth sport in the United States. The assumption is made that individuals' who participate in youth sport have advanced FMC and enhanced levels of health-related fitness when compared to the general population, while in reality youth are not prepared for the demands of sport.[38] Furthermore, no studies have addressed the potential combined impact that FMC and health-related fitness levels may have on injury Incidence in youth sport.

Purpose

Composite FMS™ scores for youth have been reported in a few studies, with all of the studies reporting different values. The maximum composite score on the FMS™ is 21, and one report states male and female individuals aged 10-17 demonstrate a mean composite FMS™ score of 14.59 (CI 14.43-14.74).[39] Those youth who participate in sport demonstrated a median score of '2' on each task, which translates to a composite score of 14.[40] However, studies with greater age ranges report mean composite FMS™ scores of 12.1 to 15.5 (individuals aged 8-21 years old).[41-43] The inconsistency within the current literature demonstrates the lack of evidence for FMS™ levels in youth, especially those who participate in sport. Furthermore, the FMS™ testing manual states that this screen has been developed for use in high school athletics.[16] There is currently only one study in this population which examined composite FMS™ score related to development of injury, finding no significant result.[41] With the lack of available information in this population regarding injury risk from performance on the FMS™, there is a need for further investigation.

An individual's FMC and health-related fitness levels are essential for the holistic development of an individual.[38] Motor competence is positively associated with and individual's health-related fitness (cardiorespiratory endurance, muscular strength, and muscular endurance) and physical activity levels, while negatively associated with body weight status (BMI).[33,34,42,43] These associations are present in the general youth population; however, individuals who participate in sport are under increased physical demands. Thus it remains to be determined if the same associations are present in a youth sport population.[34,35,37] Since youth who participate in sport generally are not physically prepared for the demand of sport,[38] and with the knowledge that decreased fitness in adults results in an increased number of sports injuries, the impact health-related fitness level has on injury risk in youth may be significant.[24,38] Additionally, the potential additive effects that decreased health-related fitness and FMC have on injury risk in youth may be even more pronounced.[8]

Statement of Purpose

Based on the previously noted literature, three studies are proposed and will be presented in this order. The purpose of the first study is to determine the mean and distribution of Functional Movement Screen performance in sport participants age 11-18. A secondary purpose is to determine if there is a composite Functional Movement Screen score proficiency barrier (cut point) that is predictive of increased injury risk. The purpose of the second study is the health-related fitness of youth sport participants age 11-18 in comparison with normative findings from U.S. and Canadian general youth population data. The purpose of the final study is to determine the relationship between health-related fitness and Functional Motor Competence in youth sport participants. Additionally this final study aims to determine if the combination of both FMC and HRF has utility for the prediction of injury in youth sport. Findings consistent with our hypotheses will demonstrate the need for development of youth FMC and health related fitness prior to sport participation at the high school level.

Aims

1.A. To evaluate the mean and distribution of Functional Movement Screen performance in sport participants age 11-18.

***Hypotheses 1.A*.** Scores on the Functional Movement Screen in youth sport participants will be similar to other normative youth findings (i.e. mean composite score of 14).

1.B. To evaluate if there is a composite Functional Movement Screen score proficiency barrier that is predictive of increased injury risk.

***Hypothesis 1.B*.** Composite Functional Movement Screen score below 14 will be associated with increased risk of injury.

2.A. To evaluate the health-related fitness of youth sport participants age 11-18 in comparison with normative findings from U.S. and Canadian general youth population data.

***Hypothesis**.* Youth sport participants' health-related fitness will not differ from that of the general population.

3.A. To assess the relationship between health-related fitness and functional motor competence in youth sport.

***Hypotheses 3.A*.** Health-related fitness and functional motor competence will present with positive associations.

3.B. To assess if the combination of both FMC and HRF has utility for the prediction of injury in youth sport.

***Hypotheses 3.B*.** The combination of functional motor competence and health related fitness will demonstrate greater utility together than alone.

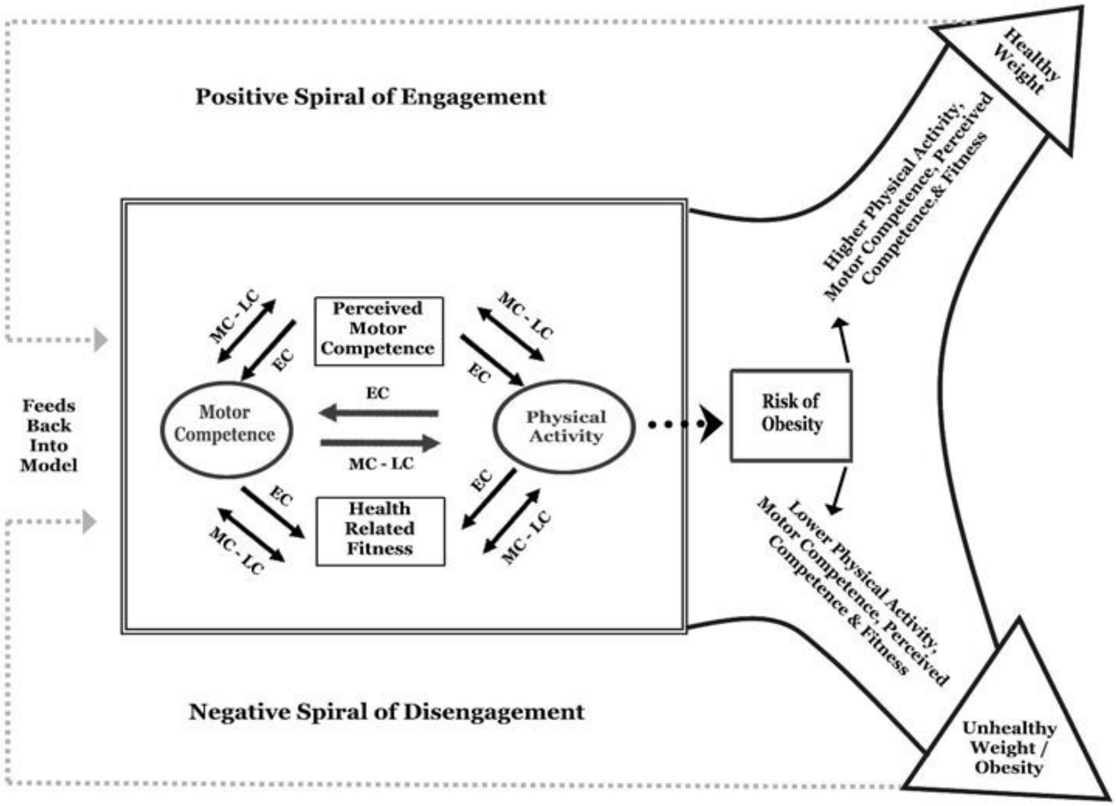

Figure 1.1. Developmental model proposed by Stodden et al. EC *early childhood*; MC *middle childhood*; LC *late childhood*[8]

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CHAPTER 2

LITERATURE REVIEW

While sport provides various different modes for individuals to be active, it also offers opportunity for individual to develop FMC and their health-related fitness.[1-4] Functional motor competence, the ability of a person to coordinate and control one's center of mass and extremities in a gravity based environment in response to perturbations to effectively attain a goal, describes ability which may be placed in the context of sport. This construct may be evaluated by varying means, though the Functional Movement Screen is used in sports medicine.[5] The FMS™ has been used in the adult population to evaluate an individual's movement ability and potentially identify risk for injury.[6-9] While FMC is essential for performance in sport, the development of health-related fitness is another construct which is associated with FMC.[4,10-12] Though these constructs are linked, their relationship may change over time and have varying effects on the risk of individuals, particularly youth, sustaining injury in the rigors associated with sport.[10-14]

Sport

With over half of youth in the United States participating in sport, the ability of this construct to reach millions of youth cannot be overstated.[1-3] Children's participation in sport (sport dependent) is positively associated with increased engagement in physical activity, meeting or exceeding international guidelines for health-related physical activity.[1] Furthermore, the Youth Risk Behavior Survey (YRBS) reported that youth who participate in sport are less likely to report risky health behaviors (e.g. cigarette smoking, use of illicit drugs) when compared with their non sport participating counterparts.[15] Results from the YRBS further elaborated that individuals participating in sport tend towards more positive health behaviors.[15] Additionally, sport has been purported to be strategy in which to promote the development of FMC, as a synergistic relationship has been reported.[16] The development of locomotor skill or early initiation of sport participation may further increase physical activity as an individual ages.[11,16] The National Strength and Conditioning Association's (NSCA) position stand for long-term athletic development supports the ideal that all youth may benefit from participation in engagement of physical activity for the improvement of physical fitness.[17] Furthermore, the NSCA support the holistic development of youth's physical development in order to promote physical activity across the lifespan, and prevent injury in sport.[4]

Functional Motor Competence

In the rehabilitation setting, there is a trend to focus on the development of specific areas of the body, without addressing its entirety. While focus on an individual unit may produce favorable results, towards the later stages of rehabilitation the integration of total body fundamental movements must come in to focus. Fundamental movements are utilized in a multitude of fashions during sport, however seem to be overlooked during return to participation. The purpose of having a movement screen is to identify individuals demonstrating physical limitations or asymmetries which may place them at risk during activity, and to create baseline measures on which to compare later performances. The Functional Movement Screen (FMS™) is one such screen which has been developed in order to assess an individual's fundamental movement patterns.[18]

The assessment of FMC of interest (e.g., Functional Movement Screen -FMS™), identifies an individual's physical limitations, asymmetries, & potential risk for injury.[10] Multiple studies have used the FMS™ to evaluate movement in relation to injury in college and professional athletes.[9,10,11,12] Additionally, the FMS™ has been shown to be related to health outcomes. Recent evidence shows that an individual's body mass index (BMI) is negatively related to FMS™ total score.[19,20] Although the FMS™ has not been related to health-related fitness, recent pilot data revealed that components of the FMS™ are related with cardiorespiratory fitness (deep squat, trunk stability) and muscular fitness (deep squat, inline lunge, trunk stability).[26] Recent pilot data also reveal correlations between injury and BMI (r=.280), FMS™ components (r=-.323 to -.436), and cardiorespiratory fitness (r=-.305). Thus, comprehensively assessing FMC and health-related fitness may increase the ability to predict injury.[21] Overall, current data suggests that the decreased FMC, health-related physical fitness and an unhealthy weight status may result in an increased Incidence of injury in youth who are participating in sport. No study to date has examined the association of FMC (evaluated by the FMS™) and health-related physical fitness to injury Incidence in youth sport.

The Functional Movement Screen

The FMS™ is a series of seven tasks, with each placed on a four point scale. A score of zero will only be given when an individual presents with pain during any portion of the screen. The area of pain should be marked for further evaluation from a medical professional. An individual will be given a score of one if they are unable to complete the given task. A score of two is given to an individual who is able to complete the movement pattern, however have to compensate in some way in order to achieve the pattern. Finally a score of three is achieved when an individual completes the movement pattern properly without any compensation.

Scoring[5,18,22]

The deep squat is a position which is assumed during a multitude of sport settings. This position requires an individual to exhibit adequate total body movement coordination and control. This test is performed by having an individual begin with their feet shoulder width apart flat on the ground and place a dowel rod on their head, grasping the rod with their hands so their elbows are in a 90° position. The individual then presses the dowel rod overhead, and is instructed to move into a squat position by moving their buttocks to their ankles going as far as possible while keeping their torso upright. This task demands adequate strength from the lower extremity, and range of motion from the lower and upper extremities, as well as spinal range of motion. If the individual is able to complete the task they are assessed a score of '3'. If unable, their heels are placed atop the test board with their toes on the ground. The ability to complete the task in the second position is scored as '2', if unable they are assessed a '1'.

The hurdle step task resembles the stepping motion in stride, and as such this task is completed on both sides of the body. For this task the testing board is placed on its narrow side with the dowel rods placed on the narrow side at the top. A band is placed in between the two dowel rods at the height of the individual's tibial tuberosity. The test is performed by having the individual placing a dowel rod over the back of their neck and shoulders while securing it with both of their hands. The individual then places their feet together and aligns their toes to touch the base of the testing board. The individual is instructed that while maintaining an upright posture, to step over the hurdle with one leg ensuring to keep their hip, knee, and ankle joints in line. Once their foot is over the hurdle, they are to touch the ground with their heel, then return to the starting position. The ability to maintain upright posture and keep their lower extremity joints in line assesses a score of '3'. Inability to stay inline or upright scores a '2', and if the individual hits the hurdle or loses their balance a score of '1' is granted. This task requires an individual to not only coordinate and control their stepping lower extremity and torso, but requires proprioception at the core and the opposite lower extremity.

The in-line lunge is another task which resembles an individual in stride, and it is also required to be competed on both sides of the body. An individual's tibia length is measured prior to the completion of this task and a mark is made on the board at this length. The individual places the heel of one foot on the end of the test board while the board is laying broad side flat. A dowel rod is help in contact with the head, thoracic spine, and mid-buttock region. The hand on the same side as the leg being testing holds the dowel at the lumbar spine, while the opposite the leg being tested holds at the cervical spine. The individual is then asked to step on the board with the heel of the other leg being placed at a point at or beyond the marked tibial height. Finally, the individual is asked to maintain an upright posture while lowering their back knee to the test board behind their lead leg. The ability to complete this task as described scores a '3'. If an individual loses their balance they are assessed a score of '1', and if they demonstrate compensations in the task (inability to hold upright posture, etc.) a score of '2' is granted. This task requires spinal, core, and lower extremity coordination, control, and proprioception. Due to the split nature of this task, and individual is required to demonstrate coordination of the lower extremities in differing fashions for completion.

The shoulder mobility task is a screening tool to assess the bilateral range of motion of the upper extremity. An individual's hand length is recorded from a measurement from the distal wrist crease to the tip of the third digit, and this measurement will serve as a reference point for this task. The individual is instructed to make a fist with each hand with their thumb inside of their fingers. Next the individual is instructed to maximally adduct, extend, and internally rotate one shoulder, while maximally abduct, flex, and externally rotate the other. This will position both fists behind their back, and the distance between the fists should be measured. The test is then completed by switching the positions of the shoulders, and measured the distance between the fists once more. An individual scores a '3' if their fists are within one hand length of each other. A score of '2' is given if their fists are within one-and-a-half hand lengths, and a '1' is given if the distance in larger. A clearing exam should be completed at the end of this task, which is performed in order to assess an underlying impingement condition. The exam is completed by placing one hand on the opposite shoulder and pointing their elbow upward. Pain on this clearing exam results in the individual scoring a zero for the entire shoulder mobility exam.

The active straight leg task is used in order to determine and individual's ability to separate motions of the trunk from the lower extremity. This task also assesses an individual's active hamstring, and gastrocnemius-soleus complex flexibility. To complete this task an individual is laying supine with the test board underneath their knees. They are instructed to keep both ankles dorsiflexed with their toes pointed upward. The individual then lifts one leg with their knee extended as far as they are able to, maintaining contact with the floor and the board with their other leg. The individual then completes this task with the opposite leg. If the individual is able to lift their leg (measured at the malleoli) above a line drawn at mid-thigh of the opposite leg a score of '3' is given. A score of '2' is achieved if their lifted legs malleoli ends between mid-thigh and their knee joint line of the opposite leg. If their lifted legs malleoli ends below the knee joint line of the opposite leg, they are given a score of '1'. If the individual cannot maintain a neutral position with the non-moving leg, they are to repeat the task in order to maintain the neutral position.

The trunk stability pushup is a closed-chain upper extremity movement which requires an individual to stabilize their core. The initial starting position for this task is prone with the individuals hands placed shoulder width apart on the ground. To test males, the starting position is with their thumbs aligned at their forehead, whereas female start with their thumbs aligned at their chin. Next the individual extends their knees, keeping their ankles dorsiflexed, and is instructed to complete a pushup. This movement should be performed with the body rising as a single unit with no arching or lag occurring in the lumbar spine. The ability to complete this task from the initial position grants a score of ‘3’ on this task. If unable to complete the task at the initial starting position, males’ thumbs are positioned in line with their chin, and females’ in line with their shoulders. The individual will then be asked to perform this task once more, and are granted a score of ‘2’ for completion in the secondary position. A score of ‘1’ will be granted if the individual is unable to complete the motion without compensation from the secondary position. A spinal extension clearing exam is administered following the completion of this task. The exam is completed with the individual prone, with their hands placed on the floor below the level of their shoulders. They are asked to press their chest off the floor as far as possible, straightening their elbows. Pain with the clearing exam results in a score of ‘0’ being assessed for the entire trunk stability pushup task.

The final task in the FMS™ battery is rotary stability. This task requires and individual to demonstrate coordination and control of their entire body, while also maintaining core stability and proprioception. This task is completed by having the individual in a quadruped position over the test board (broad side down), with their ankles dorsiflexed and knee’s flexed to 90°. The individual is instructed to contact the test board with their thumbs, knees, and toes and maintain their balance throughout. They are then instructed to flex their shoulder reaching out front of them, while extending the same side leg behind them at the same time. The individual is then asked to extend the shoulder and flex the knee so their elbow and knee touch. If able to perform this task, they are assessed a score of '3'. If unable, the individual is asked to repeat the motion using one arm and the opposite leg and will be assessed the score of '2' if completed from this position. If unable to complete the task from the second position, the individual will be assessed a score of '1' for this task. This task is to be completed bilaterally, and after the completion of the task a spinal flexion clearing exam is performed. To perform the clearing exam, the individual is instructed to begin on all fours and move their hips backward to sit atop their heels. Next, they are instructed to lower their chest to the floor and reach out in front of them with both hands. If there is pain during the clearing exam, the individual is assessed a score of '0' for the entire rotary stability task.

Reliability

Rater reliability of the FMS™ has been evaluated with multiple different populations, from undergraduate students to individuals considered experts in the tool.[23-33] A recent systematic review and meta-analysis of the reliability literature demonstrated interrater reliability of a pooled intraclass correlation coefficient (ICC) of 0.81 (C.I. 0.7-0.92) and a pooled intrarater reliability of 0.77 (C.I. 0.58-0.96).[34] Interrater and intrarater reliability for the FMS™ across various raters is consistently demonstrated to be acceptable.[23,25,28,30-32]

Normative Values

The Functional Movement Screen has been used mainly across a young active adult population, representing collegiate and professional athletes. A 2011 study from New Zealand determined normative total scores on the screen for the 18-40 year old active population (regular physical activity). The mean total FMS™ score for this population was 15.7 ± 1.9, with no differences between the total score for males and females.[27] With the FMS™ being more widely utilized and slowly moving in to the youth population, one study has aimed to determine normative values in adolescents. Across youth aged 10-17 years, males demonstrated a score of 14.93 ± 2.61, while females demonstrated a score of 14.17 ± 2.24.[35] Also, it is important to note there were no differences in total FMS™ score for those who reported injury in the past six months compared to those who did not.

Injury

For the purposes of this study, injury will be defined as any physical insult or harm resulting from sports participation that requires an evaluation from a health or medical profession and time modified or time lost from sport participation.[6-9] This operational definition is an amalgamation of the criterion other studies in the athletic population have utilized.

FMS™ and Injury

Utilizing the FMS™ as an injury predictive tool, to date there have been two cutoff scores, or proficiency barriers, which have been identified. In this context a proficiency barrier may been described as a threshold for FMC, below which an individual may be at an increased odds of injury. Initially, the proficiency barrier of a total FMS™ score less than or equal to 14 was established,[7] while recently a barrier of total FMS™ score less than or equal to 17 has been identified.[9]

The proficiency barrier of a total FMS™ score of 14 was established using data from professional football athletes. Therefore the efficacy of using this score in an amateur youth sport has yet to be determined. However, in the adult sport setting (professional and collegiate), those with a total FMS™ score of 14 or below had an 3.85 to 11.67 greater odds of injury compared to those scoring above 14.[6-8] The mean total FMS™ Score for collegiate athletes ranged from 13.6 to 15.5.[6,8] In this setting total FMS™ score strongly correlated with injury incidence (r=0.761).[6] Interestingly, when shoulder mobility was removed from the total FMS™ score, there was a strong correlation between total FMS™ score and lower extremity injury (r=0.952). In a service setting, male officer candidates for the Marine Corps demonstrate an overall total FMS™ score of 16.6 $\pm$ 1.7. In all candidates, those with an FMS™ score of 14 or below had a relative risk of 1.5 when compared with those above.[36]

The proficiency barrier of a total FMS™ score of 17 was developed from college students who were physically active at some level of sport. These students demonstrated a total mean FMS™ score of 16.7 $\pm$ 1.8, which is markedly higher than those involved in a collegiate sports team. Those who had a total FMS™ score 17 or below had a 4.7 greater odds of injury than those above.[9] When modeling injury from total FMS™ score, linearly total FMS™ score explained 58.9% of the variance in injury (r=-0.767).[6] When injury is modeled via logistic regression initially only from total FMS™ score, those scoring below 14 have an odds ratio for injury of 5.61, and with the addition of history of injury to the model increases the odds of injury to 15.11 greater odds.[8]

A recent systematic review and meta-analysis for the FMS™'s utility as a tool for injury prediction in adults demonstrated the quality of all studies performed are lacking in quality. According to Dorrel et al.,[37] the FMS™ for injury prediction exhibited a higher specificity (85.7%) than sensitivity (24.7%), and a larger negative predictive value (72.5%) than positive (42.8%).[37]

Another piece to consider is the effect previous injury plays on an individual's movement ability. Typical goals of rehabilitation post injury are to return an individual to pre-injury movement and performance status. Further evaluation of the cut point of 14 or below revealed with individuals who have a past history of injury, the odds ratio for future injury jumps from 5.16 to 15.11 times as likely to become injured.[8] Along with those findings, one study reported that individuals with a history of previous injury scored lower than those without prior history.[38]

Currently there is one study to evaluate the use of the FMS™ in the youth sport setting for evaluating risk of injury from total FMS™ score. Male soccer players 8 to 20 years old (mean 13.6) from a soccer academy demonstrated a mean total FMS™ score of 12.1 $\pm$ 2.3.[39] The players who were injured during the soccer season were those who were heavier, older, and shorter than the non-injured players. There were interactions determined between instance of non-contact injury and score on the deep squat and the trunk stability pushup. Furthermore, those who demonstrated a score of 3 on the trunk stability pushup were less likely to suffer injury than those who demonstrated a score of 1.

Health-related Fitness

Health-related fitness is a term in which was derived from physical fitness with an aim towards developing fitness which would promote lifelong health. Health-related fitness may be broken down to different constructs of body composition, flexibility, cardiorespiratory endurance, and musculoskeletal fitness.[40,41] Body composition is not only the physical distribution of components of the body (fat mass, fat free mass, total body water, etc), but also a component and modifier of an individual's fitness.[40] An unhealthy body composition has been associated with risk factors for cardiovascular disease and diabetes,[42,43] with the trajectory of body composition and these outcomes continuing in to adulthood.[44,45] Evaluating performance, a skinfold sum (fat mass) and BMI are inversely associated with performance in cardiovascular and muscular endurance fitness tests.[46] Furthermore, an unhealthy body composition may promote a negative spiral of disengagement which leads to a decreased cardiorespiratory endurance and muscular fitness.[11,40] The recommendation is a school based setting is to evaluated an individual's body weight status through the use of Body Mass Index measures due to the sensitivity of the setting.[40]

Cardiorespiratory endurance as defined by Saltin, is the ability of an individual to perform large muscle, whole body exercise at a moderate to high intensity for extended periods of time.[47,48] Cardiorespiratory endurance is a hallmark of physical fitness, and demonstrates various health benefits in adults. In youth, there are ties between cardiorespiratory endurance and an individual's adiposity,[49-53] blood pressure,[54-56] blood lipid levels,[56-58] glucose levels,[59] and insulin sensitivity.[58,59] Cardiorespiratory endurance testing in youth is performed by utilizing a 20 meter timed stage shuttle run, and the FITNESSGRAM® Progressive Aerobic Cardiovascular Endurance Run (PACER) is one example of such.[40] The PACER task is a 20m shuttle run which is used to determine an individual's cardiorespiratory fitness. The task involves timed stages in which individuals must run 20m, and as the task progresses the timing decreases up causing the individuals to increase speed to pass each mark. The number of laps completed by each individual is recorded, and the individual is completed with the task after either they fail to pass two laps or they complete the maximum laps. The PACER is relatively easy to administer when compared to other tests of cardiorespiratory endurance, due to the ability to administer the test indoors or outdoors in a small space. The PACER estimated VO_2 max demonstrates adequate validity (r=0.87) and reliability (r=0.78 to 0.93).[60-63] The ease of administering this test, that it may be completed indoors or outdoors and in a small space, makes it ideal for field data collection of cardiorespiratory fitness.

The Institute of Medicine has defined musculoskeletal fitness as, "a multidimensional construct comprising the integrated function of muscle strength, muscle endurance, and muscle power to enable the performance of work against one's own body weight or external resistance (p.155)".[47] While evidence is sparse linking musculoskeletal fitness to health outcomes, resistance training has demonstrated benefits for an individual's body composition,[64-67] blood glucose and insulin levels,[66,68] blood pressure,[64,69] blood lipid levels,[64,70] and bone health.[71] Evaluation of an individual musculoskeletal fitness may be performed with hand grip strength testing, which is valid (r=0.52 to 0.84)[72,73] with upper and lower-body strength tests (e.g. 1-RM bench press and leg press), and reliable (r=0.71 to 0.90)[74-76] in youth. Additionally, an individual's hand grip strength is strongly correlated with total muscular strength using both left (boys r=0.9, girls r=0.7) and right hands (boys r=0.9, girls r=0.8) in both boys a girls (age 8-20).[77] The ability to utilize grip strength provides an expedited and non-invasive method for measurement of overall muscular strength. Muscular endurance as a component of musculoskeletal fitness may be evaluated in youth utilizing tests such as the curl-up, where an individual must lift their body against gravity. Tests such as the curl-up hold an inversely association with body adiposity.[78] As muscular endurance is incorporated in muscular fitness, it is important to note the positive association between bone health and muscular fitness.[79] Muscular endurance in youth is important in order for individuals' to have the ability perform muscular contractions repeatedly for both the performance aspect and protective aspect. Since the body and its movement are controlled from the core, decrease muscular endurance at the core may predispose individuals for injury.

FMS™ & Health-Related Fitness

In youth, total FMS™ score is associated with physical activity (steps per day; r=.301) and inversely associated with BMI (r=-.572 to-.806).[19,20] Body Mass Index proves a strong predictor of variance in FMS™ total score (R^2=.529), and the addition of physical activity to the model further strengthens the predicted variance (R^2=.602).[19] Furthermore, normal weight children performed better on the FMS™ when compared to overweight and obese children. Gender differences have been found for the individual tasks of the FMS™, with females demonstrating higher scores in the hurdle step and straight leg raise tasks, while males score higher on the trunk stability push-up task.[19,20] Measures of performance (e.g. Squat jump height, reactive strength index, reactive agility, and core strength) are associated with an individual's total FMS™ score in youth (r= 0.66, 0.74, -0.54, & 0.31 respectively).[80,81] An examination of maturational status revealed that children who were post peak height velocity, determined by somatic maturity offset, demonstrated greater performance in the functional movement screen when compared with others.[80,81]

Two systematic reviews have examined motor competence in relation to health-related fitness.[82,83] Both report evidence for positive associations between motor competence and cardiorespiratory fitness, muscular strength, and muscular endurance in youth. There is further evidence of the inverse relationship between motor competence and body weight status. Furthermore, children who do not participate in sport demonstrate less advanced motor coordination skills than involved in any capacity of sport. Those who participated in sports continually over a three year period demonstrated more advanced motor coordination than those who stopped or began participating in sport within those years.[13] Since those who participate in sport demonstrate more advanced motor coordination, participation may have a positive effect on the trajectory of their FMC development.

Health & Injury

Given that health-related fitness is tied to FMC, it may be postulated that if a decreased FMC is a risk factor for injury, there may be a relation of health-related fitness level and injury. Army trainees in the highest BMI quartiles had a 2.8 greater risk of injury, than the middle quartiles.[84] Men in the highest quartile for body fat percentage had a greater risk of injury than other levels. Additionally, police service members with a BMI greater than 35, had a 3 times greater odds to report back pain than those with a lower BMI, when adjusted to age, gender and their service job category.[85] Both male and female trainees with lower aerobic fitness were at a greater risk for injury. Furthermore, army Trainee's and police service member who reported high self-rated physical activity level demonstrated a decreased risk of injury.[84,85] In sport (dance) there is a correlation between time lost from injury and body fat percentage (r=-0.614), and between heart rate (aerobic fitness) and number of injuries sustained (r=0.590).[86] Additionally, an increased number of sport related injuries is associated with a decreased levels of fitness in adults.[86] Therefore, the utilization of a test of FMC (Functional Movement Screen) aids in determining individual movement affinity and potentially modifiable risk factors for injury. Thus, the evaluation and promotion of both FMC and health-related physical fitness is crucial to participation in sport.

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CHAPTER 3

FUNCTIONAL MOVEMENT SCREEN IN YOUTH SPORT PARTICIPANTS: EVALUATING THE PROFICIENCY BARRIER FOR INJURY*

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Sport provides opportunities for millions of youth to be active and healthy,[1] though musculoskeletal injury remains a potential hazard to participants.[2,3] While pre-participation and physical screenings evaluate an individual's general health status, they do not determine preparedness for sport's intense physical demands or evaluate functional motor competence. Evaluations of functional motor competence aid in determining an individual's functional and physical capacity, as well as injury potential.[4-10] The Functional Movement Screen (FMS™) is an assessment of functional motor competence that evaluates qualitative movement coordination patterns and has the suggested ability to identify individuals who may be at risk for injury.[4] This assessment has been utilized in collegiate and professional sports to predict injury risk and shows promise to address the same issue for youth sport.[4,11-18] The ability to evaluate the risk for injury based on an individual's functional motor competence and address potential movement limitations prior to participation may be critical to alleviating injury prevalence.

FMS™ and Youth Sport

While the FMS™ was developed for use in high school athletes, it has mainly been utilized to address injury risk in collegiate and professional sports.[4,11,13,19] Chorba et al.[13] and Garrison et al.[19] demonstrated composite FMS™ scores ranging from 12.53 to 16.07 in college athletes,[13,19] but there has been limited use of the FMS™ in youth, with one study providing suggested normative values for a sample of adolescents in India.[20] In general, FMS™ data on youth demonstrates a range of composite FMS™ score means from 12.1 to 16.44.[18,20-24] One study assessed high school sport participants and noted their scores were on the lower end of this range (mean composite FMS™ 13-13.1). In response to these low scores, the authors called for further evaluation in youth sport.[18] Overall, there are limited data on FMS™ scores in youth sport.

FMS™ and Risk of Injury

In order to determine an individual's risk of injury from the FMS™, identifying a composite FMS™ score that is more predictive of injury may be useful. In 1980, Seefeldt proposed the idea of a movement skill "proficiency barrier", which may be viewed as a threshold, above which an individual will be able to successfully transition movement skills into more complex movements (e.g., sport skills). The application of the idea of a proficiency barrier idea for injury risk also has been explored with the FMS™ assessment in young adults in sport (collegiate and professional). Data on multiple studies has demonstrated that FMS™ levels have been able to predict injury and these data have identified a potential proficiency barrier level.[11,13,15,18,19]

The proficiency barrier utilized in multiple studies is a composite FMS™ score ≤14. This composite score was initially established using the data from professional football athletes.[11] Examining the predictive utility of this score in youth sport is important as it may establish the need to address movement deficiencies earlier in an athletes career while they are still maturing physically, have a greater adaptational window for skill development, and because the level of skill across athletes may be more heterogeneous. Thus, the potential of FMS™ screening to help alleviate future injury potential may be greater in youth sport. Unfortunately, with the varying definitions of injury throughout youth studies, it is difficult to determine if this score is applicable in youth sport.[18,21,23] In the adult sport setting (football, soccer, volleyball, basketball, rugby, swimming/diving, and handball), a composite FMS™ score of 14 or below increased the odds of injury (3.85 to 11.67) compared to those scoring above 14.[11,13,15,19] In collegiate sport (soccer, volleyball, and basketball combined), this composite FMS™ score strongly correlated with overall injury incidence (r=0.761) and lower extremity injury (r=0.952 without the shoulder score).[13]

While literature on FMS™ and injury in youth is increasing, results from current studies fail to show evidence of a proficiency barrier relating to injury in youth sport. The previously established proficiency barrier for a FMS™ composite score of <14 was no significantly associated with an increased risk of injury in youth (ages 8 – 21 years) participating in multiple sports.[18,21,23,25] The majority of studies evaluating this proficiency barrier were only evaluating one specific sport or position, with large age ranges.[21,23,25] Furthermore, the one study evaluating a potential barrier in multiple sports had a low injury rate, as they only included injuries which were musculoskeletal in nature.[18] Other types of injuries (i.e. neurological, concussions, etc.) may have an etiology related to an individual’s functional motor competence (i.e. falling on the playing surface).[26] Including multiple youth sports with an injury definition that is inclusive of all sport related injuries would be a more comprehensive method to address functional motor competence’s ability to broadly predict is potential impact on injury.[11,19,21,23] Thus, the purposes of this study were to a) evaluate the mean and distribution of FMS™ performance in sport participants age 11-18 and b) evaluate if there was a composite FMS™ score proficiency barrier that was predictive of increased odds of injury in this sample.

Methods

Participants and procedures

A total of 136 participants (63 male, 73 female) age 11-18 (16.01 ± 1.35) were recruited from local public and private high schools and local sport organizations. The ethnic breakdown of the sample was as follows: 81.6% white, 16.2% black, and 2.2% other. Individuals in the sample participated in football (40), soccer (23 male; 39 female), volleyball (18 female), lacrosse (10 female), and other (6 female). Participants with a musculoskeletal injury within the past six months that limited participation or movement capability at the time of testing, or did not have current medical clearance for participation in sport, or who were unable to complete the FMS™ testing were not allowed to participate. Individuals completed informed consent and were required to have parental consent before participating. Data was collected prior to the beginning of the individual's respective sport competitive season (Fall sport August – September; Spring sport January – February). The FMS™ data was collected during one session at each sports setting and injury information was received at the end of each sports respective season.

Measures

The FMS™ consists of seven tasks that are tested in the following order: overhead deep squat, hurdle step, inline lunge, shoulder mobility, active straight leg raise, trunk stability pushup, and rotary stability. All tasks are completed bilaterally except for the overhead deep squat and the trunk stability push up. Participants were given standardized verbal instruction (per the FMS™ manual).[4] Each task of the FMS™ is coded on a scale of 1 to 3 relating to an individual's capability to perform each suggested movement.[27,28] Participants who experienced pain during any portion of the FMS™ received a score of 0 for the task they were performing. Tasks which are completed bilaterally were scored per side, then received the lower of the two scores as the final score for that task. The final scores of each task were summed for a composite score with a maximum of 21 points. Participants were videotaped or live coded (dependent upon time of enrollment) performing a maximum of 3 trials of each FMS™ task. If participants met the criteria for a 3 prior to completion of all trials of one task, we moved to the next task as further screening is not needed.[4] The FMS™ was coded by individuals trained in the assessment. Inter/intra-rater coding reliability was adequate for all raters for both video (κ_w = 0.73 to 1) and live coding (κ_w = 0.70 to 1).[29]

A Certified Athletic Trainer employed by each site tracked participant injuries using their preferred tracking software. Injury was defined as any physical insult or harm resulting from sports participation that required an evaluation from a health or medical professional and time modified or time lost from sport participation.[13,19,21,30] This definition of injury was utilized to unify the definitions in the literature.[15,18,19,21,23] Individuals who sustained injury from any source outside of the school sport in which they were participating were excluded from injury analyses. Both contact and non-contact Injury was collected.

Statistical analysis

Data was double entered and cleaned prior to analysis. Descriptive statistics (means and standard deviations) for participants (height, mass, age) are shown in Table 3.1, and FMS™ performance is shown in Table 3.2. T-tests were performed to show differences in male and female height, mass, age, and FMS™ performance. The probability of sustaining injury was modeled as a function of composite FMS™ score via logistic regression.[11,18] Additional, logistic regression analyses were used to assess if there was a certain composite FMS™ value which was associated with an increased odds of injury after controlling for sport participation. An alpha < 0.05 was used to determine significance.

Results

There were significant differences between the sexes, with males being heavier (t=6.56, P<0.001) and taller (t=8.810, P<0.001). Youth sport participants demonstrated a mean composite FMS™ score of 13.54 ± 2.66. The distribution of sport participants scores are presented in table 3.2.

There were two composite FMS™ scores significantly related to an increased odds of injury (composite FMS™ ≤14, and ≤15) without addressing sport (Table 3.3). A composite FMS™ score of <14 or <15 is related to a 2.955 odds of sustaining injury. Evaluation of the composite FMS™ scores of <13 or <16 revealed a decreased odds of injury compared to the two aforementioned scores (OR=1.553 and 2.452 respectively). As 74% of injuries occurred in football, no significant differences were observed after adjusting for the sport being played. A breakdown of injury by sex and sport is shown in table 3.4.

Discussion

The first purpose of this study was to evaluate the mean and distribution of the FMS™ scores in youth sport. Youth sport participants tested at the beginning of their sport season demonstrated a mean composite FMS™ score of 13.54 $\pm$ 2.66, which is similar to other studies examining youth sport that demonstrated a range of composite FMS™ scores ranging from 12.1 – 16.44.[18,21-25] The males from this sample were at the low end of this range (male FMS™ composite mean 12.26), while the female participants tended towards the midrange (female FMS™ composite mean 14.4). The mean composite score also is comparable to the college and professional FMS™ mean range although it is on the lower end of that range.

Functional Movement Screen Performance by Sex

The normative findings in youth from India demonstrated that males outperformed females regarding the composite FMS™ score; however, our results indicate that females significantly outperformed males (t= -3903, *P*<0.001; Table 2). Individual task scores from the normative India youth data demonstrate that, males outperformed females on the inline lunge, trunk stability pushup, and the rotary stability tasks.[20] However, data from our sample demonstrate that females outperformed their male counterparts on tasks relating to their active range of motion (active straight leg raise, shoulder mobility), and core and lower extremity coordination and control (hurdle step, rotary stability). Previous studies on sex differences in more general functional motor competence assessments also reveal conflicting results with reports of more proficient males,[31] females,[32] and no differences between the sexes.[32-34] The specific differences in FMS™ in the current data set may be due to the differences between males and females joint range of motion (ROM) which has been previously identified in the literature.[35,36] Unfortunately, we did not assess specific joint ROM for this study. Alternatively, the equivocal findings in the literature may be a function of sport composition represented in the data set. For example, there was a prominence of football players in this male sample, and only eight did not sustain injury. Lower scores among males in this sample could be attributed to football players with lingering injuries who still met inclusion criteria. In addition to being bigger, the boys may have been closer to experiencing peak height velocity than girls, which may impact flexibility and coordination as growth in long bones precedes development of tendons and ligaments.[37-41] That three of the four skills where females out performed males involved limb movements (i.e., hurdle step, shoulder mobility, leg raise) corroborates this idea. Subsequent studies should account for previous injury and perhaps maturational timing.

Overall, the composite FMS™ scores from sport participants represent an individual task score of '2' per task. These scores demonstrate that individuals were unable to complete the task as initially instructed and were placed in a compensated testing position. Thus, it is clear that these youth participants demonstrate compensated movement patterns as evaluated by the FMS™. These movement deficiencies should be addressed as improved functional motor competence may have a protective effect on future injury incidence.[10] As FMS™ scores are generally not that different than collegiate and/or adult FMS™, these data speak to the fact that global functional motor competence is developed early in life and does not necessarily improve across age or with sport participation. Thus, promoting functional motor competence in children before they transition into high-level youth sport is warranted. Longitudinal testing also would be important to understand whether changes in functional motor competence do change across time. As secular declines in functional motor competence have been noted in recent literature,[42] these data provide additional evidence for the importance of learning how to move effectively as functional movement is important for performance as well as providing a potential protective effect against injury.

FMS™ and Injury

The second purpose of this study was to evaluate if there would be a proficiency barrier of a composite FMS™ score which would be related to increased odds of injury. We evaluated odds of injury from multiple different composite FMS™ scores and found that individuals scoring below 14 or below 15 were predisposed to injury (Table 3). However, when controlling for the injury breakdown by sport, the majority of individuals who sustained injury were males participating in football (74%). Therefore, these results may be misleading as there were very few females and individuals from other sports who sustained injury. Thus, these injury data seem to be more a product of the sport in which an individual chose to participate, rather than the quality of their movement. Previous literature shows the composite FMS™ score may be useful for evaluating injury potential in adults,[11,15,19] however, this study reaffirms previous research in youth sport that demonstrates there may not be an appropriate proficiency barrier in youth.[18,23,25] Cook, Burton, Hoogenboom, and Voight (2014) present the position that the FMS™ alone may not adequate for the prediction of injury, and that the screen should be supplemented with other measures of sport readiness (i.e. power, endurance, etc.).[27,28]

We recognize there are limitations worth mentioning with this evaluation of the FMS™ in youth sport and its relationship with injury. The intent of this study was not to evaluate FMS™ and injury within each sport, therefore, we were underpowered in the exploratory proficiency barrier analysis by sport. Additionally, the collection of mechanism of injury in future research may be useful in evaluating the effect movement versus incidental contact may have with injury.

This study provides a supplementary reference for FMS™ scores in youth sport participants, which demonstrates that most youth sport participants present with some level of movement dysfunction. These data, along with other FMS™ data across youth and into adulthood also suggest that functional motor competence is developed in childhood, as composite FMS™ data is similar across ages 8-21.[18,21-25] These data demonstrate that dysfunctional movement coordination and control is present in many youth, which ultimately may manifest as injury over time (i.e., adulthood). Thus, while using the FMS™ as an acute predictor of injury may not be appropriate in youth, it may be predictive later in an individual's sport career. In youth sport, the immediate utility of the FMS™ is more aligned for the clinical identification of dysfunctional movement.

Conclusion

While dysfunctional movement may eventually lead to injury, an acute or chronically developed injury depends on many circumstances related to the individual, the sport, and the environmental context of participation. Thus, while FMS™ scores from this sample were not predictive of injury, low FMS™ scores should be addressed in youth as its impact on improving performance, and possible reduction of future injury is important for youth to successfully participate in sport at many levels.

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Table 3.1. Descriptive Statistics

	Sex	n	Mean	Std. Dev	t
Height (cm)	Male	63	173.72	7.47	8.810*
	Female	73	163.12	6.56	
Mass (Kg)	Male	63	73.93	16.72	6.56*
	Female	70	57.38	11.61	
Age	Male	61	15.87	1.44	0.909
	Female	68	15.65	1.26	

*$P < 0.001$ for differences between males and females

Table 3.2. Functional Movement Screen Scores

	Sex	n	Mean	Mode	Std. Deviation	Minimum	Maximum	t
Deep Squat	Male	63	1.70	2	0.56	1	3	-0.934
	Female	65	1.80	2	0.67	1	3	
Hurdle Step	Male	63	1.65	2	0.54	1	3	**-2.978***
	Female	65	**1.91**	2	0.42	1	3	
Inline Lunge	Male	62	2.13	2	0.66	1	3	-1.818
	Female	65	2.32	2	0.53	1	3	
Shoulder Mobility	Male	62	2.02	3	1.00	0	3	**-4.461***
	Female	65	**2.68**	3	0.62	1	3	
Active Straight Leg Raise	Male	63	1.87	2	0.61	1	3	**-3.726***
	Female	65	**2.32**	3	0.75	1	3	
Trunk Stability Pushup	Male	63	1.60	2	0.77	0	3	1.065
	Female	65	1.46	1	0.73	1	3	
Rotary Stability	Male	63	1.65	2	0.60	0	3	**-2.875***
	Female	65	**1.91**	2	0.38	1	3	
Composite FMS™	Male	61	12.62	14	3.06	6	18	**-3.903***
	Female	65	**14.40**	15	1.88	9	18	

*$P < 0.001$ for differences between males and females

Table 3.3. Proficiency Barrier Analysis of Composite FMS™ Score Predicting Injury

	Not adjusted for sport				Adjusting for sport			
	OR	*LCL*	*UCL*	*p-value*	*OR*	*LCL*	*UCL*	*p-value*
Composite ≤13	1.553	0.687	3.511	0.2905	0.97	0.313	3.005	0.9577
Composite ≤14	2.955	1.249	6.986	0.0136*	2.066	0.676	6.316	0.203
Composite ≤15	2.955	1.249	6.986	0.0136*	2.066	0.676	6.316	0.203
Composite ≤16	2.452	0.852	7.063	0.0965	1.337	0.345	5.181	0.6748
Composite ≤17	2.826	0.595	13.422	0.1912	3.541	0.491	25.514	0.2095

*$P < 0.05$

Table 3.4. Sample Injury Breakdown

		Male	Female
Football	Injured	32	-
	Not injured	8	-
Soccer	Injured	4	4
	Not injured	19	35
Volleyball	Injured	-	0
	Not injured	-	16
Lacrosse	Injured	-	2
	Not injured	-	8
Other	Injured	-	1
	Not injured	-	1

*6 participant's injury data were not reported

CHAPTER 4

A COMPARISON OF HEALTH-RELATED FITNESS OF YOUTH ATHLETES AND PRE-ESTABLISHED GENERAL POPULATION NORMATIVE FINDINGS*

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Athleticism is a term that relates to physical characteristics of an individual, such as health-related physical fitness (e.g., musculoskeletal fitness and cardiorespiratory fitness and body composition status).[1] Those who participate in sport at all levels are deemed 'athletes',[1] and it is suggested that athletes, who generally participate in physical training as well as practice of their sport, have more favorable physical fitness than non-athletes, even in youth.[2] However, a National Strength and Conditioning Association (NSCA) position statement suggests that youth are not prepared for the physical demands of sport.[3] The demand for higher levels of various aspects of physical fitness is one part of athleticism that is consistent across competition levels into adolescence as strength, power and endurance are important performance indicators.[4-6] Thus, it is important to understand if youth sport participants meet this increasing fitness demand, as inadequate levels of fitness may result in decreased performance, sport-related injury as well as other unfavorable long-term health outcomes (i.e. obesity, high blood pressure, etc.).[7] Unfortunately, little data is available on health-related fitness levels in youth sport in the United States.

Health-related fitness has the specific aim of developing fitness that promotes lifelong health,[7,8] but it also has implications for sport participation and preparedness.[3] Health-related fitness components include body composition, cardiorespiratory endurance, musculoskeletal fitness (muscular strength, endurance and power), and flexibility.[8,9] Body composition is the physical distribution of components of the body (e.g., fat mass, fat free mass, total body water, etc.), and component of an individual's fitness.[8] An unhealthy body composition is associated with risk factors for cardiovascular disease and diabetes,[10-13] and is associated with an increased injury risk in sport.[14,15] Cardiorespiratory endurance as defined by Saltin (1973), is the ability of an individual to perform large muscle, whole body exercise at a moderate to high intensity for extended periods of time.[7,16] Appropriate cardiorespiratory fitness is important for sport, as the majority of sports require some level of prolonged aerobic activity. Low cardiorespiratory endurance is a risk factor for injury in sport,[17,18] as fatigue negatively impacts motor coordination and control, which may acutely predispose an individual to injury.[19] Furthermore, cardiorespiratory endurance is a hallmark of physical fitness, demonstrating various health benefits in youth and adults.[8] In youth, there are ties between cardiorespiratory endurance and multiple health outcomes including adiposity,[20-24] blood pressure,[25-27] blood lipid levels,[27-29] glucose levels,[30] and insulin sensitivity.[29,30]

The Institute of Medicine has defined musculoskeletal fitness as, "a multidimensional construct comprising the integrated function of muscle strength, muscle endurance, and muscle power to enable the performance of work against one's own body weight or external resistance" (p.155).[7] Musculoskeletal fitness is important in sport to not only increase performance, but also aid in the reduction of injury.[18,31] Furthermore, resistance training has demonstrated multiple health benefits for an individual's body composition,[32-35] blood glucose and insulin levels,[34,36] blood pressure,[32,37] blood lipid levels,[32,38] and bone health.[39,40]

The identification and evaluation of individuals with inadequate health-related fitness in youth sport is important as it relates to an individual's health, performance in sport, and potential to sustain injury. While it is suggested that individuals who participate in sport have more favorable health-related fitness compared to the general population,[2] there is no evidence that supports this contention. Therefore, the purpose of this study was to evaluate the health-related fitness of youth sport participants age 11-18 in comparison with normative findings from U.S. and Canadian general youth population data. We utilized normative findings from the U.S. and Canada in order to provide a holistic view of health-related fitness in youth sport

Methods

Participants and Procedures

A total of 136 participants (63 male, 73 female) age 11-18 (16.01 $\pm$ 1.35) were recruited from local public (n=76) and private high schools (n=2), and local sports organizations (n=58). The ethnic breakdown of the sample was as follows: 81.6% white, 16.2% black, and 2.2% other. Individuals in the sample participated in football (40), soccer (23 male; 39 female), volleyball (18 female), lacrosse (10 female), and other (6 female). Participants with a musculoskeletal injury within the past six months that limited participation or movement capability at the time of testing, or did not have current medical clearance for participation in sport, or who were unable to complete the testing were not allowed to participate. Individuals completed informed consent and were required to have parental consent before participating. Data was collected prior to the beginning of the individual's respective sport competitive season (Fall sport August – September; Spring sport January – February). Anthropometric (height, mass) and fitness data (BMI, body fat percentage, grip strength, SLJ, and the FITNESSGRAM® PACER and curl-up) were collected during two sessions at each sports setting. Prior to testing, participants performed a general self-selected warm-up. Anthropometric data was collected initially, followed by the other tests in random order. The PACER was tested separately from other fitness tests to minimize fatigue.

Measures

Valid and reliable health related fitness measures of musculoskeletal fitness (i.e., strength, endurance and power), cardiorespiratory endurance and body composition (BMI, & % body fat) were assessed on each individual. Standardized verbal instruction and demonstration of appropriate technique was provided for each fitness test.

The PACER is a multistage shuttle run, where individuals run 20 meters back and forth to the FITNESSGRAM® CD's decreasing time intervals. The score recorded was the maximum number completed until two passes of the interval were not completed prior to the beginning of the next interval. The PACER estimated VO_2 max demonstrates strong validity (r=0.87) and reliability (r=0.78 to 0.93) in the age range tested.[41-45] Participants' PACER score was utilized to calculate an individual's aerobic capacity (VO_2 Max).[45] The curl up task required participants to perform an abdominal curl and slide their fingers over a 12.7 cm rubber strip to the cadence on the FITNESSGRAM® CD. The score recorded was the maximum number completed until two breaks in form occurred. FITNESSGRAM® materials were used for cadence, timing, and scoring.[45]

Grip strength was tested using a Jamar hand dynamometer that was adjusted according to hand size. Participants held their arm by their side with elbow extended during this task and completed three trials for each hand, and the maximum of each hand was summed for an overall grip strength score (kg).[46] Grip strength is a valid (r=0.52-0.84)[47,48] and reliable (r=0.71-0.90)[49-51] measure of upper and lower body strength. Grip strength is suggested as a measure of muscular strength for youth, as noted from the Institute of Medicine report on Fitness Measures and Health Outcomes in Youth.[7] Height was measured to the nearest 0.5 cm using a portable standiometer (Shorrboard®). Body mass, BMI, and body fat percentage were collected using a bioelectrical impedance scale (model SC-331S, Tanita Corporation, Arlington Heights, IL).[52]

Statistical analysis

Data was double entered and cleaned prior to analysis and initial descriptive statistics were calculated. The outcome scores of the FITNESSGRAM® measures were classified according to the 2015-2016 performance standards (e.g. healthy fitness zone, needs improvement, needs improvement – health risk) by age and sex.[45] The healthy fitness zone for the FITNESSGRAM® was utilized as they are criterion referenced standards established to reflect that individuals who are in the "needs improvement" category and are at potential risk for metabolic syndrome and future health issues. Those in the "needs improvement – health risk" category have a higher probable risk of the aforementioned health issues.[45,53] Percentage classifications of individuals who were in each fitness category were noted and used to gain a general understanding of fitness levels among males and females. T-tests also were performed to compare participants'

BMI and grip strength to Canadian population normative values by age and by sex.[46] An alpha < 0.05 was used to determine significance.

Results

Sample descriptive statistics for the measures of health-related fitness (Body fat percent, BMI, PACER) are presented in Table 4.1. Health-related fitness measures of BMI, PACER, and curl-up were classified according to the 2015-2016 FITNESSGRAM® Performance standards (Tables 4.2 – 4.5).[45] Over 50% (50.8%) of male participants were classified as below the healthy fitness zone for BMI, while only 21.5% of female participants were below the healthy fitness zone. The majority of both male (70.5%) and female participants (79.7%) were in or above the healthy fitness zone for body fat percentage. Male participants' abdominal muscular endurance (curl-ups) were split equally between the healthy fitness zone (50%) and needing improvement (50%), while the majority (77.8%) of their female counterparts were classified in the healthy fitness zone. For the estimated VO_2 max from the PACER, the majority of male participants (55.9%) actually were classified below the healthy fitness zone, while the majority of female (63.2%) were in the healthy fitness zone.

We compared the BMI and grip strength of our sample of youth sport participants to Tremblay et al.'s 2010 general population data on Canadian youth (Tables 4.6 and 4.7).[46] Male sport participants in the 11-14 ($t = -6.627$, $P < 0.001$) and 15-19 ($t = -7.161$, $P < 0.001$) age ranges and female participants in the 11-14 age range ($t = -3.177$, $P < 0.05$) demonstrated a significantly lower VO_2 max compared to Canadian general population data. Female sport participants' age 11-14 years old had significantly greater grip strength than the Canadian normative data ($t = 6.009$, $P < 0.001$). Furthermore, male sport participants age 15-19 had significantly lower BMI than the Canadian general population youth ($t = 1.983$, $P < 0.05$).

Discussion

The purpose of this study was to evaluate youth sport participants health-related fitness and compare these findings to general population normative data from the FITNESSGRAM® and Canadian youth normative data. With the lack of evidence to support the claim that sport participants have favorable health-related fitness,[2] it is important to evaluate the health-related fitness of sport participants contextualized with comparisons to the general population. This information will provide valuable insight for the lifelong health and wellness of these individuals, as well as insights for their sport performance and potential to sustain injury.

Male Data

Overall, the health-related fitness for male sport participants tended to be poor in comparison to normative data and needs to be evaluated and addressed in order to improve performance, and decrease the risk for future health issues and injury. As 3 out of 4 fitness assessments had at least 50% of males needing improvement to simply reach a "healthy zone" level, it demonstrates a rather surprising lack of fitness in boys who are classified as "athletes." However, there were contradictory findings between the two assessments of body composition (BMI and body fat percentage), which prompt comparison.

Our data demonstrates why BMI is generally considered a poor measure of body composition in an athletic population, as individuals with a higher BMI may have more muscle mass, specifically in adolescent males. Males had a higher overall BMI than females, but BMI was positively correlated with muscular strength (r=0.448, *P*<0.001) and power (r=0.210, *P*<0.05). An unhealthy body composition predisposes these individuals for poor performance,[54-56] and for an increased risk of injury.[18,57,58] [14] The majority of male participants BMI was classified as "needs improvement" by the FITNESSGRAM® standards, and 24.6% were identified as having health risk based upon their BMI. BMI in youth sport may be misleading as athletes may have a higher lean mass than the general population, which inflates their BMI;[59-62] therefore, we also evaluated body fat percentage. A portion of the males who were at risk from their BMI were in the healthy fitness zone for body fat percentage, however, a third (29.5%) were still in the "needs improvement" classification. The "needs improvement" classifications means that these individuals have potential increased risk for health issues later in life based upon their body composition, and thus body composition still needs to be addressed in youth.

Surprisingly, almost half (44.1%) of males cardiorespiratory endurance (VO_2 max) classified them in the "health risk" category, which indicates these youth do not demonstrate adequate endurance for sport participation and also are at apparent risk of health issues in the future.[53] Additionally, male sport participants' demonstrated lower cardiorespiratory endurance when compared to the Canadian normative general population youth data. From both normative data points of reference, this sample of male youth sport participants generally demonstrated inadequate cardiorespiratory fitness. Cardiorespiratory endurance in participants need to be enhanced as it is an indication of future health,[53] and a marker for performance and risk of injury in sport as youth with decrease cardiorespiratory endurance demonstrate decreased performance and an increased risk of injury in sport.[18,63] Furthermore, half of male participants need improvement in their muscular endurance (curl up), and there was no difference between sport participants' and the general populations muscular strength, which demonstrates an additional risk factor for health issues in the future, decreased performance, and injury in sport. A large percentage of male sport participants' musculoskeletal and cardiorespiratory systems are not optimal or even healthy, though they participate in sport activities which places increased strain on both body systems.[3] These data indicate that cardiorespiratory fitness is not being improved by sport practices and/or competitions, and that sport coaches need to invest in developing youth health in addition to sport skills in order to decrease risk for future health issues,[53] enhance sport performance, and to decrease risk for injury from sport.[14,64]

Female Data

A portion of females were in the "needs improvement" FITNESSGRAM® category for BMI (21.6%) and body fat percentage (20.3%), though, the vast majority were within or above the healthy fitness zone. However, female sport participants demonstrated BMI's which were no different than the normative Canadian general youth population.

While the majority of females may not be at risk for future health issues based upon their BMI, the findings are concerning as they may still be at risk for decreased performance and increased injury in sport.[14,18,19,54-56,63,65]

The majority of female participants cardiorespiratory endurance and muscular endurance was classified in the healthy fitness zone. Although, a third of females were classified in the FITNESSGRAM® "needs improvement" for cardiorespiratory endurance demonstrating a potential health risk for metabolic syndrome.[53] Female sport participants' also demonstrated lower cardiorespiratory endurance compared to the normative Canadian general youth population (11-14 years old). As noted previously, low cardiorespiratory endurance also impacts their performance in sport and predisposes them to injury.[14,18,63] Furthermore, there was still a significant portion (22%) of females in the FITNESSGRAM® "needs improvement" for muscular endurance, adding to the risk for health issues in the future.[53] While females age 11-14 demonstrate greater muscular strength (via grip strength) compared to the normative Canadian data, although, this difference did not exist in the older age group (age 15-19), possibly since the majority of females (77.5%) in that age group were closer to the lower end of this range. As adequate muscular strength is imperative for performance in sport and injury prevention, specifically as competition level increases in adolescence, increasing muscular strength should be promoted in youth sport, specifically with increasing physical demands of sport.[3,63,65-67]

We recognize there are limitations worth mentioning in this comparison of youth sport participants to general youth. We have a relatively small sample size, and we have individuals from multiple different sports and sport organizations, with the majority of our sample participating in football. The organizations within our sample have different access to facilities (i.e. weight rooms) and strength and conditioning coaches, who may aid in the enhancement of health-related fitness. However, noting the insufficient levels of fitness, compared to general normative data, in both males and females is important to recognize and address.

Conclusion

The findings from this study are important as they demonstrate many youth sport participants in this sample, specifically boys, are at an increased risk for health issues, injury, and decreased performance because of their poor health-related fitness. These findings indicate that evaluating and addressing fitness deficits in youth sport should be important for sport coaches as it may impact sport performance and injury potential. Promoting health-related fitness regardless of sport participation in youth also may enhance an individual's long term athletic development and also enjoyment of sporting activities.[3,65] Participation in sport does not infer favorable health-related fitness, evidenced by the male sample who predominantly participated in football. Finally, the enhancement of youth health-related fitness may be addressed regardless of sport participation, as it has implications for the development of positive health trajectories across youth and into adulthood.[5,68,69]

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Table 4.1. Descriptive Statistics

	Sex	n	Mean	Std. Dev	t
Age	Male	61	15.87	1.44	0.909
	Female	68	15.65	1.26	
Body Fat %	Male	63	17.7%	7.4%	**-4.756***
	Female	69	**23.7%**	7.1%	
BMI	Male	63	**24.46**	5.15	**3.552***
	Female	70	21.66	3.76	
Est. VO_2 Max†	Male	34	41.26	6.36	-0.827
	Female	58	42.43	6.64	
Curl-up	Male	36	23.39	13.97	**-3.554***
	Female	68	**35.93**	21.86	
Grip Strength (kg)	Male	63	**82.37**	**19.29**	**9.517***
	Female	72	57.20	8.90	
SLJ Distance (cm)	Male	63	**193.97**	47.11	**5.442***
	Female	61	153.71	34.49	

*P < 0.001 for differences between males and females; †VO_2 Max = $(ml/kg/min)^2$

Table 4.2. Male FITNESSGRAM® Musculoskeletal & Cardiorespiratory Endurance

	Curl-up		20m PACER VO_2 Max (ml/kg/min)2		
	NI*	HFZ†	NI* - Health Risk	NI*	HFZ†
11	0	100 (1)	0	100 (1)	0
12	50 (2)	50 (2)	50 (2)	0	50 (2)
13	100 (4)	0	50 (2)	0	50 (2)
14	33.3 (1)	66.7 (2)	0	0	100 (3)
15	50 (3)	50 (3)	33.3 (2)	33.3 (2)	33.3 (2)
16	50 (3)	50 (3)	66.7 (4)	0	33.3 (2)
17	44.4 (4)	55.6 (5)	55.6 (5)	11.1 (1)	33.3 (3)
17+	0	100 (1)	0	0	100 (1)
% of total n	50.0	50.0	44.1	11.8	44.1

*NI = Needs Improvement; †HFZ = Healthy Fitness Zone

Table 4.3. Male FITNESSGRAM®® Body Composition

	Body Mass Index				Body Fat Percentage			
	NI* - Health Risk	**NI***	**HFZ†**	***Very* lean**	**NI* - Health Risk**	**NI†**	**HFZ†**	**Very lean**
11	0	0	100 (1)	0	0	0	100 (1)	0
12	25 (1)	0	75 (3)	0	0	25 (1)	75 (3)	0
13	50 (2)	0	50 (2)	0	0	50 (2)	50 (2)	0
14	0	33.3 (1)	66.7 (2)	0	0	0	100 (3)	0
15	31.3 (5)	25 (4)	43.8 (7)	0	12.5 (2)	25 (4)	62.5 (10)	0
16	16.7 (3)	27.8 (5)	55.6 (10)	0	0	22.2 (4)	77.8 (14)	0
17	28.6 (4)	35.7 (5)	35.7 (5)	0	0	35.7 (5)	57.1 (8)	7.1 (1)
17+	0	100 (1)	0	0	0	0	100 (1)	0
% of total n	24.6	26.2	49.2	0.0	3.3	26.2	68.9	1.6

*NI = Needs Improvement; †HFZ = Healthy Fitness Zone

Table 4.4. Female FITNESSGRAM® Musculoskeletal & Cardiorespiratory Endurance

	Curl-up		20m PACER VO_2 Max (ml/kg/min)2		
	NI*	HFZ†	NI* - Health Risk	NI*	HFZ†
12	0	100 (1)	0	0	100 (1)
13	66.7 (4)	33.3 (2)	40 (2)	20 (1)	40 (2)
14	30.8 (4)	69.2 (9)	0	27.3 (3)	72.7 (8)
15	11.8 (2)	88.2 (15)	25 (4)	12.5 (2)	62.5 (10)
16	18.8 (3)	81.3 (13)	31.3 (5)	12.5 (2)	56.3 (9)
17	0	100 (7)	0	33.3 (2)	66.7 (4)
17+	33.3 (1)	66.7 (2)	33.3 (1)	0	66.7 (2)
% of total n	22.2	77.8	19.3	17.5	63.2

*NI = Needs Improvement; †HFZ = Healthy Fitness Zone

Table 4.5. Female FITNESSGRAM® Body Composition

	Body Mass Index				Body Fat Percentage			
	NI* - Health Risk	NI*	HFZ†	Very lean	NI* - Health Risk	NI*	HFZ†	Very lean
12	0	0	100 (1)	0	0	0	100 (1)	0
13	16.7 (1)	33.3 (2)	50 (3)	0	0	50 (3)	50 (3)	0
14	0	0	92.9 (13)	9.1 (1)	0	0	78.6 (11)	21.4 (3)
15	11.1 (2)	11.1 (2)	77.8 (14)	0	11.8 (2)	23.5 (4)	64.7 (11)	0
16	11.8 (2)	17.6 (3)	70.6 (12)	0	0	17.6 (3)	82.4 (14)	0
17	0	14.3 (1)	85.7 (6)	0	0	14.3 (1)	71.4 (5)	14.3 (1)
17+	0	50 (1)	50 (1)	0	0	0	100 (1)	0
% of total n	7.7	13.9	76.9	1.5	3.1	17.2	73.4	6.3

*NI = Needs Improvement; †HFZ = Healthy Fitness Zone

Table 4.6. Male Sport vs Canadian Normative General Population

		n	Mean	Std. Dev.	t
Male 11-14 Years Old					
		n	**Mean**	**Std. Dev.**	**t**
BMI	Tremblay 2010	318	20.60	4.40	0.871
	Pfeifer 2017	12	22.10	5.90	
Grip (kg)	Tremblay 2010	316	51.00	17.00	1.754
	Pfeifer 2017	12	61.71	20.89	
VO_2 Max‡	Tremblay 2010	307	54.9	3.4	-6.627†
	Pfeifer 2017	12	42.08	6.66	
Male 15-19 Years Old					
		n	**Mean**	**Std. Dev.**	**t**
BMI	Tremblay 2010	287	23.8	5.3	1.983*
	Pfeifer 2017	49	22.28	4.73	
Grip (kg)	Tremblay 2010	286	85	18	1.205
	Pfeifer 2017	49	87.91	15.18	
VO_2 Max‡	Tremblay 2010	307	50.8	5.8	-7.161†
	Pfeifer 2017	22	40.81	6.31	

*$P < 0.05$; †$P < 0.001$; ‡VO_2 Max = $(ml/kg/min)^2$

Table 4.7. Female Sport vs Canadian Normative General Population

Female 11-14 Years Old					
		n	Mean	Std. Dev.	t
BMI	Tremblay 2010	302	20.4	3.8	-0.814
	Pfeifer 2017	21	19.79	3.28	
Grip (kg)	Tremblay 2010	301	42	10	6.009†
	Pfeifer 2017	20	54.56	8.98	
VO_2 Max‡	Tremblay 2010	307	48.9	4	-3.177*
	Pfeifer 2017	18	43.58	6.57	
Female 15-19 Years Old					
		n	**Mean**	**Std. Dev.**	**t**
BMI	Tremblay 2010	280	23.10	4.60	-0.613
	Pfeifer 2017	44	22.72	3.69	
Grip (kg)	Tremblay 2010	307	54.00	10.00	4.066
	Pfeifer 2017	47	59.27	7.98	
VO_2 Max‡	Tremblay 2010	307	42.2	4.3	-0.235
	Pfeifer 2017	41	41.95	6.69	

*$P < 0.05$; †$P < 0.001$; ‡VO_2 Max = $(ml/kg/min)^2$

CHAPTER 5

THE UTILITY OF THE FUNCTIONAL MOVEMENT SCREEN AND HEALTH-RELATED FITNESS FOR MITIGATING INJURY IN YOUTH SPORT*

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Over 7.8 million youth participate in at least one extramural sport each year,[1-5] but there is a current belief that youth are not adequately prepared for the physical demands that sport requires.[6] Unfortunately, failure of youth to meet the demands of sport often leads to musculoskeletal injury.[7-11] There were over 1.4 million injuries estimated nationwide in 2013-2014, and over the five previous years the number of injuries has consistently increased.[12] Thus, it is becoming increasingly important to identify and address mechanisms relating to injury incidence in youth sport.[13,14]

Functional motor competence (FMC) is the ability of an individual to coordinate and control their center of mass and extremities, in a gravity based environment, in response to perturbations, to effectively attain a goal. An individual's FMC has been linked to injury incidence in college and professional sports using various movement assessments.[7,8,15,16] Overall, young adults with less advanced FMC (as assessed using the Functional Movement Screen) are up to 11.7 times as likely to sustain injury during sport participation than their more advanced peers (OR= 4.58 to 11.67).[7,8,15,16] Preliminary evidence shows that measures of FMC that evaluate neuromuscular coordination and control have the potential to identify injury risk in youth,[17-19] though, only a few studies have evaluated the impact of FMC on injury incidence in youth sport, with conflicting results across studies.[19-22] Thus, more research is warranted to understand the impact of FMC on injury prevalence in youth.

Linked to the development of FMC, and also associated with injury incidence, is the development of multiple aspects of health-related fitness (i.e. muscular strength/power, muscular endurance, cardiorespiratory endurance, and weight status).[13,14,23,24] Decreases in health-related fitness (HRF) may relate to an increased injury risk in youth as neuromuscular and cardiorespiratory fatigue affects an individual's ability to perform in sport.[13,14,25-29] While it is generally assumed that all children continue to develop FMC and HRF across childhood and adolescence, recent evidence suggests that many children (both boys and girls) actually show a decrease in their FMC (as assessed by various movement assessments) and HRF across childhood (grade 1 to 4, age 6.3 $\pm$ 0.7 at baseline).[30] To compound the issue, secular data also indicate FMC and HRF have been declining in youth,[31-35] with 20.5% of U.S. youth (12-19 years) being obese (2011-2014).[36]

In order to impact injury prevalence, the ability to identify risk factors is key.[14] Since the development of FMC and HRF are synergistically linked across childhood and adolescence,[24,37,38] and both are related to injury incidence,[7,8,13-15,22,25,26] the concurrent evaluation of both constructs may provide vital insight for injury risk in youth athletes. Unfortunately, little data is available on the HRF and FMC in youth sport in the United States. Furthermore, no studies have addressed the potential combined impact that motor competence and HRF levels may have on injury incidence in youth sport. The purposes of this study are twofold, 1) to assess the relationship between HRF and FMC in youth sport, and 2) to assess if the combination of both FMC and HRF has utility for the prediction of injury in youth sport.

Methods

Participants and procedures

A total of 136 participants (63 male, 73 female) age 11-18 (16.01 ± 1.35) were recruited from local public and private high schools and local sport organizations. The ethnic breakdown of the sample was as follows: 81.6% white, 16.2% black, and 2.2% other. Individuals in the sample participated in football (40), soccer (23 male; 39 female), volleyball (18 female), lacrosse (10 female), and other (6 female). Participants with a musculoskeletal injury within the past six months that limited participation or movement capability at the time of testing, or did not have current medical clearance for participation in sport, or who were unable to complete the Functional Movement Screen (FMS™) testing were not allowed to participate. Individuals completed informed consent and were required to have parental consent before participating. Data was collected prior to the beginning of the individual's respective sport competitive season (Fall sport August – September; Spring sport January – February). The following information was collected during two sessions at each sports setting: anthropometric data (height, seated height, weight, BMI, body fat percentage), the FMS™, grip strength, SLJ, and the FITNESSGRAM® PACER and curl-up. Prior to testing, participants performed a general self-selected warm-up. Anthropometric data was collected initially, followed by the other tests in random order to minimize fatigue. The PACER was tested separately from other fitness tests to minimize fatigue. Injury information was received at the end of each sports respective season. Standardized verbal instruction was provided for the FMS™ and each HRF test.[29,39,40]

Measures

Height and seated height were measured to the nearest 0.5 cm using a portable standiometer (Shorrboard®). Body mass, BMI, and body fat percentage were collected using a bioelectrical impedance scale (model SC-331S, Tanita Corporation, Arlington Heights, IL).[41]

The FMS™ consists of seven tasks that are tested in the following order: overhead deep squat, hurdle step, inline lunge, shoulder mobility, active straight leg raise, trunk stability pushup, and rotary stability. All tasks are completed bilaterally except for the overhead deep squat and the trunk stability push up. Participants were given standardized verbal instruction (per the FMS™ manual).[29] Each task of the FMS™ is coded on a scale of 1 to 3 relating to an individual's capability to perform each suggested movement, with a lower score representing compensate or dysfunctional movement.[27,28] Participants who experienced pain during any portion of the FMS™ received a score of 0 for the task they were performing. Tasks that were completed bilaterally were scored per side, then received the lower of the two scores as the final score for that task. The final scores of each task were summed for a composite score with a maximum of 21 points. Participants were videotaped or live coded (dependent upon time of enrollment) performing a maximum of 3 trials of each FMS™ task. If participants met the criteria for a "Level 3" prior to completion of all trials of one task, the next task was assessed as further screening is not needed.[29] The FMS™ was coded by individuals trained in the assessment. Inter/intra-rater coding reliability was adequate for all raters for both video (κ_w = 0.73 to 1) and live coding (κ_w = 0.70 to 1).[42]

Valid and reliable health related fitness measures were assessed on each individual including: the FITNESSGRAM® 20 meter PACER test (cardiorespiratory endurance), FITNESSGRAM® curl up (muscular endurance), grip strength and SLJ (muscular strength and power).[40,43-49] The PACER is a multistage shuttle run, where individuals run 20 meters back and forth to the FITNESSGRAM® CD's decreasing time intervals. The score recorded was the maximum number completed until two passes of the interval were not completed prior to the beginning of the next interval. The PACER estimated VO_2 max demonstrates strong validity (r=0.87) and reliability (r=0.78 to 0.93) in the age range tested.[40,50-53] Participants' PACER score was utilized to calculate an individual's aerobic capacity (VO_2 Max).[40] The curl up task required participants to perform an abdominal curl and slide their fingers over a 12.7 cm rubber strip to the cadence on the FITNESSGRAM® CD ("up" and "down"). The score recorded was the maximum number completed until two breaks in form occurred. FITNESSGRAM® materials were used for cadence, timing, and scoring.[40]

Grip strength was tested using a Jamar hand dynamometer that was adjusted according to hand size. Participants held their arm by their side with elbow extended during this task and completed three trials for each hand, and the maximum of each hand was summed for an overall grip strength score (kg).[54] Grip strength is a valid (r=0.52-0.84)[55,56] and reliable (r=0.71-0.90)[57-59] measure of upper and lower body strength. Participants also completed five trials of the SLJ. Participants were asked to place their toes on a marked line and jump as far as possible. We measured the distance (cm) from the start line to their closest heel, and the mean of the five attempts was utilized for analyses. The SLJ is strongly correlated with total body strength (r=0.77) and other measures of power (e.g. vertical jump, countermovement jump, isometric strength; r=0.70-0.91).[49,56]

A Certified Athletic Trainer employed by each site tracked participant injuries using their preferred tracking software. Injury was defined as any physical insult or harm resulting from sports participation that required an evaluation from a health or medical professional and time modified or time lost from sport participation.[7,9,15,20] This definition of injury was utilized to unify the definitions in the literature.[8,15,20-22] Individuals who sustained injury from any source outside of the school sport in which they were participating were excluded from injury analyses. Both contact and non-contact Injury was collected.

Statistical Analysis

Data was double entered and cleaned prior to analysis. Descriptive statistics and FMS™ scores for participants are shown in Tables 5.1 and 5.2. Due to significant differences between male and female performances on the FMS™ and HRF tests, the analysis was stratified by sex. We utilized analyses of variance to assess the relationship between performance on each task of the FMS™ and HRF variables. Two Logistic regressions were utilized to examine the odds of injury as a function of HRF, composite FMS™ score, sex, and age. For model 1, we utilized backwards selection to model the odds of injury from the predictors of sex, age, and all HRF variables (BMI, body fat percentage, VO_2 Max, curl up score, grip strength, and SLJ distance). For model 2, a backwards selection procedure was performed to model injury from the following predictors: sex, age, composite FMS™ score, and all HRF variables (BMI, body fat percentage, VO_2 Max, curl up score, grip strength, and SLJ distance). As many participants were at various stages of physical maturation, maturity offset was calculated using the formulas provided by Malina and Kozieł.[60,61] Maturity offset was used as a categorical covariate (pre-, post-peak height velocity) in an exploratory analysis to assess the influence of maturation status and injury. An alpha < 0.05 was used to determine significance.

Results

There were no differences in the HRF variables for males, based on the performance of the overhead deep squat, active straight leg raise, or rotary stability tasks of the FMS™ (tables 5.3 to 5.9). Males who performed better on the hurdle step demonstrated significantly larger SLJ distances ($F=4.55$, $P=0.015$). On the inline lunge task, males with better performance had a significantly lower BMI ($F=3.74$, $P=0.03$), body fat percentage ($F=4.09$, $P=0.022$), and a significantly greater VO_2 Max ($F=4.80$, $P=0.015$) and SLJ distance ($F=3.62$, $P=0.033$). Males who demonstrated better performance on the shoulder mobility task had a significantly lower body fat percentage ($F=3.07$, $P=0.035$), and a significantly greater grip strength ($F=4.11$, $P=0.01$) and SLJ distance ($F=5.99$, $P=0.001$). There were also significant differences between performance on the shoulder mobility task and BMI (F=3.14, *P*=0.032), with those scoring a 0 having a greater BMI than those scoring a 2 or 3. Additionally, individuals performing better on the trunk stability pushup demonstrated greater SLJ distances (F=3.01, *P*=0.037).

There were no differences in HRF variables in female participants based on the performance of the overhead deep squat, inline lunge, active straight leg raise, or the trunk stability pushup tasks of the FMS™ (tables 5.3 to 5.9). Females who performed better on the hurdle step had a significantly lower VO_2 Max (F=3.40, *P*=0.042) and significantly greater curl up score (F=4.69, *P*=0.013). Female participants with a lower BMI demonstrated better performance on the shoulder mobility task (F=3.42, *P*=0.039). There were significant differences in the BMI (F=4.07, *P*=0.022) and body fat percentage (F=4.02, *P*=0.023) based upon the performance of the rotary stability task. Interestingly, female participants scoring a 1 or 3 had a greater BMI than those scoring a 2. Breakdown of HRF by FMS™ task and sex is presented in tables 5.5 through 5.11.

Prediction of Injury

Sex was the only significant predictor of injury when modeling the odds of injury from the predictors sex (OR= 13.02 for males, CI 4.46-38.04) and composite FMS™ score (OR= 0.95, CI 0.81-1.12). In model 1, the significant predictors of increased odds of injury were a participant’s sex (OR= 9.74, CI 2.46-38.55), VO_2 Max (OR= 0.84, CI 0.74-0.95), and SLJ distance (OR= 1.03, CI 1.00-1.05). For model 2, the significant predictors of increased odds of injury were a participant’s sex (OR= 10.55, CI 2.37-47.01), VO_2 Max

(OR= 0.85, CI 0.75-0.97), and SLJ distance (OR= 1.03, CI 1.01-1.05; table 5.10). The exploratory analysis revealed no significant relationship between injury and maturation status (pre-, post-peak height velocity) in both males and females

Discussion

The first purpose of this study was to assess the relationship between HRF and FMC in youth sport. These findings demonstrate that tasks of the FMS™ are related HRF.[27-29] Males with advanced movement capability (inline lunge and shoulder mobility) demonstrated healthier body weight status compared to those with less advanced movement, further supporting the inverse relationship between FMC and body weight status in youth.[62-64] Individuals scoring better on the hurdle step had greater muscular endurance (curl up). This may be because the hurdle step requires lower extremity stability,[27] which is a function of muscular control of the core.[65,66] Higher muscular power in males is related to most FMS™ tasks (hurdle step, inline lunge, shoulder mobility, and trunk stability pushup), demonstrating that muscular power is globally related to FMC.[67] While the squat has been highlighted as a foundational movement pattern related to measures of performance in sport,[68,69] the inline lunge may be more applicable to youth performance due to its relationship with dynamic whole body reactive movements.[70] The inline lunge pattern is a dynamic unilateral task which stresses an individual's core and lower extremity strength, stability, coordination, and balance.[27] Furthermore, males with better performance on the inline lunge have more favorable body composition, cardiorespiratory endurance, and muscular power. While the squat is a viable training option, unilateral and oppositional movements like the inline lunge may be a better choice in youth as it requires greater coordination and control since the base of support is narrower and this task requires rotational control of the core.[66] The implications of the inline lunge present an opportunity for coaches and strength and conditioning professionals to evaluate their training philosophy based on the selection of dynamic movements that are developmentally appropriate and require greater development of oppositional coordination and control.[70,71]

The second purpose of this study was to assess if the combination of both FMC and HRF has utility for the prediction of injury in youth sport. When modeling injury from FMC and HRF measures by sex, the most salient factors were an individual's sex, muscular power, and cardiorespiratory endurance. Males in our sample were at an increased odds of injury compared to females. Further evaluation of the individuals from our sample who were injured showed that the majority of injuries occurred in football (74%). Since there were no females who participated in football, the significance of sex was anticipated based on these data. Interestingly, those with higher muscular power demonstrated an increased odds of injury, which also may be related to sex differences in muscular power. When evaluating the sports in which participants were injured most, football held the majority of injuries. Football is a sport which relies high muscular strength and power,[72,73] and typically males are the main participants in this sport. While our ability to make assumptions for analyses within sport are limited, sport choice may have an implication on injury incidence as football has held the highest injury rate among high school sports from 2005-2014.[12] Those with lower cardiorespiratory endurance were at an increased odds of injury, which has been previously reported as a risk factor for injury.[14,74] Fatigue negatively impacts an individual's motor coordination and control, which places these individuals at an increased odds of injury.[75] These data suggest future research on the FMS™ and injury in youth sport should be performed within the same types of sport (i.e. contact, etc.) to examine not only injury risk in individual sports, but also to understand whether risk is global or based on individual sports. Furthermore, collecting mechanism of injury may be useful in evaluating the effect movement has on non-contact injury.

While the importance of maturation and the use of maturity offset information to categorize pre- and post-peak height velocity has been recommended to address performance and injury,[76] it did not demonstrate a relationship with injury potential in our data. While maturation may have implications for the development of HRF and FMC in youth,[70] further evaluation is needed to utilize this measure for the identification of injury risk.

Limitations

While the data represent youth athletes that participated in a variety of sports, the intent of this study was to evaluate within in each sport; therefore, our ability to offer implications within sports is limited. In addition, while Athletic Trainers are present at each facility, injuries may have gone unreported by participants when the medical staff was providing coverage elsewhere at their site.

Conclusion

Results from this study demonstrate that there are variable relationships between the tasks of the FMS™ and multiple measures of HRF. While no overall relationship was noted between FMC, HRF and injury, low FMC and HRF should be addressed in youth sport as an individual's FMC or HRF may affect their future risk of injury. In addition, the relationships between the inline lunge and HRF variables may provide insight for coaches and strength and conditioning professionals to re-evaluate their selection of training tasks based on the importance of developing advanced coordination and control in dynamic movements.

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Table 5.1. Descriptive Statistics

	Sex	n	Mean	Std. Dev	t
Age	Male	61	15.87	1.44	0.909
	Female	68	15.65	1.26	
Body Fat %	Male	63	17.7%	7.4%	**-4.756***
	Female	69	**23.7%**	7.1%	
BMI	Male	63	**24.46**	5.15	**3.552***
	Female	70	21.66	3.76	
VO_2 Max (ml/kg/min)[2]	Male	34	41.26	6.36	-0.827
	Female	58	42.43	6.64	
Curl-up	Male	36	23.39	13.97	**-3.554***
	Female	68	**35.93**	21.86	
Grip Strength (kg)	Male	63	**82.37**	**19.29**	**9.517***
	Female	72	57.20	8.90	
SLJ Distance (cm)	Male	63	**193.97**	47.11	**5.442***
	Female	61	153.71	34.49	

*P < 0.001

Table 5.2. Functional Movement Screen Scores

	Sex	n	Mean	Mode	Std. Deviation	Minimum	Maximum	t
Deep Squat	Male	63	1.70	2	0.56	1	3	-0.934
	Female	65	1.80	2	0.67	1	3	
Hurdle Step	Male	63	1.65	2	0.54	1	3	**-2.978***
	Female	65	**1.91**	2	0.42	1	3	
Inline Lunge	Male	62	2.13	2	0.66	1	3	-1.818
	Female	65	2.32	2	0.53	1	3	
Shoulder Mobility	Male	62	2.02	3	1.00	0	3	**-4.461***
	Female	65	**2.68**	3	0.62	1	3	
Active Straight Leg Raise	Male	63	1.87	2	0.61	1	3	**-3.726***
	Female	65	**2.32**	3	0.75	1	3	
Trunk Stability Pushup	Male	63	1.60	2	0.77	0	3	1.065
	Female	65	1.46	1	0.73	1	3	
Rotary Stability	Male	63	1.65	2	0.60	0	3	**-2.875***
	Female	65	**1.91**	2	0.38	1	3	
Composite FMS™	Male	61	12.62	14	3.06	6	18	**-3.903***
	Female	65	**14.40**	15	1.88	9	18	

*P < 0.001

Table 5.3. Health-Related Fitness by Performance on the Overhead Deep Squat

	Male						Female					
Task Score	BMI	Body Fat	VO_2 Max	Curl up	Grip	SLJ	BMI	Body Fat	VO_2 Max	Curl up	Grip	SLJ
0	-	-	-	-	-	-	-	-	-	-	-	-
1	25.7	20.3%	39.2	20.1	79.9	186.6	22.0	24.4%	41.9	29.0	53.8	158.4
2	23.8	16.6%	41.6	24.2	84.0	195.4	21.2	22.6%	42.2	38.4	58.3	151.8
3	23.3	12.8%	51.4	37.0	80.4	230.1	22.3	24.5%	46.0	41.6	59.8	141.6

Table 5.4. Health-Related Fitness by Performance on the Hurdle Step

Task Score	Male						Female					
	BMI	Body Fat	VO_2 Max	Curl up	Grip	SLJ*	BMI	Body Fat	VO_2 Max*	Curl up*	Grip	SLJ
0	-	-	-	-	-	-	-	-	-	-	-	-
1	26.0	20.3%	40.5	22.6	78.3	172.4	22.3	24.6%	40.2	18.8	55.7	144.2
2	23.6	16.2%	42.0	24.2	83.9	206.9	21.3	23.0%	43.4	37.5	56.9	153.5
3	21.5	14.0%	-	-	102.7	213.6	23.7	26.7%	32.4	61.5	62.7	161.7

*$P < 0.05$

Table 5.5. Health-Related Fitness by Performance on the Inline Lunge

	Male						Female					
Task Score	BMI*	Body Fat*	VO_2 Max*	Curl up	Grip	SLJ*	BMI	Body Fat	VO_2 Max	Curl up	Grip	SLJ
0	-	-	-	-	-	-	-	-	-	-	-	-
1	27.8	22.6%	35.7	21.5	74.3	158.0	21.1	23.0%	41.0	13.0	52.2	153.6
2	24.5	18.0%	41.6	23.0	82.6	199.7	21.9	23.7%	42.9	36.2	56.6	155.7
3	22.5	14.6%	44.2	25.4	85.0	199.5	21.1	23.1%	42.2	36.5	58.1	148.6

*P < 0.05

Table 5.6. Health-Related Fitness by Performance on the Active Straight Leg Raise

	Male						Female					
Task Score	BMI	Body Fat	VO_2 Max	Curl up	Grip	SLJ	BMI	Body Fat	VO_2 Max	Curl up	Grip	SLJ
0	-	-	-	-	-	-	-	-	-	-	-	-
1	26.9	21.2%	37.5	19.3	76.9	180.9	21.5	22.1%	45.5	30.9	56.6	154.9
2	23.7	16.5%	42.1	23.5	83.9	197.6	21.3	23.0%	42.6	43.7	57.7	163.9
3	23.4	16.3%	43.6	29.6	85.9	202.2	21.8	24.3%	41.4	31.8	56.6	144.6

Table 5.7. Health-Related Fitness by Performance on the Shoulder Mobility

Task Score	Male						Female					
	BMI*	Body Fat*	VO_2 Max	Curl up	Grip*	SLJ*	BMI*	Body Fat	VO_2 Max	Curl up	Grip	SLJ
0	28.2	22.4%	34.8	29.7	84.5	197.2	-	-	-	-	-	-
1	22.2	18.6%	40.8	18.0	63.1	143.0	23.5	26.4%	37.9	30.6	52.6	155.4
2	25.7	19.3%	41.1	19.5	87.6	193.0	23.6	27.3%	41.8	41.7	58.7	148.8
3	23.0	14.5%	43.3	29.6	84.2	213.4	20.9	22.1%	43.3	34.7	57.0	153.7

*$P < 0.05$

Table 5.8. Health-Related Fitness by Performance on the Trunk Stability Push up

Task Score	Male BMI	Male Body Fat	Male VO_2 Max	Male Curl up	Male Grip	Male SLJ*	Female BMI	Female Body Fat	Female VO_2 Max	Female Curl up	Female Grip	Female SLJ
0	25.7	18.9%	43.6	35.0	91.1	221.8	-	-	-	-	-	-
1	25.2	19.7%	38.8	19.9	76.2	173.3	21.4	23.5%	42.4	32.8	57.3	151.4
2	23.5	15.8%	42.3	23.3	85.9	202.9	23.2	25.5%	41.6	46.6	53.6	148.0
3	25.0	17.9%	44.8	33.8	84.6	213.3	20.4	20.0%	45.4	33.3	59.9	164.8

*P < 0.05

Table 5.9. Health-Related Fitness by Performance on the Rotary Stability

	Male						Female					
Task Score	BMI	Body Fat	VO_2 Max	Curl up	Grip	SLJ	BMI*	Body Fat*	VO_2 Max	Curl up	Grip	SLJ
0	27.1	21.2%	36.0	18.5	79.5	173.1	-	-	-	-	-	-
1	25.7	19.2%	39.6	24.3	82.5	182.1	23.2	28.1%	42.7	34.5	57.9	147.7
2	23.9	17.0%	42.7	23.3	82.5	201.0	21.1	22.4%	42.7	36.3	56.7	153.6
3	20.7	11.9%	44.3	25.0	82.5	160.2	27.5	31.7%	38.7	5.0	59.8	148.2

*P < 0.05

Table 5.10. Logistic Regression Final Model Information

Model 1					
Parameter	**Estimate**	**S.E.**	**OR**	**95% Wald Confidence Limits**	
Intercept	1.9615	2.2296			
Sex*	1.1383	0.3508	9.744	2.463	38.549
VO_2 Max	-0.1732	0.0645	0.841	0.741	0.954
SLJ distance	0.0236	0.0104	1.024	1.003	1.045
Model 2					
Parameter	**Estimate**	**S.E.**	**OR**	**95% Wald Confidence Limits**	
Intercept	0.6905	2.3115			
Sex*	1.1782	0.3811	10.553	2.369	47.005
VO_2 Max	-0.1639	0.0654	0.849	0.747	0.965
SLJ distance	0.0285	0.0112	1.029	1.007	1.052

*Male is the referent level; $^{\dagger}P < 0.05$

CHAPTER 6

DISCUSSION

The purpose of this dissertation was to evaluate FMC and HRF in youth sport, and determine their utility for the prediction of injury in youth sport participants (age 11-18). Three separate studies were conducted. The first study evaluated the mean and distribution of the FMS™ in youth sport (age 11-18), and if there was a composite FMS™ score which was predictive of increased injury risk. The mean composite FMS™ score for the sample was 13.54 ± 2.66, demonstrated that youth sport participants evaluated through the FMS™ have some level of dysfunctional movement. Furthermore, 74% of the overall injuries were sustained in football, and when controlling for sport there was no composite FMS™ score which was predictive of increased risk of injury. Thus, the injury data from our sample seem to be more a product of an individual's chosen sport rather than their quality of movement.

The purpose of the second study was to evaluate the HRF of youth sport participants (age 11-18), and provide a comparison between general youth and youth in sport. Results revealed that HRF for male sport participants tended to be poor in comparison to normative data. This study demonstrated a rather surprising lack of fitness in boys who are classified as "athletes", and the need to evaluate and address HRF in order to improve performance, and decrease the risk for future health issues and injury. The majority of females were not at risk for future health issues based upon body composition, however, the findings were concerning since these females may still be at future risk for decreased performance and increased injury in sport based upon their HRF.[1-8] Since an individual's HRF is related to their health,[9] sport performance,[3,4] and risk of injury in sport,[1,2] these results present the opportunity for strength and conditioning professionals to focus on HRF in sport preparatory programs as opposed to skill.

The purpose of the final study was to assess the relationship between HRF and the FMS™ in youth sport (age 11-18), and assess if the combination of both HRF and the FMS™ has utility for prediction of injury in youth sport. Results indicated that the relationships between HRF and the FMS™ in youth sport was varied, with no overall relationship found. The analysis of the predictive utility of HRF and FMS™ revealed that males and individuals with a higher muscular power were at and increased risk to sustain injury during sport participation. Low cardiorespiratory endurance has been previously documented as a risk factor for injury,[2,6,10] as fatigue decreases an individual's ability to coordinate and control their center of mass and extremities, placing themselves in compromising positions. As previously mentioned, the majority of injuries in this sample occurred in football athletes, and since males typically participate in football, the significance of sex was anticipated. While our ability to make assumptions for analysis within individual sports is limited, the combination of full contact and non-contact sports revealed injury to potentially be a function of sport. The

FMS™ may show potential for the prediction of injury within individual sports, and future research should consider this point.

Since individuals are being entered in to sport as children, and HRF and FMC demonstrate dynamic relationships as youth age, these constructs merit further investigation. In order to optimize youth's health, sport performance, and reduce the risk of injury, further evaluation of HRF and FMC is needed in youth sport. The evaluation and modification of HRF early may be necessary for the long term health and development of youth participating in sport in the United States.

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APPENDIX A – PARTICIPANT ASSENT FORM

PARTICIPANT ASSENT FORM

Study Title: The Association between Functional Movement Proficiency, Injury Incidence, and Health Indices in Adolescent Athletes.
Primary Investigators: David F. Stodden, Ph.D. C.S.C.S.; Craig E. Pfeifer, MS, ATC; Jim Mensch, Ph.D. ATC; Justin Goins, Ph.D. ATC; Eva Monsma, Ph.D.
Graduate Assistants: Erin Moore, MS, ATC

Participant's Name: _________________________ ID#_______________

Hello _____________ (child's name), my name is (state name). I am working with Dr. David Stodden from the University of South Carolina. We want to see how youth athletes perform during different types of movements like squatting, lunging and balancing. We also want to test your physical fitness and body height and weight measures. We want to know if your movement performance and fitness are related to whether or not you get injured during sports. Some of the tasks we want you to do are related to how you move your body and we have shown you the movements we want you to do. The fitness tests we want you to perform are jumping, curl ups, running and your hand grip strength. We also will measure how tall you are and how much you weigh. We also want you to fill two surveys. We want to know what sports you participate in and have participated in. We also want to know how you feel about physical activity and sport. You get to choose if you want to help us with this study or not. If you want to help us with this study, but then change your mind when doing the study, you are still able to stop. Your decision to help us with this study or not help us will not affect your playing time on your team. Please check the box below to let us know if you want to help us with this study or not.

☐ **YES:** If you do want to take part of this study and help us, please check this box.

☐ **NO:** If you **DO NOT** want to take part of this study please check this box.

We also will be videotaping you to see how you move. If you checked the **YES** box above, would you allow us to use the videotapes for presentations and other work that we do at the University that will help others understand our study? Please check the box below to let us know if you would allow us to use the videotapes of you moving.

☐ **YES:** If you will allow us to use the videotapes of your movements, please check this box.

☐ **NO:** If you **DO NOT** want us to use the videotapes of your movements, please check this box.

If you agreed to help us with this study and checked the first **YES** box, please write your name and put today's date.

____
Child Name / Signature Date

School District 5 of Lexington and Richland Counties is neither sponsoring nor conducting this research.

APPENDIX B – CONSENT FORM

PARENTAL/CAREGIVER CONSENT FORM

Study Title: The Association between Functional Movement Proficiency, Injury Incidence, and Health Indices in Adolescent Athletes.
Primary Investigators: David F. Stodden, Ph.D., C.S.C.S.; Craig E. Pfeifer, MS, ATC; Jim Mensch, Ph.D., ATC; Justin Goins, Ph.D., ATC; Eva Monsma, Ph.D.

Graduate Assistants: Erin Moore, MS, ATC

Dear Parent,
Your child is invited to participate in a research study conducted by David Stodden PhD, CSCS, Jim Mensch PhD, ATC, Justin Goins PhD ATC, and Eva Monsma PhD, professors and Alexander Medina and Joseph Meyer, Certified Athletic Trainers at the University of South Carolina. The relationship between movement skills and injury risk in youth has not been previously studied. One of the main components of Athletic Training is injury prevention and we want to know if their movement skills and physical fitness are related to whether they get injured in sports.

This is a parental/caregiver permission form for research participation. This form contains important information about this study and what to expect if you permit your child to participate. ***Your child's participation is voluntary. You or your child may refuse to participate in this study without penalty or loss of benefits to which you are otherwise entitled. You and or your child may discontinue participation in this study at any point.*** Please consider the information carefully. Feel free to discuss the study with your friends and family and to ask questions before making your decision whether or not to permit your child to participate. If you and your child agree to participate in the study, the following will happen:

What are we studying?
We will ask your child to complete tests to assess their physical fitness, movement skills and basic body measurements, and two surveys during practice before the start of season. All these tests will be completed before practice during one session of the preseason. We will ask your child to come 90 minutes early for one practice to complete the testing. Below are the types of tests that your child will complete.

1) Functional movement performance: We will ask your child to do movements like squatting, lunging and movements related to flexibility and balance. We will videotape your child during this part of the study to score their movements at a later time.

2) Health-Related Fitness: This information will be collected to test your child's overall physical fitness. These tests are the same types of tests that your child does in physical education. We will ask them to do a running test, hand grip strength, curl-ups and jump as high as they can.

3) Body Measurements: We will measure your child's height, sitting height and weight. Your child's body composition will be measured using the weight measurement scale.

4) Injury report: After the season, we will ask your child to fill out a form to see if they were injured during the season. We also will ask if they missed any practice or games because of the injury and whether they saw a medical professional to help with the injury.

5) Surveys: We will ask your child to complete two surveys. One survey asks what sports your child participates in currently, and has participated in the past. The other survey will ask your child questions about how they feel about physical activity and sport.

How are we protecting your child's privacy?

Any information that is obtained for this study and can be identified with your child will remain confidential and will be disclosed only with your permission. A number will be assigned to your child at the beginning of the study. This number will be used on project records and your child's name will not be used in any way. We will videotape your child's movement skills in order to score your child's movement and we would like to use the videotapes for presentations to help other health professionals understand what our study is all about. Videotaping your child's functional movement screen will help with the validity and accuracy of the study and will only be used for research and training purposes only. Study records and videotapes will be stored in locked filing cabinets and protected computer files at the University of South Carolina. The results in this study may be published or presented at professional meetings, but your child's name will never be used.

Are there risks to my child if they participate?

We will ask your child whether or not they have been injured before and we will ask them if they were injured during the season. If they have a current or recent injury that will not allow them to complete the tests, they will not be allowed to participate. If you allow your child to participate, there are minimal physical risks to your child when completing the tests in this study. The movements and tests are similar to movements and tests that they do in sports and physical education. To minimize the chance of physical injury, we will provide adequate warm-up and cool down activities for the children before participation in fitness or movement skill testing. Certified Athletic Trainers will be on site during all of the testing process to demonstrate how to safely complete the test. If by any chance an emergency happens, an emergency action plan will be activated, local EMS (911) will be activated.

Research Related Injury

If your child is injured as a result of taking part in this study, the researchers will help you get appropriate medical care. However, the University of South Carolina has not set aside funds to compensate you for any complications or injuries, or for related medical care. Any study-related injury should be reported to the research staff immediately.

Are their benefits to my child for participating in this study?

There are no direct benefits to your child for participating in the study. However, information gained from this study could potentially identify athletes at risk for sustaining an injury during a season. This information may help in the further development of pre-participation screening.

If you have any questions or concerns:

If you would like further information about this research project, you should contact Dr. David Stodden at Office- (803) 777-9882 or Email: stodden@mailbox.sc.edu or Dr. Jim Mensch at Office-(803) 777-3846 or E-mail: jmensch@mailbox.sc.edu
If you have any questions about your rights as a research subject contact, Lisa Marie Johnson, IRB Manager, Office of Research Compliance, University of South Carolina, 1600 Hampton Street Suite 414, Columbia, SC 29208, Phone: (803) 777-7095 or LisaJ@mailbox.sc.edu.

School District 5 of Lexington and Richland Counties is neither sponsoring nor conducting this research.

IF YOU WANT TO ALLOW YOUR CHILD TO PARTICIPATE IN THIS STUDY, PLEASE FILL OUT THE INFORMATION ON THE LINES BELOW:

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Printed Name of Child

____________________________________ _________________________

Signature of Parent(s) or Legal Guardian Date

____________________________________ _________________________

Signature of Investigator Date

If you would allow us to use the videotapes of your child's movement skills for presentations, please check the **YES** box below. If you do not want to allow us to use the videotapes of your child's movements for professional presentations, your child can still participate.

☐ **YES:** If you will allow us to use the videotapes of your child's movements, please check this box

☐ **NO:** I would not like my child's movements to be videotaped.