

5-9-2015

Evaluation of a Sport-Specific Performance Task Associated with a Lower Extremity Injury Prevention Program

Eric C. Roux

University of Connecticut - Storrs, eric.roux@uconn.edu

Recommended Citation

Roux, Eric C., "Evaluation of a Sport-Specific Performance Task Associated with a Lower Extremity Injury Prevention Program" (2015). *Master's Theses*. 774.
https://opencommons.uconn.edu/gs_theses/774

This work is brought to you for free and open access by the University of Connecticut Graduate School at OpenCommons@UConn. It has been accepted for inclusion in Master's Theses by an authorized administrator of OpenCommons@UConn. For more information, please contact opencommons@uconn.edu.

Evaluation of a Sport-Specific Performance Task Associated with a Lower Extremity Injury
Prevention Program

Eric Christopher Roux

B.S., LAT, ATC, High Point University, 2013

A Thesis

Submitted in Partial Fulfillment of the

Requirements for the Degree of

Master of Science

At the

University of Connecticut

2015

APPROVAL PAGE

Masters of Science Thesis

Evaluation of a Sport-Specific Performance Task Associated with a Lower Extremity Injury
Prevention Program

Presented by

Eric Roux, B.S., LAT, ATC

Major Advisor _____
Lindsay J. DiStefano

Associate Advisor _____
Douglas J. Casa

Associate Advisor _____
Craig R. Denegar

University of Connecticut

2015

ACKNOWLEDGEMENTS

I'd like to thank the members of my committee, Dr. Lindsay DiStefano, Dr. Douglas Casa, and Dr. Craig Denegar for all their input, motivation, and priceless advisement during the thesis process and throughout Graduate School. I'd also like to thank Jessica Martinez, without her help, this study would have never come into fruition. Additionally her mentorship during the writing process and graduate school as a whole can never be thanked enough.

I'd like to thank all my friends and family for their support during this process. I'd like to thank all of my professors from High Point University, without them I would never be on the path I am now and will be forever grateful. Thank you to the University of Connecticut for providing me with an outstanding environment to learn and amazing professors to help further my education in this field.

TABLE OF CONTENTS

| | |
|---|-----------|
| ABSTRACT | v |
| CHAPTER 1: REVIEW OF THE LITERATURE | 1 |
| Epidemiology | 1 |
| Epidemiology Across Genders | 1 |
| Knee Anatomy | 3 |
| Risk Factors | 4 |
| Extrinsic Risk Factors..... | 4 |
| Intrinsic Risk Factors..... | 5 |
| The Landing Error Scoring System (LESS)..... | 8 |
| Intervention Programs..... | 9 |
| Program Components..... | 9 |
| Program Effectiveness | 11 |
| Program Compliance | 11 |
| Performance Measures | 12 |
| Program Specific Performance Benefits | 14 |
| Sport-Specific Performance | 14 |
| Conclusion..... | 16 |
| References..... | 17 |
| CHAPTER II: INTRODUCTION | 23 |
| CHAPTER III: METHODS | 25 |
| Design | 25 |
| Participants..... | 25 |
| Procedures..... | 26 |
| Warm-Up Programs | 26 |
| Movement Assessment..... | 28 |
| Sport-specific Performance Measures..... | 29 |
| Data Reduction | 30 |
| Data Analyses | 30 |
| CHAPTER IV: RESULTS | 32 |
| CHAPTER V: DISCUSSION | 34 |
| Limitations | 37 |
| Delimitations..... | 39 |
| Future Considerations | 39 |
| APPENDIX..... | 41 |
| REFERENCES..... | 50 |

ABSTRACT

Evaluation of a Sport-Specific Performance Task Associated with a Lower Extremity Injury Prevention Program

Eric C. Roux, University of Connecticut

Lower extremity injuries are occurring in youth sports. Injury prevention programs (IPPs) designed to prevent these injuries are being underutilized from lack of buy-in. Evidence suggests that IPPs can improve general performance and reduce injury risk. Sports-specific performance benefits could prove to be a bartering tool in coach support. The purpose of this study was to explore the effects of an IPP on sport-specific performance in high school aged females. Additionally the study assessed the relationship between sport-specific performance and landing biomechanics. Seventy-four athletes participated in this study (age = 15.0 ± 1.0 years, height = 65.7 ± 2.5 in, weight = 60.3 ± 10.4 kg). Participants were randomized into groups and performed an IPP (Focused (FOC), Traditional (F11+), or Control (CON)) during the course of their season. Variables included the elements of the Landing Error Scoring System (LESS), performance on a Shuttle Dribble Task (SDT), before IPP implementation (PRE) and at the conclusion of their sports season (POST). Change scores for the SDT were calculated. A univariate analysis of variance was used to evaluate differences in SDT while controlling for baseline variables. The association between SDT_{BEST} and $LESS_{AVG}$ at PRE was assessed using a Pearson product-moment correlation. No significant differences were observed between groups for any of the dependent variables (SDT_{BEST} , SDT_{AVG}) ($P > 0.05$). A positive correlation ($R^2 = 0.11$, $P = 0.004$) was found between $LESS_{AVG}$ and SDT_{BEST} . This study shows that there is a relationship between landing biomechanics and sport-specific performance, identifying a further need of IPP implementation. The study showed no detrimental effects on sport-specific performance by implementing IPPs over the duration of the season.

WORD COUNT. 265

KEY WORDS. Biomechanics, Landing Error, Soccer, Field Hockey, Volleyball

CHAPTER 1

REVIEW OF THE LITERATURE

Epidemiology

A large number of sport related injuries are occurring high school athletics in the United States. The National High School Sports-Related Injury Surveillance System estimates approximately 1.4 million injuries occur each year.¹⁻³ This surveillance system uses an online injury reporting system to track injuries occurring in nine high school sports; boy's football, soccer, basketball, wrestling, and baseball, girl's soccer, volleyball, basketball, and softball. All injuries are documented and recorded by Athletic Trainers. The Surveillance System estimates 775,000 – 790,000 injuries occur during competition while 580,000 – 635,000 occur during a practice. Some research indicates that lower extremity injuries account for more than 47% of all athletic injuries.^{1,3,4} Regardless of exact percentages, lower extremity injuries are the overwhelming majority of total injuries by a significant margin.⁴⁻⁷

Ankle and knee injuries account for 200,000 knee injuries occurring each year, with many involving the patella/patellar tendon, anterior cruciate ligament, medial collateral ligament, lateral collateral ligament, posterior cruciate ligament, menisci, or combination of structural injuries often result in significant time loss or require surgical interventions.^{1,2,4,8-11}

Epidemiology Across Genders

Youth athletes are specifically vulnerable to these lower extremity injuries. Moses et al.¹² found an incident rate of anterior cruciate ligament (ACL) injuries of 0.03% for the entire United States. The annual incidence rates in professional sports ranged from 0.15% to 3.67% and 0.03%

to 1.62% in amateur athletes. Younger athletes have a higher incident rate for ACL injuries compared to other groups.¹²

Incident rates of ACL injuries vary by sport. Boys' soccer have an injury rate of 1.52 per 1000 athlete exposures and is higher during competition play (3.28 per 1000 athlete exposures) than (0.78 per 1000 exposures) practice. Knee injuries make up 14.5% of total injuries while 12.4% occur at the ankle. In boy's soccer 56.8% of all injuries occur to the lower extremity. The injury rate in boy's basketball is 1.47 per 100 athlete exposures with 2.44 per 1000 athlete exposures during games and 1.04 per 1000 athlete exposures during practice. 55.1% of all injuries occur at the lower extremity for boy's basketball. Knee injuries made up 12.4% of all injuries and 30.1% occur at the ankle. In girls' soccer there is an injury rate of 2.29 per 1000 athlete exposures. During competition the injury rate is higher (5.54 per 1000 athlete exposures) than (0.92 per 1000 athlete exposures) practice. In girls' soccer 59.8% of all injuries occurred at the lower extremity. Knee injuries account for 17.5% of all injuries, and 14.1% occur at the ankle. Girls' basketball has an injury rate of 1.83 per 1000 athlete exposures with competition play (3.13 per 1000 athlete exposures) higher than (1.24 per 1000 athlete exposures) practice. Girl's basketball had 56.4% of all injuries occur in the lower extremity injuries. Knee injuries account for 16.3% of total injuries and 27.3% of total injuries occur at the ankle.^{1,3} Although differences can be seen across males and females, there is a consistent incidence of lower extremity injuries in sport.

Adolescent females, ages 12-17, suffer 0.71 to 2.55 injuries per 1000 athletic exposures compared to 0.31 to 1.89 injuries per 1000 athletic exposures found in adolescent males.¹³ Fernandez et al.⁴ reported that female soccer players carry higher than 3.5 times likelihood of suffering a soccer related injury compared to males. When comparing males and females by

sport, in 2012 - 2013, girls' soccer had a 1.51 times higher injury rate. Girls were 1.21 times more likely to a knee and had almost twice the rate of strains and sprains. In basketball, girls have an injury rate 1.25 times boys, a 1.32 times greater knee injury rate, and 1.19 times the injury rate for strains and sprains.¹ Data for 2013 -2014 are similar.³ Adolescent females see more injuries than males. There is a greater need for reducing the injury risk in females.¹⁴

Knee Anatomy

Knee strains and sprains are the 3rd most common diagnoses in high school sports.¹ The knee consists of four main ligaments to maintain structural integrity. The ACL and Posterior Cruciate Ligament (PCL), prevent anterior and posterior translation of the femur on the tibia. The knee receives lateral support from the medial collateral ligament (MCL) and lateral collateral ligament (LCL). The joint is also stabilized through dynamic muscle activation of the quadriceps, hamstring, and gastroc-soleus muscle groups crossing the joint. The 2 menisci on the plateau of the tibia act as a shock absorbers.⁶ All of these structures play an important role in stabilizing and maintaining structural integrity. Throughout sport movements however, the ACL and collateral ligaments are more heavily relied upon.

The ACL is made up of an anteromedial bundle and a posterolateral bundle. The bundles are identified from their attachment on the tibia. The anteromedial bundle is tightest during knee flexion, whereas the posterolateral bundle is tightest in full knee extension. Shearing forces to the knee during any lower extremity movement can cause the ligaments to fail resulting in injury.¹⁵ Most ACL injuries occur without any contact between the athlete and another player and are defined as non-contact mechanism injuries. Non-contact injuries commonly occur during planting maneuvers, while cutting or changing direction, or landing.⁶

Injuries to the MCL account for 30.5% of all knee injuries (34.6% and 21.4% in males and females). The ACL accounts for 25.6% of all knee injuries. ACL injuries account for a higher portion of knee injuries in females than males (38.6% vs. 19.8% respectively). Meniscal injuries account for 24.0% of all knee injuries while injuries involving the patella, LCL, and PCL account for 15.6%, 7.6%, and 1.5% of knee injuries.¹

Risk Factors

Lower extremity injuries could be the result of numerous risk factors. Several risk factors for lower extremity injuries have been identified. These can be labeled as extrinsic or intrinsic in nature.¹⁶

Extrinsic Risk Factors

Extrinsic risk factors refer to factors outside of human body. This category would include contact ACL injuries, because there is no control on the interaction between players. Playing surface is the most commonly investigated extrinsic risk factor. There is conflicting evidence on whether artificial versus natural playing surface increase injury risk. There are studies to show that artificial surfaces can reduce ACL injury rate while studies show they increase injury rates compared to natural outdoor grass.^{2,12,17-19} Evidence shows that differences in playing surfaces, in regards to weather, can contribute to injury risk. Drier surfaces increase the amount of friction on footwear and can result in more injury.^{6,16,17,20} The factors are all beyond human control.

Literature on player surfaces goes beyond natural and artificial grass. Playing surfaces other than natural or artificial grass can play a role in increasing injury risk. Different slope conditions in skiing results in different reactions with skis causing a higher injury risk.²¹ Ice in sports like hockey and figure skating can increase in risk of injury with ice skate contact,

although more research is needed. Indoor playing surfaces, wooden and synthetic floors, affect injury risk. Synthetic indoor surfaces carry a 2.35 times greater injury risk in females compared to wooden indoor surfaces for Norwegian Handball players.^{12,20,22,23} More conclusive evidence is needed on these surfaces injury risk compared to natural and artificial grass. It is clear that surface plays an uncontrollable role.

Cleat style on playing surfaces has been another topic of interest for extrinsic risk factors. There has been correlation to the cleat size and total number of cleats in American Football players.^{6,20} Smaller and fewer cleats have the lowest injury risk. Cleat patterns that place cleats at the peripheral margin of the sole with smaller cleats placed interiorly create the highest injury risk versus other cleat patterns. The reaction between footwear and surface varies in many ways. With cleats having different wear patterns it is difficult determine which cleat and surfaces create the highest of risk. It is known that the least amount of resistance is found in footwear designed for natural grass surfaces on natural grass surface. The least amount of resistance is ideal in prevention of ACL injuries.^{6,16,17,20}

Intrinsic Risk Factors

In simplicity, intrinsic risk factors are found within the body. They can be labeled as anatomical, neuromuscular, or biomechanical in nature.

Intrinsic Risk Factors – Anatomical

In anatomy, femur length can contribute to ACL tears.⁶ Hip width to femur length ratio is predictor of injury risk.¹⁶ The quadriceps femoris angle (Q angle) is the angle of pull of the quadriceps group from its origin at the hip to its insertion below the knee. The larger the Q angle

pulls the patella laterally. This places medial stress on the knee joint and increases the injury risk. Women have larger Q angles than males because of differences in hip anatomy.^{14,17,24}

The intercondylar notch, the anchor point of the ACL, usually increases in height and width during growth in males but not in females. Taller women (whom would have a smaller intercondylar notch relative to their height) have a higher risk of ACL injury. Shape of the intercondylar notch affects injury rate. A female athlete with a small notch width and A-shaped is at the highest risk.^{6,15,16,25–28}

There is a positive correlation of body weight and ACL size, the heavier a person is the thicker the ACL becomes. When normalizing for weight, females have smaller ACLs than males. A thinner ACL results in a higher injury risk.^{16,17,29} Joint laxity is associated with ACL injury risk. Laxity is a measure mobility of joint's integrity (bony structure, ligaments, and musculature). Adolescent females are more lax than males during the same maturity range. The increased muscle tonicities in males protect the knee joint by dissipating some of the forces during dynamical stabilization. Females with greater joint laxity and flexibility at the knee are 2.7 times more likely to have an ACL injury.^{6,16,17,20}

Intrinsic Risk Factors – Neuromuscular

Neuromuscular factors contribute to lower extremity injury risk.³⁰ Males neuromuscular systems adapt to growth during developmental stages where females delay. Lack of neuromuscular control can reduce dynamic control at the knee.³¹ Females have shorter activation durations in the gluteal and gastroc-soleus group than males. Females maintain lower extremity stiffness while males utilize motion in their lower extremity segments. Females are more likely to exhibit leg dominance, a contralateral weakness in leg strength. These muscle imbalances can

result in a higher injury risk in the non-dominant/weaker leg^{14,24,31,32}. Damage to proprioceptors and mechanoreceptors at the knee can predispose ACL injuries. Reduced proprioception at the knee can result in lower extremity injury. When mechanoreceptors try to elicit a reflex response to stretching ACL, weakened or damaged proprioception results in an elongated response time. The protective muscle contraction delays which allows the ACL to be stressed.^{6,33} These differences across genders establish a need for lower extremity injury prevention programs (IPPs) in females.

Intrinsic Risk Factors – Biomechanics

Biomechanics play another role in injury risk. Changes in posture and alignment can force an individual to activate different muscles, compensate, to perform a task. These compensations are not always optimal. Most commonly biomechanical components are evaluated through landing and/or cutting tasks³⁴. Poorer mechanics such as decreased hip and knee motion, result in greater stress on the knee, resulting in greater injury risk.³⁴ No one specific component contributes alone to the increasing injury risk. It is often a combination of components that create the perfect storm for injuries.

Females have differences in muscle recruitment and activation. Females are quadriceps dominant during cutting and landing tasks while males use hamstrings and quadriceps in unison for stability.^{7,17} Through co-contraction, the hamstrings can counteract the shearing forces at the knee during cutting and landing tasks. The co-contraction in males helps reduce their injury risk.³⁰ A greater angle of knee flexion when landing from a jump, particularly in single leg activity, can create a posterior knee shift and counteract the anterior shearing forces.³⁵ The extremes of the knee angle, landing closer to full knee extension or full knee flexion, is associated in increased risk.⁶

Valgus force, opening the knee to an anteromedial shearing force (an ACL mechanism of injury), is commonly seen in females. This valgus stress results from poor muscular control at the hip^{6,17,28} and/or lower activation of the vastus medialis muscle compared to the vastus lateralis muscle.^{16,35} In landing tasks females activate their rectus femoris and decrease gluteal activation^{16,36} placing more stress on the knee instead of dissipating force over the hip and rest of the lower extremity.⁶

Biomechanics are assessed for entire lower extremity, with the foot and ankle often creating the problem and translating its effects up the kinetic chain. Excess foot pronation can affect tibial translation and alter lower extremity alignment through the lower extremity. Navicular drop, commonly called flat feet, can result in internal rotation of the tibia, placing the knee in an valgus position and making injury more susceptible.⁶ Fatigue may play a part in injury risk, especially during landing and cutting tasks. Muscular fatigue can result in delay or absence of preventative muscle activation resulting in injury.^{16,24,26,27,35}

The Landing Error Scoring System (LESS)

The LESS is a clinical assessment tool that measures potentially dangerous jump-landing movement patterns that lead to lower extremity injuries. Padua et al.³⁴ validated this tool by creating scoring quartiles. In the LESS, a lower score represents better jump-landing technique resulting in lower injury risk. The LESS quartiles identify an excellent score (<4), a good score (≥ 4 but ≤ 5), a moderate score (> 5 but ≤ 6), and a poor score (>6). A series of variance tests between quartiles and known risk factors proved the LESS's validity, where a poor score would be associated with the presence of risk factors. The LESS accurately differentiates between numerous biomechanical risk factors that have previously shown to be related lower extremity

injuries. The LESS demonstrated significant interrater and intrarater reliability and proves to be a reliable clinical assessment tool for detecting poor jump-landing technique/biomechanics.^{27,34}

The LESS can be used to predict injuries across all performance levels.³⁷ Females have higher LESS scores, meaning females land with more errors than males.³⁸ When controlling for activity level, females are more likely to score higher in the LESS and are placed in the poorest quartile.³⁴ Females land poorer than males, the poorer jump-landing technique the more likely injury will occur.

Intervention Programs

Intervention programs have been designed to combat the risk of injury across all ages. Intervention programs are multifaceted to address any deficiency an individual may have. IPPs have components of strength training, neuromuscular training, proprioception or balance training, plyometric training, and flexibility training. Each component plays an integral part in reducing the injury risk because each individual has different deficiencies. A multifaceted program can address multiple areas of concern for multiple people at the same time.

Program Components

Strengthening components improve gluteal deficits than create valgus stress on the knee. Exercises such as double and single leg squats, single leg deadlift, and side planks help strengthen the gluteal group. Strengthening components address hamstring deficits, increasing the likelihood of co-contraction during jump landing and cutting.^{39,40} The increase in knee flexion and reduction of knee stiffness diminishes valgus loading and anterior shearing. Common hamstring exercises use eccentric loading to increase strength. An exercise such as Russian hamstring curls are effective in strengthening the hamstrings.^{7,41} Utilization of single leg

movements reduce bilateral strength deficits, or leg dominance.⁷ Strength is crucial in the rehabilitation process after an injury, regaining strength after muscle atrophy aids in stability.²⁵ Strengthening components in IPPs reduce risk factors associated to weakness and activation, but they alone cannot reduce total injury risk.

Neuromuscular components, through feedback and proper coaching during exercises, instill ideal movement patterns. Proper and efficient movement habits elicits better lower extremity mechanics.^{24,27,38,42} Feedback commonly occurs on squatting and jump landing. Feedback plays a role in reducing ground reaction forces, by coaching participants to land softer, dissipating the force across multiple joints and reducing injury risk.^{27,41}

Proprioception and balance training, in conjunction with neuromuscular training, provides a consistent base of support throughout the kinetic chain. Flexibility training allows greater knee flexion during cutting and landing maneuvers.^{16,19,43-45} Increasing quadriceps and hamstring flexibility allows for greater co-contraction and reduction of muscular dominance.^{40,41} Proprioception is an important measure in return to play following an ACL injury, because it provides the body with awareness in space.⁴⁶ This awareness helps an athlete place their extremity in a safer position.

There is no singular component of an IPP that is the most effective in reducing injury, but plyometric training is often the largest component because of its crossover to sport activity.^{19,22,31,35,47-50} Plyometric training mimics performance components found in sport, allowing for neuromuscular adaption to occur during an common sport activity.²⁶ Examples of plyometric training exercises include box jumps, jump squats, single leg hops, and broad

jumps.^{36,41} Strength, neuromuscular, proprioceptive, balance, and plyometric components in IPPs address the broad spectrum of known risk factors in lower extremity.

Program Effectiveness

IPPs are effective in reducing injury risk^{8,26,28,30} and correcting poor knee biomechanics.^{28,35,44} Mandelbaum et al.¹⁹ determined that IPPs directly benefit participants by reducing the number of injuries, and injury risk could be reduced by 74% - 88%. Emery et al.¹⁰ discovered an association between balance training and injury prevention. After an IPP, improvements in balance training correlated with a reduction in injury risk related movement patterns. Myklebust et al.²³ assessed IPPs effectiveness in female team handball players, finding a reduction of injuries during each of the IPP seasons. Lower extremities IPP are effective in reducing injuries and correcting poor movement mechanics.

Program Compliance

Even with the proven effectiveness of IPPs, there is a lack of utilization. Time is a large barrier in implementation and compliance. Intervention programs are time consuming, some programs need to be implemented everyday and take more than 2 hours to implement. IPPs require training to implement the programs properly. Time is valuable especially at the high school level. To reduce time many new programs are designed to be used as a warm-up, consuming only 10-15 minutes of a practice session.^{29,41} IPPs differ based on age and sport to address specific concerns.^{44,51} IPPs begin prior to the sport season and are used as the team's warm-up for the duration of the season.²⁸ With IPPs condensed into warm-up programs, 62% of coaches state that time is still factor in implementing the IPP.⁵²

IPPs cannot eliminate all injuries because of non-modifiable risk factors. IPPs are only effective in reducing modifiable risk factors if an individual has poor mechanics, or attributes that be altered. Individuals with excellent mechanics would not be considered at risk. The adage “You cannot fix what is not broken” comes to mind. It is difficult to get coaches to utilize IPPs because there is no “need” for improvement. Coach buy-in often follows a player sustaining an ACL injury instead of proactive buy-in. Universal utilization of programs would reduce overall ACL injury incidence.⁵³

An unpublished work by Martinez et al.⁵⁴ determined youth sport coaches’ willingness to utilize an IPP. More than 90% of coaches are willing to implement IPPs. Coaches are willing to implement a program that takes 5 or 10 minutes (88% and 79% acceptance) but not willing to implement a 20 or 30 minute IPP (26% and 20% acceptance). Coaches are not against IPPs but identify duration as a limiting factor. Coaches identify other areas that affect their willingness to implement programs. Coaches are heavily influenced by performance factors such as; running faster (79%), cutting/changing direction faster (82%), fewer injury risk factors (94%), less ACL injuries (94%), and fewer leg injuries (94%). Time is precious to coaches, especially in youth sports, busy schedules, resources, venues, and league regulations limit athlete exposures. Coaches’ unwillingness to implement extended duration programs are due to these time constraints. Coaches are influenced by performance outcomes and injury reduction. Coaches should be educated on the outcomes associated with IPPs to garner more compliance and utilization.

Performance Measures

Buy-in for IPP use could increase with performance based outcomes. Programs are effective in reducing injury risk, but performance outcomes are a bonus incentive. Performance

is the difference between skill levels across multiple sports and age levels. Performance makes the difference between being a starter or a bench as a secondary player. Silvestre et al.⁵⁵ compared measures of performance in starters and non-starters on a NCAA Division I soccer team. Starters outperform non-starters in every performance variable except for a short distance (9.1m) sprint. Starters have faster sprint times (36.5m), higher vertical jumps, and higher maximal oxygen uptake. Starters have higher total lower body power, measured by vertical jump tests.⁵⁵ In American collegiate football athletes, performance is the difference between Division I, II, and III levels. Division I athletes outperformed the Division II group which than outperformed Division III.⁵⁶ Performance outcomes could be the means to more successful team compliance in IPPs.

Total performance is difficult to measure. Performance differs from sport to sport and individual to individual. The main components of performance are power/explosiveness and endurance. Power is work over time. Power often is commonly associated as strength and speed. Jumping, sprinting, and one-repetition maximal resistance tasks typically measure power performance. The most common performance tasks for power include; vertical jump testing, a test in which an individual will jump as high as possible with their net vertical jump recorded after subtracting their height with a full extension reach; standing long jump tests, where an individual will maximally jump horizontally for distance; grip strength, measuring strength as a one-repetition maximal trial; and sprint distances, 40 yard dash is most commonly used.^{50,56,57} Endurance pertains to aerobic capacity, the ability to maintain a training volume over time. Common tests for endurance include; endurance running, measuring the time it takes to complete a required distance; maximal oxygen uptake tasks, these tasks measure total aerobic capacity; and standardized non-maximal resistant lifts, for example, using a specific weight for bench

press and counted completed repetitions over a time or bout.^{56,58} Repetitive sprint drills, where an individual will maximally sprint a distance and then repeat the drill and compare times across each trial, measures muscular endurance and power in combination because speed is needed over multiple trials.

Program Specific Performance Benefits

IPP studies have measured performance as an outcome.⁵⁹ Performance measures for strength, agility, endurance, speed, and limb symmetry have conflicting benefits. However there are no detrimental effects on performance from the IPPs. DiStefano et al.⁴⁵ concluded that IPPs improve vertical jump height, improving overall power. Vescovi et al.⁶⁰ showed improvements in agility tests (27.3m and 36.6m sprints) during the first 6 weeks of the season and a plateauing of improvements for counter movement jumping where control groups decline.⁶⁰ Improvements in balance testing and improvements in the T-Test, a test designed to evaluate agility, are found after an IPP implementation in coed basketball players.¹¹ The FIFA 11+ program, a commonly researched IPP, effectively improves concentric quad strengthening on dominant and non-dominant legs and improvements to core stability associate with improvements in strength/power and agility.⁶¹ General performance is important in all sports. Sport-specific skills can make or break an athletes success. These sport-specific skills are labeled as sport-specific performance, or performance in their relative sport.

Sport-Specific Performance

Performance in sport is pivotal, the deference between starting for the team or being on the bench. Measures of power and endurance alone are not appropriate in measuring sport-specific performance. In sport-specific performance, star athletes excel. Sports specific tasks

need to relate directly to tasks repeatedly performed in a sport.⁵⁰ The NFL Combine is notable for its display of sports-specific performance. The combine measures power and endurance for general performance but include drills for football including throwing, catching, running, and footwork.⁶² Lateral shuffle time and side cut performance, a task in which a participant laterally move between two points as fast as possible, are critical in cutting sports. The shuffle and side cut associate with changing direction, potentially faster than an opponent. This task is a functional measure of a sport-specific task.⁶³ The shuttle run, similar to the shuffle and side cut, is a task where individual will sprint between 2 points rather than lateral movement back and forth for time. Shuttle runs measure speed, agility, and the ability to quickly change direction. This task is realistic for all sports that require change of speed and direction.³⁹

There is only one study to date that evaluates lower extremity IPPs and sport-specific performance. In a 2-hour IPP implemented 3 times a week, no improvements were seen in shooting accuracy in adolescent female soccer players.⁶⁴ Shooting is a specific skill in soccer, however not all players shoot the ball, nor do they shoot often. Sport-specific drills should incorporate infinitely repeatable tasks. The shuttle sprint and dribble test (SDT) was designed as a reliable measure for field hockey performance. The task required an individual to dribble a ball on a grass surface to multiple touchlines and back to the starting position for time. This task not only measures agility and speed but also added a component of ball handling. Ball handling is required any time a player receives the ball making is infinitely repeatable. The slalom sprint and dribble test was created as another reliable measure of speed, agility, and ball handling. The task requires the participant to weave in and out of cones over a distance for time.¹⁸ These sport-specific tasks were also adapted for soccer players to measure soccer ball handling performance

during a shuttle run task. This task would mimic changes in speed, direction, and ball handling performance mimicking on field play.⁶⁵

Conclusion

The current literature makes an abundantly clear need for IPP utilization on injury data alone. The number of injuries that affect adolescent athletes each year are alarming, specifically in females. Although there is no clear individual risk factor that plays a role in these injuries there is evidence to show a number of potential causes. Clinical assessment tools have been established to help determine injury risk and have been useful in determining the effectiveness of IPPs. IPPs however are being underutilized in youth sports for reasons such as time, cost, education, and a lack of desire to utilize the protocols. IPPs have been proven to be effective in increasing performance and reducing injury, sport-specific performance benefits may hold the key to increasing program utilization and compliance.

REFERENCES

1. Comstock RD, Collins CL, Currie DW. National High School Sports-Related Injury Surveillance Study 2012-2013. 2014.
2. Yard EE, Collins CL, Comstock RD. A comparison of high school sports injury surveillance data reporting by certified athletic trainers and coaches. *J Athl Train*. 2009;44(6):645–52. doi:10.4085/1062-6050-44.6.645.
3. Comstock RD, Currie DW, Pierpoint LA. National High School Sports-Related Injury Surveillance Study 2013-2014. 2015.
4. Fernandez WG, Yard EE, Comstock RD. Epidemiology of lower extremity injuries among U.S. high school athletes. *Acad Emerg Med*. 2007;14(7):641–5. doi:10.1197/j.aem.2007.03.1354.
5. Daneshjoo a, Mokhtar A, Rahnama N, Yusof a. The effects of injury prevention warm-up programmes on knee strength in male soccer players. *Biol Sport*. 2013;30(4):281–8. doi:10.5604/20831862.1077554.
6. Giugliano DN, Solomon JL. ACL tears in female athletes. *Phys Med Rehabil Clin N Am*. 2007;18(3):417–38, viii. doi:10.1016/j.pmr.2007.05.002.
7. Graziano J, Green D, Cordasco F. Anterior Cruciate Ligament Injury Prevention in the Young Athlete: Evidence-Based Application. *Strength Cond J*. 2013:89–97. Available at: <http://scholar.google.com/scholar?hl=en&btnG=Search&q=intitle:Anterior+Cruciate+Ligament+Injury+Prevention+in+the+Young+Athlete+:+Evidence-Based+Application#0>. Accessed December 5, 2013.
8. Hewett TE, Johnson DL. ACL prevention programs: fact or fiction? *Orthopedics*. 2010;33(1):36–9. doi:10.3928/01477447-20091124-19.
9. Walden M, Atroshi I, Magnusson H, Wagner P, Hagglund M. Republished research: Prevention of acute knee injuries in adolescent female football players: cluster randomised controlled trial. *Br J Sports Med*. 2012;46(13):904–904. doi:10.1136/bjsports-2012-e3042rep.
10. Emery C a., Cassidy JD, Klassen TP, Rosychuk RJ, Rowe BH. Effectiveness of a home-based balance-training program in reducing sports-related injuries among healthy adolescents: A cluster randomized controlled trial. *Cmaj*. 2005;172(6):749–754. doi:10.1503/cmaj.1040805.
11. Fisher P, Paton B, Mias E. The effects of an eight week ankle injury prevention pilot programme on recreational basketball players balance and agility: a within subject design.

- Br J Sports Med.* 2014;34(7):592–594. Available at: <http://bjsm.bmj.com/content/48/7/592.3.short>. Accessed November 29, 2014.
12. Moses B, Orchard J, Orchard J. Systematic review: Annual incidence of ACL injury and surgery in various populations. *Res Sports Med.* 2012;20(3-4):157–79. doi:10.1080/15438627.2012.680633.
 13. Louw Q, Manilall J, Grimmer K. Epidemiology of knee injuries in adolescents: a review. *Clin J Sport Med.* 2009;19(2):150–154. doi:10.1136/bmj.a439.Objective.
 14. Devan M, Pescatello L. A prospective study of overuse knee injuries among female athletes with muscle imbalances and structural abnormalities. *J Athl* 2004;39(3):263–267. Available at: <http://www.ncbi.nlm.nih.gov/pmc/articles/pmc522150/>. Accessed November 29, 2014.
 15. Zantop T, Petersen W, Sekiya JK, Musahl V, Fu FH. Anterior cruciate ligament anatomy and function relating to anatomical reconstruction. *Knee Surg Sports Traumatol Arthrosc.* 2006;14(10):982–92. doi:10.1007/s00167-006-0076-z.
 16. Ireland ML. The female ACL: why is it more prone to injury? *Orthop Clin North Am.* 2002;33(4):637–51. Available at: <http://www.ncbi.nlm.nih.gov/pubmed/12528906>.
 17. Silvers HJ, Mandelbaum BR. ACL Injury Prevention in the Athlete. *Sport - Sport - Sport Orthop Traumatol.* 2011;27(1):18–26. doi:10.1016/j.orthtr.2011.01.010.
 18. Lemmink K a PM. Evaluation of the reliability of two field hockey specific sprint and dribble tests in young field hockey players. *Br J Sports Med.* 2004;38(2):138–142. doi:10.1136/bjism.2002.001446.
 19. Mandelbaum BR, Silvers HJ, Watanabe DS, et al. Effectiveness of a neuromuscular and proprioceptive training program in preventing anterior cruciate ligament injuries in female athletes: 2-year follow-up. *Am J Sports Med.* 2005;33(7):1003–10. doi:10.1177/0363546504272261.
 20. Smith HC, Vacek P, Johnson RJ, et al. Risk factors for anterior cruciate ligament injury: a review of the literature-part 2: hormonal, genetic, cognitive function, previous injury, and extrinsic risk factors. *Sports Health.* 2012;4(2):155–61. doi:10.1177/1941738111428282.
 21. Ruedl G, Ploner P, Linortner I, et al. Interaction of potential intrinsic and extrinsic risk factors in ACL injured recreational female skiers. *Int J Sports Med.* 2011;32(8):618–22. doi:10.1055/s-0031-1275355.
 22. Ter Stege MHP, Dallinga JM, Benjaminse A, Lemmink K a PM. Effect of interventions on potential, modifiable risk factors for knee injury in team ball sports: a systematic review. *Sports Med.* 2014;44(10):1403–26. doi:10.1007/s40279-014-0216-4.

23. Myklebust G, Engebretsen L, Braekken IH, Skjølberg A, Olsen O-E, Bahr R. Prevention of anterior cruciate ligament injuries in female team handball players: a prospective intervention study over three seasons. *Clin J Sport Med*. 2003;13(2):71–78. doi:10.1097/00042752-200303000-00002.
24. Yeung SS, Suen a MY, Yeung EW. A prospective cohort study of hamstring injuries in competitive sprinters: preseason muscle imbalance as a possible risk factor. *Br J Sports Med*. 2009;43(8):589–94. doi:10.1136/bjsm.2008.056283.
25. Kobayashi A, Higuchi H, Terauchi M, Kobayashi F, Kimura M, Takagishi K. Muscle performance after anterior cruciate ligament reconstruction. *Int Orthop*. 2004;28(1):48–51. doi:10.1007/s00264-003-0502-5.
26. McLean SG, Beaulieu ML. Complex integrative morphological and mechanical contributions to ACL injury risk. *Exerc Sport Sci Rev*. 2010;38(4):192–200. doi:10.1097/JES.0b013e3181f450b4.
27. Padua D a, Distefano LJ. Sagittal Plane Knee Biomechanics and Vertical Ground Reaction Forces Are Modified Following ACL Injury Prevention Programs: A Systematic Review. *Sports Health*. 2009;1(2):165–73. doi:10.1177/1941738108330971.
28. Voskanian N. ACL Injury prevention in female athletes: review of the literature and practical considerations in implementing an ACL prevention program. *Curr Rev Musculoskelet Med*. 2013;6(2):158–63. doi:10.1007/s12178-013-9158-y.
29. Giza ER, Silvers HJ, Mandelbaum BR. Anterior cruciate ligament tear prevention in the female athlete. *Curr Sports Med Rep*. 2005;4(6):341–3. Available at: <http://www.ncbi.nlm.nih.gov/pubmed/16282037>.
30. Lamontagne M, Caraffa A, Cerulli G. Neuromuscular strategy to prevent ACL injury. *Gait Posture*. 2009;30(2009):S23–S24. doi:10.1016/j.gaitpost.2009.07.106.
31. Paterno M V, Rauh MJ, Schmitt LC, Ford KR, Hewett TE. Incidence of contralateral and ipsilateral anterior cruciate ligament (ACL) injury after primary ACL reconstruction and return to sport. *Clin J Sport Med*. 2012;22(2):116–21. doi:10.1097/JSM.0b013e318246ef9e.
32. Franettovich M. Muscle imbalance among elite athletes. *Br J Sport* 2011:348–350. doi:10.1136/bjsm.2011.084038.
33. Dai B, Herman D, Liu H, Garrett WE. Research in Sports Medicine : An Prevention of ACL Injury , Part II : Effects of ACL Injury Prevention Programs on Neuromuscular Risk Factors and Injury Rate. 2012;(December 2013):37–41.
34. Padua D a, Marshall SW, Boling MC, Thigpen C a, Garrett WE, Beutler AI. The Landing Error Scoring System (LESS) Is a valid and reliable clinical assessment tool of jump-

- landing biomechanics: The JUMP-ACL study. *Am J Sports Med.* 2009;37(10):1996–2002. doi:10.1177/0363546509343200.
35. Laughlin W a, Weinhandl JT, Kernozek TW, Cobb SC, Keenan KG, O'Connor KM. The effects of single-leg landing technique on ACL loading. *J Biomech.* 2011;44(10):1845–51. doi:10.1016/j.jbiomech.2011.04.010.
 36. Engelen-van Melick N, van Cingel REH, Tijssen MPW, Nijhuis-van der Sanden MWG. Assessment of functional performance after anterior cruciate ligament reconstruction: a systematic review of measurement procedures. *Knee Surg Sports Traumatol Arthrosc.* 2013;21(4):869–79. doi:10.1007/s00167-012-2030-6.
 37. Harmon K, Dick R. The Relationship of Skill Level to Anterior Cruciate Ligament Injury. *Clin J Sport Med.* 1998. Available at: <http://www.bmhllibrary.info/9884789.pdf>. Accessed March 23, 2014.
 38. Theiss J, Gerber P. Jump-Landing Differences between Varsity, Club, and Intramural Athletes: The Jump-ACL study. *J strength* 2013. Available at: <http://europepmc.org/abstract/MED/23820560>. Accessed March 10, 2014.
 39. Kong DH, Yang SJ, Ha JK, Jang SH, Seo JG, Kim JG. Validation of functional performance tests after anterior cruciate ligament reconstruction. *Knee Surg Relat Res.* 2012;24(1):40–5. doi:10.5792/ksrr.2012.24.1.40.
 40. Hewett TE, Myer GD, Ford KR, Paterno M V, Quatman CE. The 2012 ABJS Nicolas Andry Award: The sequence of prevention: a systematic approach to prevent anterior cruciate ligament injury. *Clin Orthop Relat Res.* 2012;470(10):2930–40. doi:10.1007/s11999-012-2440-2.
 41. Macaluso T. Anterior Cruciate Ligament Injury Prevention for Female High School Athletes. *Strength Cond J.* 2012;34(5):56–59. Available at: <http://scholar.google.com/scholar?hl=en&btnG=Search&q=intitle:Anterior+Cruciate+Ligament+Injury+Prevention+for+Female+High+School+Athletes#0>. Accessed December 5, 2013.
 42. Theiss JL, Gerber PJ, Cameron KL, et al. Jump-Landing Differences between Varsity, Club, and Intramural Athletes: The Jump-ACL study. *J Strength Cond Res.* 2013. doi:10.1519/JSC.0b013e3182a1fdcd.
 43. Van Beijsterveldt a MC, van der Horst N, van de Port IGL, Backx FJG. How effective are exercise-based injury prevention programmes for soccer players? : A systematic review. *Sports Med.* 2013;43(4):257–65. doi:10.1007/s40279-013-0026-0.
 44. DiStefano LJ, Blackburn JT, Marshall SW, Guskiewicz KM, Garrett WE, Padua D a. Effects of an age-specific anterior cruciate ligament injury prevention program on lower

- extremity biomechanics in children. *Am J Sports Med.* 2011;39(5):949–57. doi:10.1177/0363546510392015.
45. DiStefano LJ, Padua DA, Blackburn JT, Garrett WE, Guskiewicz KM, Marshall SW. Intergrated Injury Prevention Program Improves Balance and Vertical Jump Height in Children. *J Strength Cond Res.* 2010;24(2):332–342.
 46. Katayama M, Higuchi H, Kimura M, et al. Proprioception and performance after anterior cruciate ligament rupture. *Int Orthop.* 2004;28(5):278–81. doi:10.1007/s00264-004-0583-9.
 47. Stojanovic MD, Ostojic SM. Preventing ACL injuries in team-sport athletes: a systematic review of training interventions. *Res Sports Med.* 2012;20(3-4):223–38. doi:10.1080/15438627.2012.680988.
 48. FIFA, F-MARC. *The “11+” Manual.*; 2007.
 49. Soligard T, Myklebust G, Steffen K, et al. Comprehensive warm-up programme to prevent injuries in young female footballers: cluster randomised controlled trial. 2008;(December). doi:10.1136/bmj.a2469.
 50. Nikolenko M, Brown L. Relationship between core power and measures of sport performance. *Kinesiol (...)* 2011;43:163–168. Available at: http://www.researchgate.net/publication/228462932_RELATIONSHIP_BETWEEN_CORE_POWER_AND_MEASURES_OF_SPORT_PERFORMANCE/file/32bfe5137a40a0dc2a.pdf. Accessed December 6, 2013.
 51. Trojan T, DiStefano L. Prevention of Anterior Cruciate Ligament Injury in Athletes : A Review. *Clin J Sport Med.* 2013;23(2):120–121. doi:10.1136/bjsports-2011-090664.2.
 52. Saunders N, Otago L, Romiti M, Donaldson a, White P, Finch C. Coaches’ perspectives on implementing an evidence-informed injury prevention programme in junior community netball. *Br J Sports Med.* 2010;44(15):1128–1132. doi:10.1136/bjsm.2009.069039.
 53. Verhagen E, Finch CF. Setting our minds to implementation. *Br J Sports Med.* 2011;45(13):1015–6. doi:10.1136/bjsports-2011-090485.
 54. Martinez JC. *Youth Sport Coaches’ Beliefs and Influences on Injury Prevention Program Implementation.*; 2015.
 55. SILVESTRE R, WEST C. Body Composition and Physical Performance in Men’s Soccer: A Study of a National Collegiate Athletic Association Division I Team. *J ...* 2006;20(1):177–183. Available at: http://journals.lww.com/nsca-jscr/Abstract/2006/02000/Body_Composition_and_Physical_Performance_in_Men_s.29.aspx. Accessed March 23, 2014.

56. Fry A, Kraemer W. Physical Performance Characteristics of American Collegiate Football Players. *J Strength Cond* 1991. Available at: http://journals.lww.com/nsca-jscr/Abstract/1991/08000/Physical_Performance_Characteristics_of_American.4.aspx. Accessed March 23, 2014.
57. Coburn JW. Measuring power. *Strength Cond J.* 2012;34:25–28. Available at: <http://citeseerx.ist.psu.edu/viewdoc/download?doi=10.1.1.1.1998&rep=rep1&type=pdf>. Accessed March 10, 2014.
58. Buchheit M. Repeated-sprint performance in team sport players: associations with measures of aerobic fitness, metabolic control and locomotor function. *Int J Sports Med.* 2012;33(3):230–9. doi:10.1055/s-0031-1291364.
59. Noyes FR, Barber Westin SD. Anterior Cruciate Ligament Injury Prevention Training in Female Athletes: A Systematic Review of Injury Reduction and Results of Athletic Performance Tests. *Sport Heal A Multidiscip Approach.* 2012;4(1):36–46. doi:10.1177/1941738111430203.
60. Vescovi JD, VanHeest JL. Effects of an anterior cruciate ligament injury prevention program on performance in adolescent female soccer players. *Scand J Med Sci Sports.* 2010;20(3):394–402. doi:10.1111/j.1600-0838.2009.00963.x.
61. McGill S. Core Training: Evidence Translating to Better Performance and Injury Prevention. *Strength Cond J.* 2010;32(3):33–46. doi:10.1519/SSC.0b013e3181df4521.
62. Robbins D. The National Football League (NFL) Combine: Does Normalized Data Better Predict Performance in the NFL Draft? *J Strength Cond Res.* 2010:2888–2899. Available at: http://journals.lww.com/nsca-jscr/Abstract/2010/11000/The_National_Football_League__NFL__Combine__Does.2.aspx. Accessed March 23, 2014.
63. Whitting J. Measuring Lateral Shuffle and Side Cut Performance. *J* 2013;27(11):3197–3203. Available at: http://journals.lww.com/nsca-jscr/Abstract/2013/11000/Measuring_Lateral_Shuffle_and_Side_Cut_Performance.34.aspx. Accessed March 10, 2014.
64. Steffen K, Bakka HM, Myklebust G, Bahr R. Performance aspects of an injury prevention program: A ten-week intervention in adolescent female football players. *Scand J Med Sci Sport.* 2008;18(5):596–604. doi:10.1111/j.1600-0838.2007.00708.x.
65. Huijgen BCH, Elferink-Gemser MT, Post WJ, Visscher C. Soccer skill development in professionals. *Int J Sports Med.* 2009;30(8):585–91. doi:10.1055/s-0029-1202354.

CHAPTER II

INTRODUCTION

An estimated 1.4 million injuries occur each year in high school athletics.¹⁻³ Nearly 50% of these injuries occur to the lower extremity.²⁻⁴ Among high school athletes, females have a higher risk of injury than males when participating in the same sport.⁵⁻¹⁴ In soccer, females had a 3.5 times greater incidence of injuries requiring surgery.⁴ These injuries are associated with time-loss from the sport^{1,3,15} as well as cost to individual from surgery and rehabilitative services.^{16,17} Exercise-based injury prevention programs (IPPs) have been designed to alter biomechanics and prevent lower extremity injury.

IPPs have been proven to reduce the risk of injury across age groups.^{5,6,18,19} Almost all of the intervention programs have components of strength training, proprioception or balance training, plyometric training, and flexibility training, and are designed to emphasize proper neuromuscular control and improve biomechanics.^{5,14,16,17,20-22} These multifaceted programs are often adopted into a warm-up performed prior to sport participation, combining the programs into warm-ups save time which may increase compliance of the part of coaches and athletes.^{20,23-25} Although IPPs reduce injury up to 64% in female soccer athletes,^{26,27} several studies^{11,28} have reported poor compliance with these programs.

To promote adoption and adherence to IPPs potential benefits to performance were explored. IPPs have been demonstrated to improve strength, speed, agility, endurance, core strength, balance, and reduce leg dominance in adolescent athletes.^{8,28-33} Adolescent females soccer players have demonstrated improved sprint performance,⁸ vertical jumping, and balance.²⁸ Research has shown that performance tasks play a pivotal role in sports,^{30,34-36} especially in

determining starting versus non-starting players.³⁷ However, measures of general performance alone are not appropriate in determining a players' success in a sport. IPPs can help improve general performance but there is no literature to support any improvement in sport-specific performance skills. Sport-specific performance can be defined as a skill needed to perform a specific task during participation in sport that is infinitely repeatable.³⁰ Evidence to support sport-specific skill improvement could offer more adoption of IPPs.

The primary purpose of this study was to evaluate the effect of IPPs on sport-specific performance, measured through a sports-specific shuttle dribble task, in high school female athletes. It was hypothesized that the 2 IPPs performed as a sport warm-up will elicit improvements in the Shuttle Dribble Test (SDT)^{38,39} compared to an active control group. Additionally, the association between performance on the SDT and reduced lower extremity injury risk, as measured by the Landing Error Scoring System (LESS)^{13,40} was evaluated in high school female athletes. We hypothesized that faster performers in the sport-specific task will exhibit better landing technique, as measured by lower scores on the LESS, compared to high school female athletes who perform on the sport-specific task.

CHAPTER III

METHODS

Design

A cluster-randomized controlled trial study design was used to evaluate sport-specific performance outcomes in participants before and after a high school interscholastic sports season. Players were recruited from a local high school (female soccer, volleyball, or field hockey). After the baseline test session, participants were stratified by sport and interscholastic level (freshmen, junior varsity, and varsity teams) and then randomized into three warm-up groups. The groups were made up of two IPPs; a focused IPP (FOC) (n=25) and traditional IPP (F11+) (n=24), and an active control group (CON) (n=26).

Participants

Seventy-four high school aged female athletes volunteered to participate in this study (Table 1. Demographic Information). Participants were free from any injury or illness that prohibited sport participation at the time of baseline testing. Written informed assent and consent were obtained from all participants and their legal guardians, respectively. This study was approved by the university's institutional review board.

| Table 1. Demographic Information | | | |
|----------------------------------|------------|-------------|-------------|
| Warm-Up Group | Age (yrs.) | Height (in) | Mass (kg) |
| FOC (n=24) | 15 ± 1 | 65.4 ± 2.5 | 57.7 ± 7.4 |
| F11+ (n=24) | 15 ± 1 | 65.6 ± 2.9 | 59.6 ± 9.7 |
| CON (n=26) | 15 ± 1 | 65.9 ± 2.1 | 63.4 ± 12.7 |

Procedures

All participants attended a baseline test session (PRE) that evaluated neuromuscular control, via the jump-landing task, and sport-specific performance, via a SDT. Participants were blinded to the purpose of each warm-up group. The testing at PRE included a jump-landing task along with a sport specified SDT. The testing session after warm-up program implementation (POST) only included the SDT. The timeline for testing occurred before the start of the sport season with POST occurring afterwards. Program implementation lasted for 8-10 weeks depending on sport and sport level.

Warm-Up Programs

Trained research assistants, including certified athletic trainers, athletic training students, and physical therapy students, implemented the warm-up programs. Each research assistant was assigned a program to maximize consistency for implementation and participants. Research assistants were knowledgeable in their respective program. The F11+ program required a 20-minute implementation session while the FOC and CON took approximately 10 minutes to

complete. Coaches of the three sports included in this study agreed to adopt these warm-up programs as part of their daily practice plan. Exercises were implemented using a script for all warm-up programs. Instructions included telling participants to “land softly” “keep their feet forward” and “keep your knees over your feet/toes”. Attendance for each warm-up group was taken prior to the start of the program. A participant lost attendance if they were later than halfway through the warm-up program or did not attend the session at all.

Focused (FOC) Program

This experimental warm-up program used similar tasks to found in the F11+ but in a condensed 10-minute version. Specific Tasks are depicted in Figure 4 of the Appendix. Field set-up also corresponded with the set-up for the F11+. The FOC included core strengthening, leg strengthening, balance, plyometrics, and brief running tasks.

Traditional (F11+) Program

The traditional warm-up program used the 11+ program, formulated by Fédération Internationale de Football Association (FIFA) and it's Medical Assessment and Research Centre (F-MARC). Research demonstrated that utilization of the program resulted in a 30% - 50% reduction of lower extremity injuries.⁴¹ The program consists of 15 exercises, performed in their designated sequence prior to each of the teams' daily practice. Part 1 includes running exercises at a relaxed pace combined with active stretching and controlled partner contacts, Part 2 consists of 6 sets of exercises focusing on core strength, leg strength, balance and plyometrics, each with three levels of increasing difficulty; and finally Part 3 includes running exercises at moderate/high speed combined with planting and cutting movements. Specific tasks are depicted

in Figure 5 of the Appendix.^{11,41} Field set-up corresponded precisely with the set up in the F11+ Workbook.

Control (CON)

This active control warm-up consisted of 10 minutes of guided dynamic stretching and flexibility training. Instructors did not give individualized feedback on movement, instructors could use the scripted descriptions for the movements to remind athletes on the proper method of completing the exercise. This warm-up program was similar to warm-up techniques already being utilized by these interscholastic teams. Specific Tasks are depicted in Figure 6 of the Appendix.

Movement Assessment

Movement assessment was examined using the LESS. Participants were asked to perform 3 trials of the jump-landing task. Participants were instructed to jump outward from a 30-centimeter high box, past a distance half of their height, marked by a line. Immediately following that jump, participants were instructed to jump vertically for maximal height. Participants received no feedback on technique but were instructed to perform another trial if they did not jump with both feet from the box, did not jump past their indicated distance with both feet, or did not complete the task in a fluid motion. Participants were allowed practice attempts as needed until they verbally indicated that they were comfortable with the task and performed it correctly. The jump-landing task was video recorded by two standard digital video cameras (Canon FS400, Canon U.S.A. Inc., Lake Success, NY, USA) placed approximately 12 feet from the front of jump box and approximately 12 feet beside of the participant to record frontal and sagittal plane movements. Video footage was analyzed at a later date by one blinded rater using the

standardized LESS scoring sheet (Figure 7 in Appendix). All of the participants' trials were averaged into a singular composite score.

Sport-specific Performance Measures

The SDT, consisted of 3 trials of maximal sprints covering 30 meters while performing a sport-specific task. Participants were allowed a practice session before the 3 trials began to reduce the learning effect. Timed rests of approximately 20 seconds were given between each trial to correspond with the original study. For soccer and field hockey participants, each trial of the SDT required 3 changes of direction, players were required to cross the line with the ball in order to be valid. The participants were given no feedback during the trial on technique. The only verbal instruction was to keep the ball within the coned area. Field set-up was altered for ease of testing but all components of the original test were consistent, the set-up is depicted below. Time was measured using photoelectric timing gates (TC-Speed-Trap II Wireless Timing System, Brower Timing Systems, Draper, UT, USA) placed at approximately hip height above the ground. The timing gates were not placed at the start and finish of the task but at the 1m mark in order to eliminate reaction timing, starting speed, and make the distance the required 30m. The SDT measured peak sport-specific performance (SDT_{BEST}), indicated by fastest trial time, and an average sport-specific performance outcome (SDT_{AVG}), indicated by the average time of all 3 trials. The SDT was originally developed for use in field hockey however was validated for use in soccer in which dribbling was quantified as a adequate sport performance measure because it incorporated speed and ball control while changing directions^{38,39}. Volleyball, however, lacks a dribbling component therefore the test could not be easily adapted. In order to keep consistency across all participants, volleyball players performed commonly repeatable task (with coach and player input) with the same field set-up. Instead of being instructed to control a ball throughout

the task they were required to pass each line with both feet and jump maximally as if they were performing a block, immediately after landing they were required to change their direction 180° and continue the drill. SDT_{BEST} , and SDT_{AVG} were measured for the volleyball specific task.

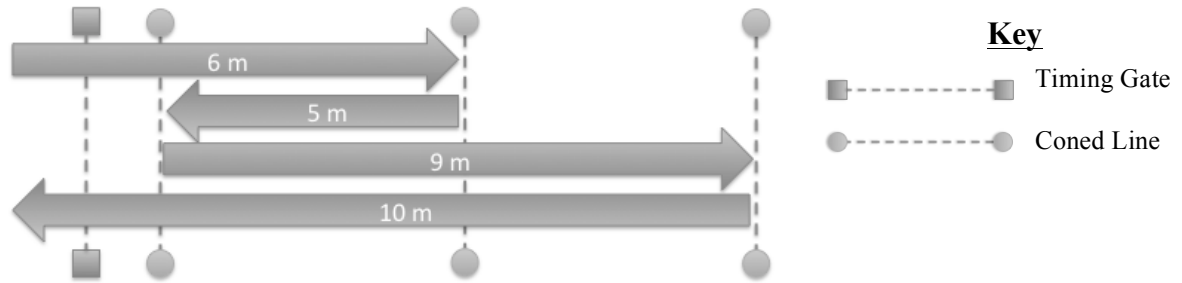


Figure 1. SDT Field Layout

Data Reduction

The movement assessment was scored using the LESS, a valid and reliable tool for measuring jump-landing biomechanics¹³. The LESS scores were calculated by viewing observable errors corresponding with a scoring sheet; see Appendix. One rater blinded to group scored each trial and total scores were averaged. A high score on the LESS indicates poor landing technique while a lower score indicates the contrary.

Data Analyses

A univariate analysis of variance was performed to evaluate differences in SDT scores between warm-up groups when controlling for baseline $LESS_{AVG}$, Sport, Sport Level, and Total Exposures. Change scores were calculated as a new variable, SDT_{CHANGE} ($SDT_{POST} - SDT_{PRE}$), to see the change in participants after implementation. Negative change scores represent a decrease in time to complete, or improvement in score between PRE and POST and thus improved performance. We calculated 95% confidence intervals for SDT_{BEST} to compare results across

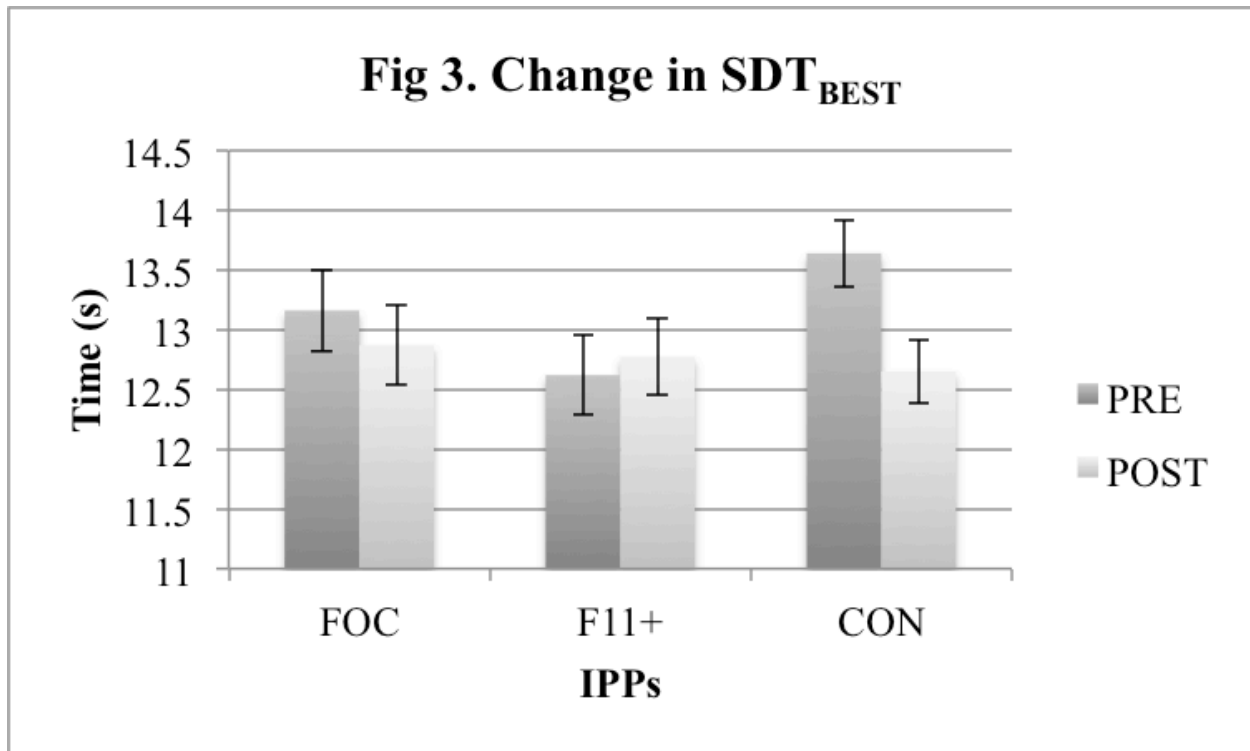
warm-up groups. We calculated a correlation of SDT_{BEST} and $LESS_{AVG}$ at PRE to determine if there were any relationships between the two dependent measures. All data were analyzed using SPSS (version 22.0, SPSS Inc., Chicago, Illinois).

CHAPTER IV

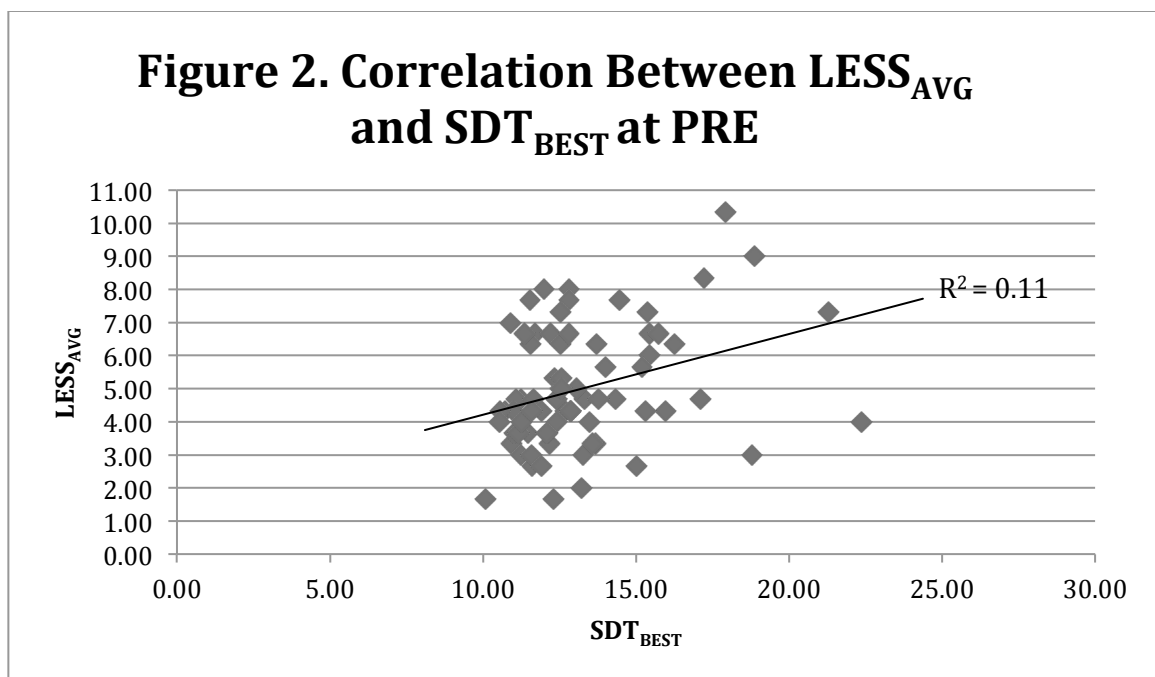
RESULTS

Twenty-one participants did not complete POST, their breakdown by warm-up group, sport, sport level can be seen in the Appendix. Participants who completed both test sessions (PRE and POST) and a warm up program were included in the analyses ((n=53, FOC (n=15), F11+ (n=17), CON (n=21)). The groups were similar at baseline for demographic information (age (years), height (inches), mass (kilograms)), SDT_{BEST} scores, and attended a similar number of warm-up sessions. No significant differences between warm-up groups were observed for any of the dependent variables (SDT_{BEST}, SDT_{AVG}) (P>0.05). The CON group sustained a significant improvement over time within group.

| Table 2. Performance Outcomes Associated with a Lower Extremity Injury Prevention Program | | | |
|--|-------------------------------|--------------------------------|--|
| Warm-Up Group | PRE SDT_{Best} | POST SDT_{Best} | Mean Change Score (95% Confidence Interval) |
| FOC (n=15) | 13.16 ± .34 | 12.87 ± .33 | -0.28 (-0.85, 0.30) |
| F11+ (n=17) | 12.62 ± .33 | 12.77 ± .32 | -0.11 (-0.67, 0.45) |
| CON (n=21) | 13.64 ± .28 | 12.65 ± .27 | -0.70 (-1.08, -0.20) |



All participants ($n=74$, FOC ($n=25$), F11+ ($n=24$), CON ($n=26$)) who completed the baseline test sessions were included in the correlation analysis. A positive correlation ($R^2 = 0.11$, $P=0.004$) was found between $LESS_{AVG}$ and SDT_{BEST} at PRE.



CHAPTER V

DISCUSSION

The current literature makes it abundantly clear that there is a need for IPPs based on injury data alone.^{1-4,7,42} Injuries affect adolescent athletes each year, with the female population at the highest risk. No individual risk factor alone has been shown to play a specific role in these injuries however there is evidence to show potential causes in culmination.^{6,9,12,40,43,44} Clinical assessment tools have been established to help assess injury risk and have been useful in determining the effectiveness of IPPs.¹³ These same IPPs, even with their injury risk reduction, are being underutilized in youth sports for reasons such as time, cost, education, and a lack of desire to adopt the programs.^{45,46} In attempt to combat the lack of IPP utilization, researchers began to assess IPPs effects on performance.^{5,8,15,31,32} IPPs displayed improvements in performance for strength, speed, agility, endurance, and balance^{8,28-33} and play a role in all sports.^{30,34-36}

Sport-specific performance benefits may hold the key to increasing program utilization and compliance. Performance in sport is crucial to success; however, basic measures of performance alone are not appropriate measures one's success in a sport. Current evidence shows that IPPs can help improve general performance but there is no current literature to support any improvement in sport-specific performance skills.³⁰ Evidence to support sport-specific skill improvement could offer advocacy for adherence for IPPs.

Despite not identifying any improvements in sport-specific performance with IPPs, our results indicated that there were no negative impacts by implementing these IPPs on sport-specific performance, seen by negative average SDT_{CHANGE} scores for all warm-up groups at

POST. Noyes et al.³¹ concluded that of the 5 IPP programs utilized over 42 included studies, only 2 reported improvements for both reducing knee injury risk and performance benefits. Other studies reported no improvements during the course of implementation but put emphasis on time as a limiting factor. One program that reported performance benefits took approximately 2 hours to complete, 3 times a week. This type of program is not realistic in a youth or high school setting.

Our findings agree with Noyes et al. in that there were no detrimental effects on sport-specific performance by using the IPPs. Steffen et al.³² reported similar results in that no reductions of performance were seen while implementing the F11+ program in elite level female high school soccer players of the course of a season. Although our findings of sport-specific performance do not directly support the literature, it is quite evident that altering movement mechanics could potentially enhance performance in an individual.^{8,20,28–30,47–49}

The potential lack of improvements could be based on the effectiveness of implementing the IPP programs. With current literature reporting performance benefits and injury risk reduction, if a program was not effective in improving modifiable risk factors of the participants no improvements would be seen. Unfortunately being a portion of a larger doctoral dissertation study, this portion did not measure LESS_{AVG} as a POST measures therefore, no conclusions can be made on the IPPs effectiveness in improving movement in our participants. A lack of movement improvement could be the reason for the lack of sport-specific performance improvements. Improvement in the LESS from PRE to POST could change the results of our primary research question, which aimed to evaluate sport-specific performance outcomes associated with an IPP.

Our secondary purpose, exploring the relationship between sport-specific performance and movement mechanics, showed a connection between proper movement and high sport-specific performance. The results indicated a positive relationship between sport-specific performance and movement, identified by the SDT_{BEST} and LESS. The results identify a statistically significant relation in which participants with higher, or worse, LESS_{PRE} scores correlated with slower, or worse, SDT_{BEST} at PRE. Although correlation does not identify causation, with the LESS only contributed determining a small amount of the SDT scores, it supports current literature identifying a significant relationship between proper and ideal biomechanics and improvements in performance outcomes^{10,11,20,22,33}. Our sport-specific performance measure was made up of general movement demands, athleticism, and repeatable sport-specific skills needed to complete a sport task. Because of our measures components, improvements of sport-specific performance and proper biomechanical movement could be associated with one another.

Our sport-specific task, SDT, required participants to display athleticism, through general performance, and decision-making within the scope of their respective sport. Our criteria for the SDT's effectiveness was measured by achieving faster shuttle dribble task scores on average while advancing the sport level; varsity level participants being the best performers compared to junior varsity who performed better than freshman level participants. The SDT was found to be a successful tool in evaluating sport-specific performance between groups across all sports because we did see a pattern of faster SDT_{BEST} times as sport level increased (see Table 3 in Appendix).

Additionally the SDT developed for volleyball was developed to duplicate the SDT task for soccer and field hockey^{38,39}. The scores for volleyball were in between the minimum and maximum scores seen in soccer and field hockey, showing that the time the task took to

complete was no more or less taxing than what had been previously developed. The task was developed through observation of commonly seen movements within volleyball and drills typically used in a practice. The task proved to be effective for volleyball players by displaying a similar trend of scores based on sporting level. Although junior varsity volleyball had the fastest SDT time, they were not significantly different than the varsity team. The high school in this study has an extremely competitive program and commonly added players from the junior varsity to the varsity roster for state playoffs. The similarity between the two sport levels is likely due to their common skill level. The SDT should continue to be used as a tool for measuring sport-specific performance for soccer, field hockey, and volleyball.

This study provides a new path towards gathering better program compliance. Coaches most commonly excuse their lack of program utilization to the time it takes away from their practices.^{10,50} Results across groups for the SDT can show that the IPP warm up groups versus the control group do not diminish an athletes' ability to perform within their sport. Even though there were no direct improvements in sport-specific performance found in this study, its contribution to the literature could offer a justification that implementing IPPs will not "take away" from practice time. Regardless to our findings, the literature shows that IPPs programs benefit our athletes with improvements in performance and injury reduction. Therefore the benefits of the IPPs outweigh the falsely proposed time lost from practice.

Limitations

As a true field study, limitations were found and improvements could be made in the future. First and foremost we saw a dropout of 21 participants from PRE to POST. The loss of those 21 participants greatly affected the variability of the groups. There was a 9 participant reduction in the FOC group, 7 participant reductions in the F11+ group, and a 5 participant

reduction in the CON group. Having data for all 74 participants may have yielded different results.

During the implementation of the warm-ups, we often found low attendance from some participants due to conflicts of seasonal schedules. Participants were not required to attend the daily implementation session if they were travelling for practice off of school grounds, participating in a game, injured, or receiving athletic training services before practice. This left a finite number of sessions each participant could attend. Missing any of the required implementation sessions would negatively our results. Participants were encouraged to attend the implementation at a designated time so practice could begin at the time coaches had determined daily. The stipulations put in place significantly lowered our compliance because few participants attended all of their required sessions. If our participants had more opportunities to attend the warm-up sessions or warm up sessions occurred during games our results may have differed and followed results seen in current literature.

Testing surface was limitations noted by participants from field hockey that identified that the length of the grass was longer than they normally practiced upon. Players from all sports were testing outside for the ease of data collection. Some PRE testing sessions included just volleyball players, which perform their test indoors. All participants were tested on the same surface for PRE and POST. Weather proved to be an issue during post testing of the SDT task for a small number of participants. A light drizzle may have affected the grass on the outdoor task resulting in suboptimal scoring for some participants in soccer, field hockey, and volleyball. Volleyball participants who performed the SDT indoors were not affected. Although the study did not differentiate by position within a sport, some position players, specifically goalies, noted that the task was not completely indicative of their sport-specific performance.

Delimitations

There was a homogeneous population of only high school female athletes that were randomized into groups to reduce any preexisting confounding factors between the groups.

Future Considerations

The study explored sport-specific performance outcomes associated with lower extremity warm-up style IPPs, which has not been previously studied. Further improvements could be made in warm-up implementation in regards to time of the programs, duration of the implementation programs (more than just the sporting season), and addition of biomechanical and performance measurements. Further studies need to focus on a method of acquiring better attendance to implementation settings. Even if the coaches are on board with the program adolescent players may not have the discipline to attend the sessions on their own free will. Our study included only females; further research could explore similar outcomes and their association with males. Additional sports where IPPs are commonly used could prove to be beneficial for a broader population. Further studies exploring the improvements to performance and biomechanics associated with IPPs and the possible long-term retention improvements on sport-specific performance may offer different outcomes than the results found in this study.

Additionally our secondary research question offers insight for future research. We did find a correlation between good biomechanics and better sport-specific performance, as measured by the SDT, however we did not measure the biomechanical adaptations seen following IPP implementation. In this case we cannot assume that our IPP was effective in improving biomechanics. Fortunately the sport-specific performance measure was taken before the IPP implementation therefore our correlation could still validate a sport-specific performance

outcome associated with proper IPP implementation. These findings can prove that there is a direct sport-specific crossover benefit that can be associated with IPP implementation if it is an effect improver of an athlete's biomechanics.

APPENDIX

| Table 3. SDT _{BEST} by Sport, Sport Level, and Total Exposures | | | | |
|---|--------------------|--------------|----------------------------------|------------------------|
| <u>Sport</u> | <u>Sport Level</u> | | <u>SDT_{Best} (POST)</u> | <u>Total Exposures</u> |
| VB | Freshman | n= 8 | 12.05 ± .64 | 16.13 ± 4.64 |
| | JV | n= 4 | 11.50 ± .46 | 16.50 ± 1.92 |
| | Varsity | n= 8 | 11.63 ± .90 | 15.88 ± 3.23 |
| | Total | n= 20 | 11.77 ± .73 | 16.10 ± 3.52 |
| SOC | Freshman | n= 6 | 13.23 ± 2.19 | 14.83 ± 4.07 |
| | JV | n= 4 | 12.97 ± .60 | 8.25 ± 2.87 |
| | Varsity | n= 10 | 11.66 ± .97 | 11.09 ± 2.51 |
| | Total | n= 20 | 12.36 ± 1.51 | 11.62 ± 3.75 |
| FH | JV | n= 8 | 17.55 ± 2.10 | 14.88 ± 5.28 |
| | Varsity | n= 5 | 14.43 ± .84 | 20.00 ± .00 |
| | Total | n= 13 | 16.35 ± 2.30 | 16.85 ± 4.79 |
| Total | Freshman | n= 14 | 12.55 ± 1.56 | 15.57 ± 4.29 |
| | JV | n= 16 | 14.89 ± 3.16 | 13.63 ± 5.11 |
| | Varsity | n= 24 | 12.23 ± 1.45 | 14.54 ± 4.32 |
| | Total | n= 53 | 13.10 ± 2.39 | 14.54 ± 4.53 |

Table 5. Participants by Group/Sport/Sport Level and Participants Lost

| PRE | | | | | POST | | | | | LOSS | | | | | | | | | | | |
|------|----|-------|----|-------------|------|------|----|-------|----|-------------|----|------|----|-------|----|-------------|----|-------|----|----|---|
| IPP | n= | Sport | n= | Sport Level | n= | IPP | n= | Sport | n= | Sport Level | n= | IPP | n= | Sport | n= | Sport Level | n= | | | | |
| FOC | 24 | VB | 8 | F | 1 | FOC | 15 | VB | 5 | F | 1 | FOC | 9 | VB | 3 | F | 0 | | | | |
| | | | | JV | 3 | | | | | JV | 2 | | | | | JV | 1 | | | | |
| | | | | V | 4 | | | | | V | 2 | | | | | V | 2 | | | | |
| | | SOC | 10 | F | 2 | | | SOC | 6 | F | 1 | | | SOC | 4 | F | 1 | | | | |
| | | | | JV | 3 | | | | | JV | 1 | | | | | JV | 2 | | | | |
| | | | | V | 5 | | | | | V | 4 | | | | | V | 1 | | | | |
| F11+ | 24 | FH | 6 | JV | 4 | F11+ | 17 | FH | 4 | JV | 2 | F11+ | 7 | FH | 2 | JV | 2 | | | | |
| | | | | V | 2 | | | | | V | 2 | | | | | V | 0 | | | | |
| | | | | F | 4 | | | | | F | 4 | | | | | F | 0 | | | | |
| | | VB | 8 | JV | 1 | | | VB | 7 | JV | 1 | | | VB | 1 | JV | 0 | | | | |
| | | | | V | 3 | | | | | V | 2 | | | | | V | 1 | | | | |
| | | | | F | 3 | | | | | F | 2 | | | | | F | 1 | | | | |
| CON | 26 | SOC | 10 | JV | 2 | CON | 21 | SOC | 6 | JV | 1 | CON | 5 | SOC | 4 | JV | 1 | | | | |
| | | | | V | 5 | | | | | V | 3 | | | | | V | 2 | | | | |
| | | | | F | 4 | | | | | F | 3 | | | | | F | 1 | | | | |
| | | FH | 6 | JV | 4 | | | CON | 17 | FH | 4 | | | JV | 3 | CON | 5 | FH | 2 | JV | 1 |
| | | | | V | 2 | | | | | | | | | V | 1 | | | | | V | 1 |
| | | | | F | 3 | | | | | | | | | F | 3 | | | | | F | 0 |
| CON | 26 | VB | 8 | F | 1 | CON | 21 | | | VB | 8 | F | 1 | CON | 5 | | | VB | 0 | F | 0 |
| | | | | JV | 4 | | | | | | | JV | 4 | | | | | | | JV | 0 |
| | | | | V | 4 | | | | | | | V | 4 | | | | | | | V | 0 |
| | | SOC | 10 | F | 3 | | | CON | 21 | SOC | 8 | F | 3 | | | CON | 5 | SOC | 2 | F | 0 |
| | | | | JV | 2 | | | | | | | JV | 2 | | | | | | | JV | 0 |
| | | | | V | 5 | | | | | | | V | 3 | | | | | | | V | 2 |
| FH | 8 | JV | 5 | CON | 21 | FH | 5 | | | JV | 3 | CON | 5 | FH | 3 | | | JV | 2 | | |
| | | V | 3 | | | | | | | V | 2 | | | | | | | V | 1 | | |
| | | Total | 74 | | | | | | | Total | 53 | | | | | | | Total | 21 | | |

EO WARM-UP FOCUSED PROGRAM

PHASE 2

Key Points to Emphasize for EVERY Exercise!



Toes straight ahead, Knees over toes, Bend your knees

Field Set-up

10 yards

→ Progressive run → Jog

15 yards



Exercise

Description

CUES

1. WALKING QUAD PULL w/ Calf Stretch



- Pull heel of one leg to buttock
- Balance on other leg with knee slightly bent
- Lower leg, take step forward, stretch calf of rear leg

- Keep balance leg slightly bent
- Toes straight ahead
- Hold for 3 seconds

2. WALKING LUNGE



- Hands on hips
- Lunge forward with one leg lowering opposite knee
- Push with front leg to return to standing. Alternate legs.

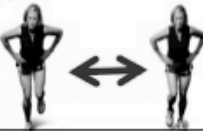
- Toes straight ahead
- Knee stacked over toe
- Controlled motion
- Keep back knee OFF the ground

3. HIP GATES

- Take two steps forward lift right knee up and outward as if over a hurdle.
- Alternate legs
- Repeat with knee moving up and in.

- Lift knee as high as comfortably possible

4. SIDE HOP TO BALANCE 30s



- Balance on 1 leg w/ hands on hips
- Hop sideways as if over a small hurdle
- Land on opposite foot
- Bend at hip, knees, and ankle

- Land as softly toe to heel
- Keep stance knee bent
- Toes straight ahead

5. SINGLE LEG SQUAT 5, rest, 5 Each leg



- Hands on hips
- Squat down like sitting in a chair

- Toes straight ahead
- Knees over toes
- Sit back
- Squat as low as is comfortable

6. PLANK 30 seconds



- Push-up position with elbows on the ground
- Keep upper and lower body as straight as possible

- Stay "straight as an arrow"
- Draw your belly button towards your spine while breathing

Good technique and form are most important

EO WARM-UP FOCUSED PROGRAM

Exercise

7. SIDE PLANK

30 seconds each side



Description

- Lay on side, elbow under shoulder, feet stacked.
- Lift hips bringing them in a straight line with shoulder and feet.

Key Points

- Stay “straight as an arrow”
- Draw your belly button towards your spine while breathing

8. SINGLE LEG REACH

10 each leg



- Extend arms by ears and tip forward at the hips, extending left leg to the rear.
- Return to standing. Right leg stays slightly bent.

- Hips level
- Keep back flat
- Resemble the letter T

9. SQUAT JUMPS

5 rest 5



- Squat down
- Jump up for maximum height
- Land softly in squat position

- Toes straight ahead
- Knees over toes
- Stay on balls of feet
- Land as soft as possible

10. Z-CUT to BALANCE



- Run diagonal to the right 3 steps
- Hop off of left leg to land on right leg and balance 3 counts
- Repeat in opposite direction

- Get low
- Toes forward

11. SIDE SHUFFLE

Repeat facing other direction



- Start in athletic position
- Side shuffle to the second cone without crossing over

- Stay low
- Sit back
- Quick feet

Always emphasize soft landings, knees over toes, & toes ahead

Figure 4. FOC Workbook

11+

PART 1 RUNNING EXERCISES - 8 MINUTES

1 RUNNING STRAIGHT AHEAD

The course is made up of 8 to 12 pairs of parallel cones, spaced, 5 to 6 meters apart. Two cones are at the outer ends from the pair of cones. **Key technique:** 8 to 9 steps to the last pair of cones. On the way back, you can increase your speed progressively as you return. **2 sets.**

2 RUNNING HIP OUT

Walk on your heels, stepping at each pair of cones to 50% your knee and **rotate your hip backwards.** Alternate between left and right legs at successive cones. **2 sets.**

3 RUNNING HIP IN

Walk on your heels, stepping at each pair of cones to 50% your knee and **rotate your hip forwards.** Alternate between left and right legs at successive cones. **2 sets.**

4 RUNNING CIRCLING PARTNER

Run forwards as you pass the first pair of cones. Shuffle sideways by 90 degrees to meet in the middle. **Shuffle on either circle around one other and return back to the cones.** Repeat for each cone clockwise. Remember to take your knee and keep your centre of gravity low by bending your hips and knees. **2 sets.**

5 RUNNING SHOULDER CONTACT

Run forwards in pairs to the first pair of cones. Shuffle sideways by 90 degrees to meet in the middle. **Run a zig-zag towards each other to make shoulder-to-shoulder contact.** Have either one you stand on both feet with your hips and knees back. The rest of your time, touch each other's shoulders. Take a 10-second rest and repeat. **2 sets.**

6 RUNNING QUICK FORWARDS & BACKWARDS

As you run quickly to the second set of cones then **run backwards quickly to the first set of cones keeping your hips and knees slightly bent.** Keep moving the feet, carrying one foot forward, and one back. Remember to take your knee, squish step. **2 sets.**

PART 2 STRENGTH - PLYOMETRICS - BALANCE - 10 MINUTES

LEVEL 1

7 THE BENCH STATIC

Starting position: Lie on your front, supporting yourself on your forearms and keep your elbows directly under your shoulders.
Exercise: Lift your body up, supported on your forearms, and pull your elbows in, and lift your hips to 20-30 cm. Your body should be in a straight line. Try to hold for 30 sec. **2 sets.**

LEVEL 2

7 THE BENCH ALTERNATE LEGS

Starting position: Lie on your front, supporting yourself on your forearms and keep your elbows directly under your shoulders.
Exercise: Lift your body up, supported on your forearms, and pull your elbows in, and lift your hips to 20-30 cm. Try to hold for 30 sec. **2 sets.**

LEVEL 3

7 THE BENCH ONE LEG LIFT AND HOLD

Starting position: Lie on your front, supporting yourself on your forearms and keep your elbows directly under your shoulders.
Exercise: Lift your body up, supported on your forearms, and pull your elbows in, and lift your hips to 20-30 cm. Try to hold for 30 sec. **2 sets.**

8 SIDEWAYS BENCH STATIC

Starting position: Lie on your side with the knee of your lowermost leg bent to 90 degrees. Support your upper body by resting on your forearm and knee. The elbow of your supporting arm should be directly beneath your shoulder.
Exercise: Lift your uppermost leg and hold it straight. Hip and knee are in a straight line. Hold the position for 20-30 sec. Take a short break, change sides and repeat. **2 sets on each side.**

8 SIDEWAYS BENCH RAISE & LOWER HIP

Starting position: Lie on your side with both legs straight. Lean on your forearm and the side of your foot so that your body is in a straight line from shoulder to hip. The elbow of your supporting arm should be directly beneath your shoulder.
Exercise: Keep your leg to the ground and raise it back up again. Repeat for 20-30 sec. Take a short break, change sides and repeat. **2 sets on each side.**

8 SIDEWAYS BENCH WITH LEG LIFT

Starting position: Lie on your side with both legs straight. Lean on your forearm and the side of your foot so that your body is in a straight line from shoulder to hip. The elbow of your supporting arm should be directly beneath your shoulder.
Exercise: Lift your uppermost leg up and down twice in 30 sec. Repeat for 20-30 sec. Take a short break, change sides and repeat. **2 sets on each side.**

9 HAMSTRINGS BEGINNER

Starting position: Stand on a soft surface. Ask your partner to hold your ankles from behind.
Exercise: Your body should be completely straight from the shoulder to the knee. Keep your feet straight. Lean forward as far as you can, maintaining the straightness with your hamstrings and your gluteal muscles. When you can no longer hold it straight, gently take your weight on your hands. Take into a push-up position. Complete a minimum of 7-10 repetitions under 60 sec. **2 sets.**

9 HAMSTRINGS INTERMEDIATE

Starting position: Stand on a soft surface. Ask your partner to hold your ankles from behind.
Exercise: Your body should be completely straight from the shoulder to the knee. Keep your feet straight. Lean forward as far as you can, maintaining the straightness with your hamstrings and your gluteal muscles. When you can no longer hold it straight, gently take your weight on your hands. Take into a push-up position. Complete a minimum of 7-10 repetitions under 60 sec. **2 sets.**

9 HAMSTRINGS ADVANCED

Starting position: Stand on a soft surface. Ask your partner to hold your ankles from behind.
Exercise: Your body should be completely straight from the shoulder to the knee. Keep your feet straight. Lean forward as far as you can, maintaining the straightness with your hamstrings and your gluteal muscles. When you can no longer hold it straight, gently take your weight on your hands. Take into a push-up position. Complete a minimum of 7-10 repetitions under 60 sec. **2 sets.**

10 SINGLE-LEG STANCE HOLD THE BALL

Starting position: Stand on one leg.
Exercise: Balance on one leg while holding the ball with both hands. Keep your body straight. Hold the ball for 30 sec. Repeat for 20-30 sec. **2 sets.**

10 SINGLE-LEG STANCE THROWING BALL WITH PARTNER

Starting position: Stand 2-3 m apart from your partner, with each of you standing on one leg.
Exercise: Keep your balance, and with your shoulder back, throw the ball to one another. Keep your weight on the ball of your foot. Remember, keep your feet and hips back and your feet to the floor. Repeat for 20-30 sec. Change legs and repeat. **2 sets.**

10 SINGLE-LEG STANCE TEST YOUR PARTNER

Starting position: Stand on one leg, opposite your partner and at arm's length.
Exercise: Hold your body by keeping your balance. Each of you has to keep the other off balance in different directions. Try to keep your weight on the ball of your foot and prevent your feet from building muscles. Complete for 20-30 sec. Change legs. **2 sets.**

11 SQUATS WITH TOE RAISE

Starting position: Stand with your feet hip-width apart. Place your hands on your knees.
Exercise: Squat down as far as you can. Perform squats by bending your hips and knees to 90 degrees. Do not let your knees buckle. Repeat the exercise for 20-30 sec. **2 sets.**

11 SQUATS WALKING LUNGES

Starting position: Stand with your feet hip-width apart. Place your hands on your knees.
Exercise: Squat down as far as you can. Perform squats by bending your hips and knees to 90 degrees. Do not let your knees buckle. Repeat the exercise for 20-30 sec. **2 sets.**

11 SQUATS ONE-LEG SQUATS

Starting position: Stand on one leg, holding onto your partner.
Exercise: Squat down as far as you can. Perform squats by bending your hips and knees to 90 degrees. Do not let your knees buckle. Repeat the exercise for 20-30 sec. **2 sets.**

12 JUMPING VERTICAL JUMPS

Starting position: Stand with your feet hip-width apart. Place your hands on your hips.
Exercise: Jump up as high as you can. Land on both feet. Repeat the exercise for 20-30 sec. **2 sets.**

12 JUMPING LATERAL JUMPS

Starting position: Stand on one leg with your upper body slightly forward. Bend your knees, with knees and feet slightly bent.
Exercise: Jump up and down. Repeat the exercise for 20-30 sec. **2 sets.**

12 JUMPING BOX JUMPS

Starting position: Stand with your feet hip-width apart. Imagine that there is a box in front of you. Jump up and down. Repeat the exercise for 20-30 sec. **2 sets.**

PART 3 RUNNING EXERCISES - 2 MINUTES

13 RUNNING ACROSS THE PITCH

Run across the pitch, from one side to the other, at 75-80% maximum pace. **2 sets.**

14 RUNNING BOUNDING

Run with high bounding, knees with a high knee 90 degrees, gently on the ball of your foot. Use an exaggerated arm swing for each step. Repeat the exercise for 20-30 sec. **2 sets.**

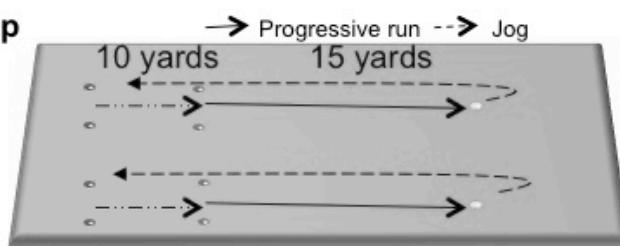
15 RUNNING PLANT & CUT

Run 5-6 steps, then plant on the outside leg and cut to change direction. Accelerate and give 5-7 steps at 90 degrees. Repeat the exercise for 20-30 sec. **2 sets.**

Figure 5. F11+ Workbook

EO SMITH DYNAMIC WARMUP

Field Set-Up



Exercise

1. WALKING QUAD PULL



Description

- Pull heel of one leg to buttock
- Feel stretch on front of thigh
- Balance on other leg with knee slightly bent
- Hold for 3 seconds

CUES

- Keep balance leg slightly bent

2. FRANKENSTEINS



- Step forward and balance on one leg.
- Raise your other leg straight ahead while keeping your knee straight

- Raise leg to lower height if needed to keep knee straight when lifting

3. INCHWORMS



- Begin in push-up position
- Inch feet towards hands.
- Place hands on ground and repeat inchworm until 2nd cone.

- Controlled, slow motion

4. HIP FLEXOR STRETCH w/rotation



- Lunge forward with one leg, lowering back knee
- Lean back and rotate torso towards front leg

- Feel stretch in front of back hip

5. HIP GATES

- Take two steps forward lift right knee up and outward as if over a hurdle.
- Alternate legs
- Repeat with knee moving up and in.

- Lift knee as high as comfortably possible

6. WALKING LUNGES



- Lunge forward with one leg, lowering back knee
- Alternate legs until second cone

- Keep back knee off of ground

7. SIDE LUNGES



- Take large step to right.
- Sit back and keep knees behind toes.

- Feel stretch in inner thigh

EO SMITH DYNAMIC WARMUP

Exercise

8. HIGH KNEES

Description

- Jog quickly to the second cone with knees reaching hip height or higher.

Key Points

9. BUTT KICKS



- Jog at 50% speed with heel hitting the buttocks each step.

10. QUICK FEET

- Take small quick choppy steps to the second cone.
- Quick feet!

Figure 6. CON Workbook

| LESS Scoring Sheet | | | | | | | | |
|--------------------|---|-------------|-----------------|------------|---------|---------|---------|-------|
| Subject: | | | Date: | | | | | |
| LESS Item | Definition | Camera View | Error Condition | LESS Score | Trial 1 | Trial 2 | Trial 3 | Score |
| 1 | Knee flexion angle at initial contact At the time point of initial contact, if the knee of the test leg is flexed more than 30 degrees, score YES. If the knee is not flexed more than 30 degrees, score NO. | Side | No | Y=0, N=1 | | | | |
| 2 | Hip flexion angle at initial contact At the time point of initial contact, if the thigh of the test leg is in line with the trunk then the hips are not flexed and score NO. If the thigh of the test leg is flexed on the trunk, score YES. | Side | No | Y=0, N=1 | | | | |
| 3 | Trunk flexion angle at initial contact At the time point of initial contact, if the trunk is vertical or extended on the hips, score NO. If the trunk is flexed on the hips, score YES | Side | No | Y=0, N=1 | | | | |
| 4 | Ankle plantarflexion angle at initial contact If the foot of the test leg lands toe to heel, score YES. If the foot of the test leg lands heel to toe or with a flat foot, score NO. | Side | No | Y=0, N=1 | | | | |
| 5 | Knee valgus angle at initial contact At the time point of initial contact, draw a line straight down from the center of the patella. If the line goes through the midfoot, score NO. If the line is medial to the midfoot, score YES. | Front | Yes | Y=1, N=0 | | | | |
| 6 | Lateral trunk flexion angle at initial contact At the time point of initial contact, if the midline of the trunk is flexed to the left or the right side of the body, score YES. If the trunk is not flexed to the left or right side of the body, score NO. | Front | Yes | Y=1, N=0 | | | | |
| 7 | Stance width-Wide Once the entire foot is in contact with the ground, draw a line down from the tip of the shoulders. If the line on the side of the test leg is inside the foot of the test leg then greater than shoulder width (wide), score YES. If the test foot is internally or externally rotated, grade the stance width based on heel placement. | Front | Yes | Y=1, N=0 | | | | |
| 8 | Stance width-Narrow Once the entire foot is in contact with the ground, draw a line down from the tip of the shoulders. If the line on the side of the test leg is outside of the foot then score less than shoulder width (narrow), score YES. If the test foot is internally or externally rotated, grade the stance width based on heel placement. | Front | Yes | Y=1, N=0 | | | | |
| 9 | Foot position-Toe In If the foot of the test leg is internally more than 30 degrees between the time period of initial contact and max knee flexion, then score YES. If the foot is not internally rotated more than 30 degrees between the time period of initial contact to max knee flexion, score NO. | Front | Yes | Y=1, N=0 | | | | |
| 10 | Foot position-Toe Out If the foot of the test leg is externally rotated more than 30 degrees between the time period of initial contact and max knee flexion, then score YES. If the foot is not externally rotated more than 30 degrees between the time period of initial contact to max knee flexion, score NO. | Front | Yes | Y=1, N=0 | | | | |

| | | | | | |
|----|-----------------------------------|---|-------------|---|------------------------|
| 11 | Symmetric initial foot contact | If one foot lands before the other or if one foot lands heel to toe and the other lands toe to heel, score NO. If the feet land symmetrically, score YES. | Front | No | Y=0, N=1 |
| 12 | Knee flexion displacement | If the knee of the test leg flexes more than 45 degrees from initial contact to max knee flexion, score YES. If the knee of the test leg does not flex more than 45 degrees, score NO. | Side | No | Y=0, N=1 |
| 13 | Hip flexion at max knee flexion | If the thigh of the test leg flexes more on the trunk from initial contact to max knee flexion angle, score YES. | Side | No | Y=0, N=1 |
| 14 | Trunk flexion at max knee flexion | If the trunk flexes more from the point of initial contact to max knee flexion, score YES. If the trunk does not flex more, score NO. | Side | No | Y=0, N=1 |
| 15 | Knee valgus displacement | At the point of max knee valgus on the test leg, draw a line straight down from the center of the patella. If the line runs through the great toe or is medial to the great toe, score YES. If the line is lateral to the great toe, score NO. | Front | Yes | Y=1, N=0 |
| 16 | Joint displacement | Watch the sagittal plane motion at the hips and knees from initial contact to max knee flexion angle. If the subject goes through large displacement of the trunk, hips, and knees then score SOFT. If the subject goes through some trunk, hip, and knee displacement but not a large amount, then AVERAGE. If the subject goes through very little, if any trunk, hip, and knee displacement, then STIFF. | Side | Average or Stiff (double penalty for Stiff) | Soft=0, Avg=1, Stiff=2 |
| 17 | Overall impression | Score EXCELLENT if the subject displays a soft landing and no frontal plane motion at the knee, Score POOR if the subject displays a stiff landing and large frontal plane motion at the knee. All other landings, score AVERAGE. | Side, Front | Average or Poor (double penalty for Poor) | Ex=0, Avg=1, Poor=2 |

TOTAL

****For items 1-15, a positive score is defined as an Error on at least 2 of the 3 trials. For items 16 & 17, a positive score is defined as Average on at least 2 of the 3 trials or Poor/Stiff on at least 1 of the 3 trials**

Figure 7. LESS Scoring Sheet

REFERENCES

1. Yard EE, Collins CL, Comstock RD. A comparison of high school sports injury surveillance data reporting by certified athletic trainers and coaches. *J Athl Train*. 2009;44(6):645–52. doi:10.4085/1062-6050-44.6.645.
2. Comstock RD, Collins CL, Currie DW. National High School Sports-Related Injury Surveillance Study 2012-2013. 2014.
3. Comstock RD, Currie DW, Pierpoint LA. National High School Sports-Related Injury Surveillance Study 2013-2014. 2015.
4. Fernandez WG, Yard EE, Comstock RD. Epidemiology of lower extremity injuries among U.S. high school athletes. *Acad Emerg Med*. 2007;14(7):641–5. doi:10.1197/j.aem.2007.03.1354.
5. Voskanian N. ACL Injury prevention in female athletes: review of the literature and practical considerations in implementing an ACL prevention program. *Curr Rev Musculoskelet Med*. 2013;6(2):158–63. doi:10.1007/s12178-013-9158-y.
6. McLean SG, Beaulieu ML. Complex integrative morphological and mechanical contributions to ACL injury risk. *Exerc Sport Sci Rev*. 2010;38(4):192–200. doi:10.1097/JES.0b013e3181f450b4.
7. Ireland ML. The female ACL: why is it more prone to injury? *Orthop Clin North Am*. 2002;33(4):637–51. Available at: <http://www.ncbi.nlm.nih.gov/pubmed/12528906>.
8. Vescovi JD, VanHeest JL. Effects of an anterior cruciate ligament injury prevention program on performance in adolescent female soccer players. *Scand J Med Sci Sports*. 2010;20(3):394–402. doi:10.1111/j.1600-0838.2009.00963.x.
9. Ter Stege MHP, Dallinga JM, Benjaminse A, Lemmink K a PM. Effect of interventions on potential, modifiable risk factors for knee injury in team ball sports: a systematic review. *Sports Med*. 2014;44(10):1403–26. doi:10.1007/s40279-014-0216-4.
10. Myklebust G, Engebretsen L, Braekken IH, Skjølberg A, Olsen O-E, Bahr R. Prevention of anterior cruciate ligament injuries in female team handball players: a prospective intervention study over three seasons. *Clin J Sport Med*. 2003;13(2):71–78. doi:10.1097/00042752-200303000-00002.
11. Soligard T, Myklebust G, Steffen K, et al. Comprehensive warm-up programme to prevent injuries in young female footballers: cluster randomised controlled trial. 2008;(December). doi:10.1136/bmj.a2469.

12. Yeung SS, Suen a MY, Yeung EW. A prospective cohort study of hamstring injuries in competitive sprinters: preseason muscle imbalance as a possible risk factor. *Br J Sports Med.* 2009;43(8):589–94. doi:10.1136/bjism.2008.056283.
13. Padua D a, Marshall SW, Boling MC, Thigpen C a, Garrett WE, Beutler AI. The Landing Error Scoring System (LESS) Is a valid and reliable clinical assessment tool of jump-landing biomechanics: The JUMP-ACL study. *Am J Sports Med.* 2009;37(10):1996–2002. doi:10.1177/0363546509343200.
14. Padua D a, Distefano LJ. Sagittal Plane Knee Biomechanics and Vertical Ground Reaction Forces Are Modified Following ACL Injury Prevention Programs: A Systematic Review. *Sports Health.* 2009;1(2):165–73. doi:10.1177/1941738108330971.
15. Graziano J, Green D, Cordasco F. Anterior Cruciate Ligament Injury Prevention in the Young Athlete: Evidence-Based Application. *Strength Cond J.* 2013:89–97. Available at: <http://scholar.google.com/scholar?hl=en&btnG=Search&q=intitle:Anterior+Cruciate+Ligament+Injury+Prevention+in+the+Young+Athlete++Evidence-Based+Application#0>. Accessed December 5, 2013.
16. Laughlin W a, Weinhandl JT, Kernozek TW, Cobb SC, Keenan KG, O'Connor KM. The effects of single-leg landing technique on ACL loading. *J Biomech.* 2011;44(10):1845–51. doi:10.1016/j.jbiomech.2011.04.010.
17. Silvers HJ, Mandelbaum BR. ACL Injury Prevention in the Athlete. *Sport - Sport - Sport Orthop Traumatol.* 2011;27(1):18–26. doi:10.1016/j.orthtr.2011.01.010.
18. Hewett TE, Johnson DL. ACL prevention programs: fact or fiction? *Orthopedics.* 2010;33(1):36–9. doi:10.3928/01477447-20091124-19.
19. Lamontagne M, Caraffa A, Cerulli G. Neuromuscular strategy to prevent ACL injury. *Gait Posture.* 2009;30(2009):S23–S24. doi:10.1016/j.gaitpost.2009.07.106.
20. DiStefano LJ, Blackburn JT, Marshall SW, Guskiewicz KM, Garrett WE, Padua D a. Effects of an age-specific anterior cruciate ligament injury prevention program on lower extremity biomechanics in children. *Am J Sports Med.* 2011;39(5):949–57. doi:10.1177/0363546510392015.
21. Kiani A, Hellquist E. Prevention of soccer-related knee injuries in teenaged girls. *Arch* 2010;170(1):43–49. Available at: <http://archpsyc.jamanetwork.com/article.aspx?articleid=481521>. Accessed November 28, 2014.
22. Mandelbaum BR, Silvers HJ, Watanabe DS, et al. Effectiveness of a neuromuscular and proprioceptive training program in preventing anterior cruciate ligament injuries in female athletes: 2-year follow-up. *Am J Sports Med.* 2005;33(7):1003–10. doi:10.1177/0363546504272261.

23. Giza ER, Silvers HJ, Mandelbaum BR. Anterior cruciate ligament tear prevention in the female athlete. *Curr Sports Med Rep*. 2005;4(6):341–3. Available at: <http://www.ncbi.nlm.nih.gov/pubmed/16282037>.
24. Macaluso T. Anterior Cruciate Ligament Injury Prevention for Female High School Athletes. *Strength Cond J*. 2012;34(5):56–59. Available at: <http://scholar.google.com/scholar?hl=en&btnG=Search&q=intitle:Anterior+Cruciate+Ligament+Injury+Prevention+for+Female+High+School+Athletes#0>. Accessed December 5, 2013.
25. Trojian T, DiStefano L. Prevention of Anterior Cruciate Ligament Injury in Athletes : A Review. *Clin J Sport Med*. 2013;23(2):120–121. doi:10.1136/bjsports-2011-090664.2.
26. Walden M, Atroshi I, Magnusson H, Wagner P, Hägglund M. Republished research: Prevention of acute knee injuries in adolescent female football players: cluster randomised controlled trial. *Br J Sports Med*. 2012;46(13):904–904. doi:10.1136/bjsports-2012-e3042rep.
27. Waldén M, Atroshi I, Magnusson H, Wagner P, Hägglund M. Prevention of acute knee injuries in adolescent female football players: cluster randomised controlled trial. *BMJ*. 2012;344(May):e3042. doi:10.1136/bmj.e3042.
28. DiStefano LJ, Padua DA, Blackburn JT, Garrett WE, Guskiewicz KM, Marshall SW. Intergrated Injury Prevention Program Improves Balance and Vertical Jump Height in Children. *J Strength Cond Res*. 2010;24(2):332–342.
29. McGill S. Core Training: Evidence Translating to Better Performance and Injury Prevention. *Strength Cond J*. 2010;32(3):33–46. doi:10.1519/SSC.0b013e3181df4521.
30. Nikolenko M, Brown L. Relationship between core power and measures of sport performance. *Kinesiol (....* 2011;43:163–168. Available at: http://www.researchgate.net/publication/228462932_RELATIONSHIP_BETWEEN_CORE_POWER_AND_MEASURES_OF_SPORT_PERFORMANCE/file/32bfe5137a40a0dc2a.pdf. Accessed December 6, 2013.
31. Noyes FR, Barber Westin SD. Anterior Cruciate Ligament Injury Prevention Training in Female Athletes: A Systematic Review of Injury Reduction and Results of Athletic Performance Tests. *Sport Heal A Multidiscip Approach*. 2012;4(1):36–46. doi:10.1177/1941738111430203.
32. Steffen K, Bakka HM, Myklebust G, Bahr R. Performance aspects of an injury prevention program: A ten-week intervention in adolescent female football players. *Scand J Med Sci Sport*. 2008;18(5):596–604. doi:10.1111/j.1600-0838.2007.00708.x.
33. Emery C a., Cassidy JD, Klassen TP, Rosychuk RJ, Rowe BH. Effectiveness of a home-based balance-training program in reducing sports-related injuries among healthy

- adolescents: A cluster randomized controlled trial. *Cmaj*. 2005;172(6):749–754. doi:10.1503/cmaj.1040805.
34. Buchheit M. Repeated-sprint performance in team sport players: associations with measures of aerobic fitness, metabolic control and locomotor function. *Int J Sports Med*. 2012;33(3):230–9. doi:10.1055/s-0031-1291364.
 35. Coburn JW. Measuring power. *Strength Cond J*. 2012;34:25–28. Available at: <http://citeseerx.ist.psu.edu/viewdoc/download?doi=10.1.1.1.1998&rep=rep1&type=pdf>. Accessed March 10, 2014.
 36. Fry A, Kraemer W. Physical Performance Characteristics of American Collegiate Football Players. *J Strength Cond* 1991. Available at: http://journals.lww.com/nsca-jscr/Abstract/1991/08000/Physical_Performance_Characteristics_of_American.4.aspx. Accessed March 23, 2014.
 37. SILVESTRE R, WEST C. Body Composition and Physical Performance in Men’s Soccer: A Study of a National Collegiate Athletic Association Division I Team. *J* 2006;20(1):177–183. Available at: http://journals.lww.com/nsca-jscr/Abstract/2006/02000/Body_Composition_and_Physical_Performance_in_Men_s.29.aspx. Accessed March 23, 2014.
 38. Lemmink K a PM. Evaluation of the reliability of two field hockey specific sprint and dribble tests in young field hockey players. *Br J Sports Med*. 2004;38(2):138–142. doi:10.1136/bjsm.2002.001446.
 39. Huijgen BCH, Elferink-Gemser MT, Post WJ, Visscher C. Soccer skill development in professionals. *Int J Sports Med*. 2009;30(8):585–91. doi:10.1055/s-0029-1202354.
 40. Theiss JL, Gerber PJ, Cameron KL, et al. Jump-Landing Differences between Varsity, Club, and Intramural Athletes: The Jump-ACL study. *J Strength Cond Res*. 2013. doi:10.1519/JSC.0b013e3182a1fdcd.
 41. FIFA, F-MARC. *The “11+” Manual*.; 2007.
 42. Louw Q, Manilall J, Grimmer K. Epidemiology of knee injuries in adolescents: a review. *Clin J Sport Med*. 2009;19(2):150–154. doi:10.1136/bmj.a439.Objective.
 43. Ruedl G, Ploner P, Linortner I, et al. Interaction of potential intrinsic and extrinsic risk factors in ACL injured recreational female skiers. *Int J Sports Med*. 2011;32(8):618–22. doi:10.1055/s-0031-1275355.
 44. Smith HC, Vacek P, Johnson RJ, et al. Risk factors for anterior cruciate ligament injury: a review of the literature-part 2: hormonal, genetic, cognitive function, previous injury, and extrinsic risk factors. *Sports Health*. 2012;4(2):155–61. doi:10.1177/1941738111428282.

45. Soligard T, Nilstad A, Steffen K, et al. Compliance with a comprehensive warm-up programme to prevent injuries in youth football. *Br J Sports Med.* 2010;44(11):787–793. doi:10.1136/bjsm.2009.070672.
46. Van Beijsterveldt a MC, van der Horst N, van de Port IGL, Backx FJG. How effective are exercise-based injury prevention programmes for soccer players? : A systematic review. *Sports Med.* 2013;43(4):257–65. doi:10.1007/s40279-013-0026-0.
47. Kong DH, Yang SJ, Ha JK, Jang SH, Seo JG, Kim JG. Validation of functional performance tests after anterior cruciate ligament reconstruction. *Knee Surg Relat Res.* 2012;24(1):40–5. doi:10.5792/ksrr.2012.24.1.40.
48. Katayama M, Higuchi H, Kimura M, et al. Proprioception and performance after anterior cruciate ligament rupture. *Int Orthop.* 2004;28(5):278–81. doi:10.1007/s00264-004-0583-9.
49. Engelen-van Melick N, van Cingel REH, Tijssen MPW, Nijhuis-van der Sanden MWG. Assessment of functional performance after anterior cruciate ligament reconstruction: a systematic review of measurement procedures. *Knee Surg Sports Traumatol Arthrosc.* 2013;21(4):869–79. doi:10.1007/s00167-012-2030-6.
50. Martinez JC. *Youth Sport Coaches' Beliefs and Influences on Injury Prevention Program Implementation.*; 2015.