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Comparative Effectiveness Of Injury Prevention Programs In Female Adolescent Athletes

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ABSTRACT

Background: Injury prevention programs (IPP) decrease lower extremity injury rates and improve movement-based risk factors, but many coaches and players do not adopt these programs. The time required for these programs is frequently reported as a barrier to program adoption. It is not known if a shorter duration IPP can improve movement technique in a manner thought to reduce the risk of injury.

Purpose: To examine if a shorter duration IPP is able to elicit improvements in movement technique similar to the F11+ program in female, high school athletes. A secondary aim was to assess high-risk (LESS ≥ 5) participants' response to the intervention.

Study Design: Randomized controlled clinical trial

Methods: Seventy-six healthy, female athletes (Age=15±1 y, Mass: 59.9±10.4 kg, Height: 166.4±6.3 cm) (Field Hockey=21, Soccer=31, Volleyball=24). Participants were stratified by team and randomized into one of three warm-up interventions: Focused (N=25), F11+ (N= 24) or Control (N=27). Participants completed a test session before and after their 2014 Fall season (8-10 weeks). At each session they performed three trials of a jump-landing task. Each jump was scored using the Landing Error Scoring System (LESS). All participants performed their assigned warm-up program prior to sport practices. Separate 3x2 mixed model ANOVA or analysis of covariance (ANCOVA) tests for each dependent variable were used to evaluate differences between groups or test sessions.

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Results: Participants improved their overall LESS scores ($P=.002$) regardless of group. High-risk participants reduced their LESS scores by nearly 2 errors (PRE: 7.00 ± 1.24, POST 5.06 ± 1.74, $P<.001$).

Conclusions: All warm-up groups were able to decrease their risk of lower extremity injury as they improved their LESS scores. Participants with a LESS score ≥ 5 responded better as they had more to improve and should be a focus of clinicians implementing IPPs.

Key Words: jump-landing, injury prevention

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Comparative Effectiveness Of Injury Prevention Programs In Female Adolescent Athletes

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CHAPTER 1
INTRODUCTION

1.1 Injury in Youth Sports

Musculoskeletal injuries are the most common cause of long-term pain and disability in the United States.[1] Adolescents, particularly females, are participating in high school athletics at increasingly high numbers. According to the 2013-2014 High School Athletics Participation Survey conducted by the National Federation of State High School Associations, approximately 7.8 million students participated in sport and the participation rate for females as increased for the 25th consecutive year.[2] The physiological and psychological benefits of physical activity are well known but unfortunately participation in sport can sometimes result in musculoskeletal injury. Over two million musculoskeletal injuries each year during high school sports, with the highest risk for injury occurring in female athletes.[3-5] Sport-related injuries not only remove an athlete from participation resulting in reduced physical activity, but sustaining a sport-related injury also increases the risk of future injury as well as the early development of osteoarthritis in the case of injuries involving a joint.[6] Sustaining a sport-related injury can greatly influence a child's future involvement in physical activity, which may result in poor long-term health related quality of life.[7]

1.2 Injury in the Female Athlete

In gender-comparable sports, anterior cruciate ligament (ACL) injury rates are 2.5-6.2 times higher in females than in their male counterparts.[8,9] In soccer, the rate of non-contact ACL injuries is twice as high in females as in males.[10] Much of this higher rate of injury is attributed to risky movement patterns female athletes exhibit during sport specific tasks. During early puberty, female athletes exhibit multiple risk factors for

lower extremity injury when landing from a jump, such as large knee abduction moments and limited sagittal plane motion resulting in decreased force absorption.[11,12] These potentially risky landing biomechanics continue to persist throughout puberty and if not addressed can continue as the athlete matures and place the female athlete at risk for lower extremity injury.[11,13,14] In addition to biomechanical risk factors, females are also thought to be at higher risk of sustaining an ACL injury due to anatomical and hormonal factors, such as size and shape of the intercondylar notch,[15] tensile strength of the ACL,[16] and fluctuations of estrogen and progesterone during the menstrual cycle.[17]

1.3 Injury Prevention Programs

Exercise-based injury prevention programs are effective at decreasing lower extremity injury rates, particularly in the female, athletic population.[18-22] Steffen et al.[23] reported that the F11+ injury prevention program improved both dynamic balance performance and decreased injury rates in 13-18-year-old female soccer players. Exercise-based injury prevention programs utilize sport-specific tasks (i.e. landing and cutting) to improve movement technique and therefore decrease the rate of lower extremity injury in female adolescent athletes.[24,25] Poor neuromuscular control, such as the inability to balance[26] or control the body in motion with proper alignment,[14,27] increases the risk of lower extremity injury, particularly ACL injury. Despite this evidence, injury prevention programs have not been widely adopted in high school athletics. A recent study of high school basketball and soccer coaches found that only 21% of coaches reported using an injury prevention program with their team and only 9% report using the program exactly as it was designed.[28] Coaches not using

neuromuscular training programs as they are designed is may lead to low compliance as the programs have a lower chance of success. Compliance is necessary for the success of an injury prevention program, as the higher the rate of athlete compliance the lower the observed injury rate.[29] Higher program compliance as not only been associated with a reduction of injuries but also an increase in hip strength.[30]

1.4 Barriers to Implementation of Injury Prevention Programs

One of the major barriers to the adoption of injury prevention programs is time. Netball coaches who implemented an IPP stated that the top three barriers to implementing the programs were running out of time, players finding the drills too difficult, and too many sets and reps to complete.[31] Programs that have been shown to be successful in reducing injury rates and modifying neuromuscular control typically require at least 20 minutes per session to perform and are associated with poor compliance.[32] The compliance of both the coaches and players is an integral piece in determining the success of an injury prevention program.[33,34] Preliminary data suggests youth sport coaches may be more willing to implement an injury prevention program lasting only 5-10 minutes, but there is no evidence to support the effectiveness of a shortened program. Injury prevention programs have been shown to increase performance measures such as sprint time, agility, and vertical jump.[35-37] However most of this research has been done in male athletes. Coaches and players need to be educated and made aware that injury prevention programs can result in improved performance outcomes and this may serve to increase adoption of injury prevention programs. Prevention of lower extremity musculoskeletal injuries is both necessary and possible. If a shortened duration injury prevention program is effective in improving

neuromuscular control and performance, which is a critical motivating factor for athletes and coaches, this design could dramatically improve long-term compliance and adoption across high school sports. It is possible that a shortened duration injury prevention program will address and help to overcome the time barrier and provide coaches and athletes with performance incentives to increase compliance.

1.5 Limitations of Injury Prevention Programs

The F11+ has been shown to improve sprint time, agility and vertical jump ability in college-aged male soccer players but the F11+ has not been studied as a means to improve measures of performance in a female, high school population. The mechanistic explanation for changes in movement technique and a reduction of injury rates for the F11+ is also unknown. The purpose of this study was to examine if a shortened duration injury prevention program (Focused) elicits neuromuscular control changes and performance benefits equivalent to or greater than a well-researched lower extremity injury prevention program in a female, athletic, adolescent population. We hypothesized that the Focused injury prevention program warm-up would result in greater performance and movement technique benefits compared to both a well-researched injury prevention program and dynamic warm-up.

1.6 Research Questions

RQ1: Can a shortened duration injury prevention program, performed as a warm-up, elicit greater or equivalent changes in movement technique compared to a well-researched injury prevention program and an active control in female high school athletes?

1. Movement Technique
    a. Kinematic variables during a jump-landing task

i. At ground initial contact
1. Knee flexion angle
2. Knee valgus angle
3. Hip flexion angle
4. Hip adduction angle
5. Hip rotation angle

ii. Peak during first 50% of stance phase
1. Knee flexion angle
2. Knee valgus angle
3. Hip flexion angle
4. Hip adduction angle
5. Hip rotation angle

b. Kinetic variables measured during jump-landing task

i. At initial ground contact
1. Vertical ground reaction force

RQ2: Can a shortened duration injury prevention program, performed as a warm-up, elicit greater or equivalent performance effects (balance, power and agility) compared to a well-researched injury prevention program and an active control in female high school athletes?

1) Balance measured using the Y Balance Test
   a. Anterior reach distance
   b. Posteromedial reach distance
   c. Posterolateral reach distance
   d. Composite reach score

2) Power measured as maximal distance during a standing long jump test

3) Agility measured as through the Edgren Side Step Test

RQ3: What factors influence a female adolescent athlete's willingness and perceptions of an injury prevention program?

RQ4: What is the length of time a female adolescent athlete believes an injury prevention program should take to perform?

1.7 Research Hypotheses:

RH1: The shortened duration injury prevention program warm-up will result in equivalent improvements in movement technique compared to the well-researched injury prevention program and greater improvements in movement technique compared to the active control.

RH2: The shortened duration injury prevention program warm-up will result in equivalent improvements in performance measures compared to the well-researched injury prevention program and greater improvements in performance measures compared to the active control.

RH3 & RH4: No stated hypotheses as the data are qualitative and a hypothesis may bias the results.

1.8 Operational Definitions

Adolescent: 13-18 years old

Athlete: Participating in a Fall interscholastic sport

Initial ground contract: The moment the foot makes contact with the ground identified by the force plate registering a vertical ground reaction force greater than 10N.

Toe-off: The moment the foot leave the ground represented by the moment vertical ground reaction force drops below 10 N.

Limb dominance: The leg used to kick a ball for maximal distance.

Jump–landing task: Participants begin the jump-landing test standing on a box 30- cm high and jump forward off the box towards a non-conductive force plate placed a

distance half the participant's body height away from the box. Participants land with their dominant foot in the center of the force plate and immediately perform a vertical jump for maximum vertical height upon landing.

Standing long jump test: Standing broad jump. Participants begin will feet behind a designated starting line and jump forward for maximal height landing on both feet. Participants must land without stumbling or moving their feet once landing.

Well-researched ACL injury prevention program: The F11+ is the well-researched ACL injury prevention program. It consists of 15 exercises, divided into three parts including initial and final running exercises with a focus on cutting, jumping and landing techniques and strength, plyometrics, agility and field balance components

Focused injury prevention program: A 10-minute IPP consisting of flexibility, core, agility, plyometric, strengthening, and balance exercises. The Focused program incorporated exercises in three planes of motion (sagittal, frontal, and transverse) and involved cues, instruction, and feedback for correcting movement (i.e. "Bend your knees", "Keep your knees over your toes", "Keep your toes pointed straight ahead", "Hips square").

Active Control Warm-up: A 10-minute dynamic warm-up consisting of movements similar to what the teams were currently performing before practice: i.e. high knees, inchworms, butt kicks, and lunges.

Intervention Period: The warm-up interventions took place for the duration of the Fall 2014 season, including post season for varsity teams; approximately 8-10 weeks.

Compliance: Number of sessions attended divided by number of sessions the participant had the opportunity to attend. This is expressed at a percentage. Sessions

missed due to injury or receiving treatment from the athletic trainer were not counted against compliance rate.

CHAPTER 2
REVIEW OF THE LITERATURE

2.1 Injury Epidemiology

2.11 Musculoskeletal Injury Epidemiology

The National Federation of State High School Associations (NFHS) reported that during the 2013-2014 school year 7,795,658 adolescents participated in high school sports, an increase of almost a million participants over the last ten years.[2] As the number of participants has increased so has the number of injuries. Nearly 3.5 million musculoskeletal injuries occur each year in children under fourteen.[38] Knee injuries now account for 44.6% of all orthopedic surgeries performed on high school aged athletes and 60% of sport-related surgeries.[5] The most common surgically managed injury involves the anterior cruciate ligament (ACL).[39]

2.12 ACL Injury Epidemiology

An estimated $2 billion dollars is spent each year in the United States on ACL injuries and this estimate does not include initial evaluation or rehabilitation.[40] More than 200,000 ACL injuries occur every year and on average can cost a family $20,000 per an injury.[41] When rehabilitation costs are taken into consideration the annual cost is estimated to be as high as $7.6 billion.[41] In high school athletics, football players sustain a higher number of injuries, but female athletes sustain injuries at a higher rate.[3] Joseph et al.[4] reported that boys playing football were 4 times as likely to sustain an ACL injury as boys playing other sports. Girls were nearly 4 times as likely to sustain an ACL injury playing soccer and basketball compared with volleyball or softball. Athletes, regardless of sex, are 7 times more likely to sustain an ACL injury during competition than in practice. Among gender-comparable sports (baseball/softball, basketball, soccer, track,

and volleyball) ACL injury rates are 2.5-6.2 times higher in females.[8,9] In soccer, the rate of non-contact ACL injuries is twice as high in females as in males.[10] This sex disparity continues to persist despite increased awareness and improved quality of injury prevention programs.

2.13 Long Term Effects of ACL Injury

The effects of sustaining an ACL injury are long-term and persist well past the surgical intervention and subsequent rehabilitation. A person who has sustained an ACL injury is at an increased risk for early onset of osteoarthritis, for re-injury, and decreased health-related quality of life. Thelin et al.[42] reported that regardless of treatment, athletes who sustain an ACL injury retire from sport at a higher rate. In a study of retired soccer players, 46% retired due to acute career-ending knee injuries and of those that suffered an ACL injury 80% reported decreased activity levels.[43] History of a previous injury is the chief risk factor for sustaining another injury at either the same or a different location.[44,45] A significant number of patients that sustain an ACL injury go on to re-injure and they have equal risk to re-injure their repaired (ipsilateral) or contralateral ACL.[46,47] Secondary (re-injury) ACL injury rates range from 6% to 27% which means that as many as 1 in 3.7 people re-injure their repaired ACL or the contralateral ACL.[46-48]

Patients who sustain an ACL injury and undergo ACL reconstruction (ACLR) demonstrate altered lower extremity movement patterns that may not be able to be corrected by traditional rehabilitation.[49] The JUMP-ACL study collected baseline data on incoming military cadets and followed those who went on to tear their ACL. After surgery, rehabilitation, and return to duty cadets presented with kinematic changes

during a jump-landing task that were not present before their injury.[49] The cadets demonstrated increased peak knee valgus and hip adduction angles at initial contact as well as decreased peak knee varus angle and increased peak knee valgus during the landing phase. These movement patterns in conjunction with the history of ACL injury place the cadets at an increased risk of re-injury. Female athletes who have torn an ACL demonstrated higher vertical ground reaction forces (VGRF) and a higher loading rate on their uninjured limb when landing from a jump.[50] This uneven landing and weight shift place the athlete at an increased risk of re-injury. Jump-landing movement patterns are not the only mechanics changed by ACL injury but balance and proprioception are also altered.[51]

2.14 Summary of Injury Epidemiology

Increased participation in youth and high school sports has the potential to lead to increased injuries sustained, particularly to the lower extremity. An injury sustained during childhood or adolescence can have lasting effects on the child's quality of life and level of activity.

2.2 Etiology of ACL Injury

2.21 ACL Mechanism of Injury

The main function of the ACL is to prevent excessive anterior tibial translation at various degrees of flexion. While studying knee diagnostic tests Butler et al.[52] identified that the ACL provides 85% of the restraining force to anterior tibial displacement at 30^o and 90^o of knee flexion. The most common mechanism of injury for an ACL injury is a non-contact in nature and typically involve: a change of direction or cut combined with deceleration, landing from a jump at or near full knee extension, or pivoting with the

knee in full extension with the foot planted.[53] The most commonly described mechanism of injury is deceleration with high internal knee extension torque, dynamic valgus rotation with the athlete's body weight shifted to the injured leg and the foot fixed to the playing surface.[54] This combination of motions can occur during cutting around a defender in soccer or landing from a rebound in basketball. Other common injury mechanisms are knee hyperextension or hyperflexion.

2.22 Risk Factors for ACL Injury

Risk factors for ACL injury can be divided into two categories extrinsic (outside the body) and intrinsic (within the body) risk factors. Extrinsic risk factors include weather, playing surface, contact with another player, and type of shoe. Intrinsic risk factors include generalized laxity, narrow intercondylar notch, hormonal fluctuations, increased quadriceps to hamstring ratio, increased dorsiflexion of the ankle during sport tasks, altered neuromuscular control and proprioception, and lack of core strength. Intrinsic factors can be separated into modifiable and non-modifiable risk factors.

2.23 Non-Modifiable Risk Factors

Non-modifiable risk factors can be divided into two categories: (1) anatomical and (2) developmental/hormonal. Anatomical risk factors include: a high body mass index (BMI), a narrow femoral notch width, increased Q angle and greater recurvatum at the knee.[53] A large BMI, a measurement that takes height and weight into account, has been identified as a risk factor for ACL injury in female adolescent soccer players and female military cadets.[55,56] The BMI of female soccer players was identified as a significant risk factor for injury after the age of 11 and particularly in those who were post-pubescent.[55] Yund also noted that knee injury rates in female athletes began to

increase around age 12, when BMI typically increases in girls.[55] Women have a differently shaped pelvis (generally wider) than males and a greater quadriceps (q) angle. The q angle is an angle formed by lines representing the line of pull of the quadriceps muscle relative to the patella, an angle of greater than 20^o is considered abnormal. The literature is divided on the association of q angle and the incidence of lower extremity injury.[27,57]

Recurvatum or hyperextension of the knee is often observed in conjunction with generalized joint laxity, but can occur in isolation so is considered a unique risk factor. A narrow femoral notch is also associated with increased risk of injury.[15,58,59] Lund-Hanssen et al.[15] reported that athletes with notch widths of less than 17 mm were six times more likely tear an ACL than athletes with notch widths greater than 17 mm, even after controlling for age, height, weight, and level of performance.

Congenital/hormonal risk factors include: generalized joint laxity, family history of ACL injury, genetic predisposition, prior history of lower extremity injury, maturation status (pubertal or post pubertal), preovulatory menstrual status, tensile strength of the ACL, and neuromuscular shunt. The chief risk factor for sustaining a lower extremity injury is previous history of injury. One in 3.7 people who have torn their ACL go on to reinjure the same knee or the contralateral limb. There is also thought to be a possible genetic link to ACL injuries. It has not yet been identified if the predisposition lies in the generalized joint laxity leading to ACL rupture or a if there exists a predisposition specifically for ACL injury. Much of the research on a genetic has been looked at polymorphisms of proteoglycan genes. Proteoglycans play a role in fibrillogenesis and assist in the maintaining the structural integrity of ligaments.[60] The goal of this line of

research is to identify genes or region within proteoglycans that increase the risk of ACL injury in order to add to the body of knowledge regarding ACL injury and risk.

The role of hormones in ACL injury has been much discussed and estrogen is the hormone most directly associated with ACL injury. The literature is divided on when estrogen has the greatest effect on injury risk during the menstrual cycle. Wojtys reported an increase in non-contact ACL injuries during the ovulatory phase of the menstrual cycle.[61] Slauterbeck et al.[17] reported the luteal phase is when the largest number of ACL injuries occurs. Studies on the effects of oral contraceptive use and the female athlete have reported conflicting findings. Martineau et al.[62] reported that oral contraceptive use decreased the ligamentous laxity in female soccer players. Another study found that female athletes on oral contraceptives demonstrated decreased impact forces during landing and reduced medial and lateral torques at the knee, increased hamstrings to quadriceps strength ratios, increased stability on one leg and decreased knee laxity relative to non-users.[63] Many of these are noted risk factors for ACL injury. A more recent study of collegiate female athletes reported that oral contraceptive users displayed increased anterior tibial displacement compared to those not using hormonal replacement therapy.[64]

The size and tensile strength of the ACL is also believed to play a role in injury risk. In cadaveric studies women were found to have ACLs that were smaller in length, cross-sectional area, volume, and mass when compared with that of men.[16] The same study reported a lower fibril concentration and lower percentage of area occupied by collagen fibrils in females compared to males. This is of note as ACL stiffness in females is highly correlated to fibril concentration.[65] Women may also have lower tensile

linear stiffness with less elongation at failure, and lower energy absorption and load at ACL failure than men.[16] Although cadaveric studies are not generalizable to the population at large they give insight as to what may be occurring prior to and ACL rupture.

2.24 Modifiable Risk Factors

Modifiable risk factors are often the focus of injury prevention research as they have the potential for improvement. Risk factors can be biomechanical or neuromuscular in nature. Examples of neuromuscular risk factors include: (1) muscle imbalances due to poor strength or flexibility, and (2) altered neuromuscular control that can often manifest itself as either poor balance or movement technique. Decreased strength of musculature at the hip and knee has been cited as a risk factor for lower extremity injuries.[27,53,66] Decreased hamstring to quadriceps ratio has been associated with risk of lower extremity injury in female soccer players. [67] Limited dorsiflexion at the ankle has been reported as a risk factor for lower extremity injury. [68] A decrease in motion at the foot/ankle needs to be compensated further up or down the kinetic chain and can lead to overcompensation and injury. Specific movements have also been identified as risk factors for ACL injury: decreased trunk, hip and knee flexion angles, lateral trunk displacement, dynamic knee valgus (hip adduction combined with knee abduction moments), increased hip internal rotation and tibial external rotation with/without foot pronation.[69]

2.25 Females and ACL Injury Risk

Studies have shown that the prevalence of ACL injuries in females is four to six times higher than that in males.[70-72] Several factors have been suggested to explain why females sustain ACL injuries at a higher rate than males. Females have sensitivity

to hormone fluctuations, steeper lateral tibial plateaus, narrower intercondylar notches, navicular drop and decreased hamstring to quadriceps ratios.[58,73-76] These non-modifiable intrinsic risk factors are thought to contribute to the higher rate of ACL injuries in females, but are not easily addressed. Females also have different landing and movement strategies, which may also contribute to their increased risk of injury. Females had less knee separation while landing from a drop jump compared to males, leading to a more valgus limb alignment.[77] Females have different muscle activation patterns and motor patterns during landing than males. A study of recreational athletes' performance of a stop-jump task indicated that females exhibited less knee flexion, hip abduction, and hip external rotation and greater knee internal rotation and quadriceps activation than the males.[78] Landing with decreased hip and knee flexion in addition to increased quadriceps activation can increase the risk of ACL injury during landing as it adds increased stress and loading on the ACL.

During early puberty, female athletes exhibit several risk factors for sustaining a lower extremity injury when landing from a jump, such as increased knee abduction moments and reduced force absorption.[11,12] Hewett et al.[14] reported that knee abduction moments during landing predict ACL injury status in adolescent females with 73% specificity and 78% sensitivity and dynamic valgus showed a predictive r2 of 0.88. These risky landing mechanics persist in subsequent years and if not addressed may become habitual as the athlete matures and increases the risk for lower extremity injury.[11,13,14] When studying the rate of ACL injury, Paterno et al.[79] reported that female athletes with a history of ACL injury demonstrated 16 times greater rate of injury than

non-ACL females. Female athletes were also 4 times more likely to suffer a second ACL injury and 6 times more likely to suffer a contralateral injury than male athletes.[79]

2.26 Summary of ACL Injury Etiology

ACL injuries are becoming increasingly common in younger, female athletes. Although there are many risk factors to consider clinicians and researchers need to focus on modifiable risk factors and make them the emphasis of injury prevention programs.

2.3 Injury Prevention Programs

Lower extremity injury prevention programs can address strength, flexibility, and/or movement deficits and alterations in athletes. Injury prevention programs have been utilized in a variety of sports but the majority of research is focused on soccer, handball and basketball. Injury prevention programs have proven to be successful in the female athletic population in reducing future lower extremity injuries.[19,79,80 81] Injury prevention programs improve strength and flexibility of adolescent female athletes[32,82] as well as sagittal plane motion (i.e. knee flexion) and vertical ground reaction forces.[32,82,83] Both limited sagittal plane motion and large vertical ground reaction forces are risk factors for injury as mentioned previously as they indicate that the body is not absorbing the forces of a landing throughout the body.

Injury prevention programs often utilize a multitude of exercise components such as balance, strengthening and landing. In order to increase knee flexion angle during landing the evidence indicates that programs should include components of balance, plyometric training, strength, flexibility, and feedback/instruction.[84] Multicomponent programs are not only able to change movement technique but also reduce the risk of

non-contact ACL injury during physical activity.[18,81,85,86] Athletes who perform a neuromuscular training program have lower odds (Odds Ration: 0.54, 95% CI= 0.35, 0.82) of sustaining an ACL injury then those who do not.[24]

A recent cost-effectiveness analysis reported that a universal neuromuscular training program reduced the incidence of ACL injury by 63 percent (from 3 to 1.1 percent per season).[87] Large-scale implementation of cost-effective injury prevention interventions under real-life conditions continues to be an ongoing challenge. Programs are often successful under the watchful eyes of a research team but lose compliance once under the direction of a coach. There is a need for practicality in injury prevention program implementation as a program cannot truly be successful or efficacious if coaches and/or players will not use it. Ecological implementation is needed in order to truly measure the success and feasibility of injury prevention programs.[88] The Centers for Disease Control has declared it a Tier 1 priority to examine strategies to increase dissemination and adoption of effective interventions to prevent sports-, recreation-, and exercise-related injuries.

2.31 Effects of Injury Prevention Programs on Risk Factors

Kinematics

Injury prevention programs improve biomechanical risk factors such as reduced sagittal plane motion and excessive frontal and transverse plane motion of the trunk and lower extremities. These atypical motions may place increased loads and stresses on the soft tissue and joints of the lower extremity and are associated with increased risk of injury.

Sagittal

Sagittal plane motion is often the focus of neuromuscular training programs as it is the motion where the body absorbs much of the forces of physical activity through flexion at the trunk, hips, knees and ankles. This plane of motion is also highly studied because cadaveric studies have identified anterior tibial shear force as the most direct mechanism of ACL loading.[89] A systematic review by Padua et al.[84] found moderate evidence to suggest that prevention programs that incorporate balance, plyometric training, strength, flexibility, and feedback or individualized instruction increase knee flexion angle. A study of a neuromuscular program by Myer et al.[90] was unique in that it studied the effects of plyometrics and balance when added to a program while using two distinct jumping tasks to measure the change. They reported that plyometric training affected sagittal plane kinematics primarily during a drop vertical jump and balance training affected sagittal plane kinematics during single-legged drop landing. These findings indicate that movement technique improvements are task dependent and there may not be a one size fits all approach to injury prevention programs. Exercises and components of a program should be designed with movements and needs of the athlete in mind. Knee flexion angle has been improved in both the high school and college-aged female athlete. [90-93] Chappell et al.[92] utilized a 6-week program with collegiate female athletes and reported an increase in knee flexion at initial contact as well as an increase in peak knee flexion during a drop jump task. Lephart et al.[91] and two studies by Myer et al. focused on the high school female athlete.[90,93] Both programs utilized plyometrics and strength training and were able to increase both hip and knee flexion.

Research indicates that a combination of balance and strength training are needed to result in improved (increased) knee flexion during a jumping task.[91,92] An isolated training approach or the integration of only one balance exercise into an intervention program is not able to increase knee flexion angle during landing.[94,95] These types of training may not challenge the body enough to cause an increase in muscle force capacity and change the athlete's biomechanics.[84]

Frontal

Injury prevention programs are also able to improve movement in the frontal plane.[77,83,90,96]The most analyzed movement in the frontal plane is knee valgus as the motion is a mechanism of ACL injury, [54,97] as well as a risk factor for sustaining a lower extremity injury[14,98,99] Dynamic or 3D knee valgus is not a motion that can occur in isolation during activities of daily living or sport as it often is a result of a combination of motions such as: hip adduction, tibial external rotation and/or pronation of the foot.[100] The motion commonly observed as "knees caving in" or "knock kneed" is typically characterized as 2D knee valgus and measured in terms of knee separation or medial knee displacement.[101,102] For example, Noyes et al.[77] reported an increase in knee separation at initial contact of a drop jump task indicating that athletes were landing with a more neutral lower extremity alignment after participating in a neuromuscular training program. The amount of knee valgus is not only noted at the point of initial contact during a landing task but also the peak amount of knee valgus attained during the task. This is an important measurement as an athlete can go further into dynamic knee valgus during deceleration from a jump. Lim et al.[83] found peak interknee distance improved after implementing an 8-week injury prevention program in high school female

basketball athletes. A unique aspect of this study was that the jump test used to assess movement technique was rebound jump-task, which is a more sport-specific task with the potential to translate to their movement during sport. 3D knee valgus has also been widely studied but only Myer et al.[90] reported improvements in knee valgus at initial contact and peak knee valgus during a landing task. According to the literature, 3D knee valgus is not improved after a neuromuscular training program or traditional injury prevention program. This may be due to the multiple joint motions that contribute to the measurement.

Transverse

Injury prevention programs are not as effective in improving movements in the transverse plane as they are in effecting flexion/extension or adduction/abduction of the hip and knee. Neuromuscular training programs are able to alter peak hip rotation but the direction of hip rotation differs by study. Chappell and Limpisvasti[92] reported a reduction of peak external hip rotation during a stop jump task in collegiate female athletes after a 6-week neuromuscular training program. In contrast, Pollard et al.[25] reported a decrease in hip internal rotation during a drop jump task. The difference in findings may be due to differences in the task or the study population as Chappell studied collegiate athletes and Pollard adolescent athletes. DiStefano et.al[103] looked at the effects of an age-specific injury prevention program in youth soccer players have observed significant changes as the athletes exhibited less knee external rotation at initial contact as well as decreased peak knee rotation. Lim et al.[83] studied the effects on an injury prevention program on knee kinematics in female high school basketball

players but not significantly reduce peak knee internal rotation, this may be due in part to a small size of 11 in their intervention group.

Vertical Ground Reaction Forces

Injury prevention programs reduce vertical ground reaction forces (VGRF) during landing tasks.[95,104,105] A decrease in VGRF indicates that the athlete is landing with less force registered by a force plate and with more landing forces dissipated across the joint and musculature of the body. [106] Decreased VGRF are used to indicate improved landing technique, as they are often the result of increased flexion during a landing. Programs have used a variety of components such as plyometrics, balance and agility in order to be effective at reducing ground reaction forces.[95,104,105] An IPP with a focus on plyometrics led to a decrease in not only VGRF but also deviation of center of pressure during a hop landing in female athletes.[107] Neuromuscular training programs featuring multiple exercise components have reduced ground reaction forces in female athletes.[104,105,107,108] The use of feedback (verbal or visual) during a neuromuscular training program also aids in decreasing VGRFs.[109,110] Key features of programs that have reduced ground reaction forces are the use of verbal instructions and feedback on proper landing technique, auditory cues for minimizing landing forces, and direct supervision of the exercises.[84] A study of collegiate female team sport athletes reported a decrease in dynamic knee valgus moment during the stance phase of a stop jump task but not a drop jump task after completing a neuromuscular training program.[92] This may indicate that improvements in movement technique may be task specific and not transferred or generalized to other sport-related tasks.

Global Movement Technique

In addition to improving specific risk factors in the three plans of motion, injury prevention programs can improve overall movement technique and decrease the risk of sustaining a lower extremity injury.[111-114] Two methods used to perform an overall assessment of movement technique, particularly landing mechanics are the Landing Error Scoring System (LESS)[115] or tuck jump.[111] Both tools are scored using the number of movement errors or deficits performed during a jumping task; a lower score indicates better movement quality. Paduea et al.[116] used the LESS to assess the movement patterns of youth soccer players after a short duration (3-months) and longer duration (9-months) injury prevention programs and reported that both groups improved their movement technique but only the longer duration group retained the improvements after a 3-month detraining period. Klugman et al.[112] utilized an in-season neuromuscular training program similar to that used in Myer et al.[117], with female adolescent soccer players and observed reduced landing and jumping deficits. The LESS and tuck jump are able to assess changes and potential improvements in landing technique by way of sport-related tasks. These findings are important as many clinicians do not have the access to equipment to measure 3D biomechanics.

2.32 Effects of Injury Prevention Programs on Measures of Performance

Performance testing is typically used to assess how fit or capable an athlete is at a particular task and assess areas such as power, speed/agility and balance. There are several ways to assess an athlete's power, some of the more common ways used in field-research are the vertical jump and the standing long jump. Speed and agility are often assessed using the T-test of agility, 40-yard dash, Illinois Agility Test or the

Edgren Side Step Test.[118] There are many ways to measure balance in field research and two of the more popular methods are the Balance Error Scoring System (BESS) and the modified Star Excursion Balance Test (SEBT). The F11+ and HarmoKnee neuromuscular training programs improve dynamic balance, as measured by the SEBT, in Under-21 male soccer players after an 8-week intervention.[119]

Myer et al.[93] implemented a neuromuscular training program with adolescent female basketball, soccer, and volleyball players to examine the program's effect on performance. Participants were able to improve their maximum vertical jump, single-leg hop distance, 9-meter sprint speed, and 1 repetition maximum squat and bench press after six weeks of training. Similar improvements have been demonstrated in youth athletes as well. DiStefano et al.[37] reported that after a 9-week IPP youth soccer players were able to improve their dynamic balance and vertical jump. Using a combination of balance and plyometric training during an IPP, female athletes were able to increase hamstring strength and vertical jump.[107] Improvements in performance are also seen at the collegiate level. Division One female soccer and basketball players improved both vertical jump and hop test performance after completing a 6-week neuromuscular performance program.[92] Injury prevention programs not only improve power, but also strength and dynamic balance, all of which are important for sport performance. Neuromuscular training programs do not always result in improvements performance measures. A program developed by Swedish researchers utilizing a one-legged knee squat, pelvic lift, two-legged knee squat, the bench, lunge, and jump/landing as the exercises for an 11-week intervention with 12-16 year old soccer players saw no improvement in SEBT and the Illinois Agility Test.[120] The Illinois Agility Test is a valid

and reliable measure of agility and correlates with the T-Test and ESST.[118] The researchers indicated that the lack of an improvement might be due to low compliance, sample size or program volume.

A recent systematic review set out to determine if ACL injury prevention are able to decrease the rate of ACL injury while improving tests of athletic performance.[121] Forty injury prevention programs were able to either reduce the rate of ACL injuries or improve performance measures, but only two were able to do both, the Prevent Injury and Enhance Performance program (PEP) and Sportsmetrics. Sportsmetrics significantly increased lower extremity and abdominal strength, vertical jump height, estimated VO2 max, speed and agility.[77,86,122-124] The PEP was not able to improve vertical jump height, agility or speed but improved knee flexion strength.[83,108]

In a recent survey, high school basketball and soccer coaches indicated that they would be willing to implement specific training with their team if it was proven to improve player performance.[28] There appears to be a gap in communication and education as there are data that show improvements in performance measures. Injury prevention program facilitators and health care professionals need to educate coaches, as they are willing to implement injury prevention programs into their practice plan.

2.33 Barriers to Implementation of Injury Prevention Programs

It is easy to assume that players and coaches are not aware of the causes of sport-related injury but the literature indicates that this may no longer be the case. In a recent survey of international, professional soccer clubs, the players ranked what they considered to be the top five risk factors for injury. In order of importance, they stated the top factors are previous history of injury, fatigue, muscle imbalance, fitness level,

and movement efficiency.[125] While the previous study utilized professional players who may be more mature and knowledgeable, it is encouraging that the players are aware of what factors increase their risk of injury.

Saunders et al.[31] surveyed Australian junior netball coaches to identify what the coaches' believed were the main barriers to the implementation of lower extremity injury prevention program. The coaches in the survey who had previously implemented an injury prevention program identified the top three barriers to implementation as (1) running out of time, (2) players finding the drills too difficult, and (3) too many sets and reps to complete. These reported issues led to coaches changing the programs from their prescribed durations and repetitions of exercises. These changes could dramatically alter the effectiveness of the program, as the players are not getting as much exposure to the potentially new and different movement patterns. 79% of the coaches reported that they would require help to develop or modify training drills to incorporate the program into their training sessions. This number is striking as the ultimate goal of injury prevention program implementation and adoption is to have a program be coach or player led. Having a coach or player lead the team in a program may increase the sense of ownership and help get players more involved.

The Australian netball coaches also believed there were also player-based barriers to implementation. 71% of coaches reported that junior players do not perceive the value of injury prevention programs and 83% cited poor concentration and motivation levels in their players as a barrier to implementation.[31] A solution to player-based barriers is educating the players as to the benefits and importance of injury prevention programs.[126] Athletes often believe that if they have never been injury they

do not need to participate in an injury prevention program. Players may be more apt to perform an injury prevention program if they know why and what they may be getting out of the program. 42% of the netball coaches reported that their general coach training did not adequately prepare them to implement a safe-landing program.[31] As we look to coaches as the primary facilitators of injury prevention programs we need to make sure that coaching education is comprehensive or create modules/seminars to provide them with injury prevention program knowledge. The netball coach study illustrates that there are several types of barriers to the implementation and possibly the adoption of injury prevention programs; player-centered barriers, coach-centered barriers and program-centered barriers.

2.34 Compliance with Injury Prevention Programs

Compliance can often be the deciding factor that determines the success of an injury prevention program. A recent meta-analysis by Sugimoto et al.[29] reported that participants with moderate compliance rates had a 3.1 times greater risk of injuring their ACLs and those with low compliance rates demonstrated a 4.9 times greater risk of injuring their ACLs. Heidt et al.[85] reported 100% compliance rate in a preseason injury prevention program and attributed this extremely high compliance rate to the coaches encouraging players to be involved in all training sessions. This avenue of player motivation must be capitalized on when implementing an injury prevention program. Soligard et al.[127] were able to accomplish high program compliance rates, which they believe resulted in lowered injury risk in a youth soccer population. The researchers of the previous study identified a compliance continuum, those of high compliance and the greatest reduction in injury rates. One factor that can determine the success of an injury

prevention program is the coach's, players' or other facilitator's readiness to change i.e. readiness to implement an injury prevention program.[127]

2.35 Summary of Injury Prevention Programs

Injury prevention programs may vary in their exercise components but overall have shown that they are able to decrease injury rates and improve measures of performance. Improvements in performance measures may be the key to increasing buy in from coaches and players who are still reluctant to implement and perform injury prevention programs. Increasing player and coach buy-in may also increase program compliance, which can improve a program's likelihood of success. A limitation of current evidence on the performance effects of injury prevention program is that the research has largely been conducted in male athletes and it is the female athlete who has a higher risk of sustaining an ACL injury.

2.4 Injury Risk Screening Tools

There are several screening tools discussed in the literature that are used to assess athletes' or patients' movement technique and potential risk of injury. Two commonly used are the Landing Error Scoring System (LESS) and the Functional Movement Screen (FMS).

2.41 Landing Error Scoring System (LESS)

The LESS is a seventeen-item movement assessment tool to be used to assess a jump-landing task. The LESS is both valid and reliable (interrater reliability: intraclass correlation coefficient [2,1] = 0.84, standard error of the mean = 0.71) tool to assess for high-risk movement patterns.[115] In a study of elite, youth soccer players the following errors on the LESS were shown to be the most predictive of going on to sustain an ACL

injury: trunk-flexion displacement, hip-flexion displacement, knee-flexion displacement, joint displacement, trunk flexion at initial contact, external rotation of the foot.[113] The displacement errors indicate that the athlete was landing with a small amount of flexion at the trunk, hip, or knee. In addition to the aforementioned errors increasing the risk of injury, athletes with LESS scores of 5 or more were at greater risk (1.2% risk difference) of sustaining an ACL injury than their counterparts with scores below 5.[113] There is also an abbreviated version of the LESS called the LESS Real Time (LESS RT) and is scored real time as the clinician is assessing the athlete/patient as opposed to retrospectively.[128] The LESS RT has reported interrater reliability from 0.72 to 0.81 with standard error of measurements ranging from 0.69 to 0.79. The LESS RT gives clinicians a means to identify individuals who may be at a higher risk for lower extremity injury without needing video recording equipment. This also allows screenings to take place in the settings that clinicians work in such as an athletic training room, basketball court or outdoor playing field.

2.42 Functional Movement Screen (FMS)

The Functional Movement Screen (FMS) is a tool used by clinicians to assess seven fundamental movement patterns: deep squat, hurdle step, inline lunge, shoulder mobility, active straight leg raise, trunk stability push-up and rotary stability.[129] Kiesel et al.[130] reported that among American professional football players, a lower movement pattern score or the presence of asymmetries correlate with time-loss injury during a preseason. The Y-Balance Test was developed to complement the FMS and measures dynamic balance, flexibility, and strength of the upper and lower extremities.[131] It is often used to detect possible asymmetries between dominant and dominant limbs.

2.43 High-Risk Athletes and Injury Prevention Programs

Previous research indicates that athletes with risky movement patterns (ex. increased frontal plane movement) may exhibit greater improvements in movement technique after exposure to an injury prevention program as they have more room to improve. Various risk factors have been used to identify high-risk movers, knee abduction angles, LESS score, Myer et al.[132] examined the effects of a neuromuscular training program on individuals classified as high or low-risk and found that high-risk individuals responded better to the IPP, meaning that they improved their movement and thus decreased their risk factors. DiStefano et al.[133] saw a similar response in youth athletes participating in an injury prevention program; players with a higher LESS score improved the most after the intervention. High-risk movement patterns are not exclusively in those with less sport experience or skill. Theiss et al.[134] compared the LESS scores of varsity, club, and intramural athletes with their scores on the Army Physical Fitness Test (APFT) had found that even the elite Division One athletes demonstrated high-risk movement patterns.

2.44 Summary of Injury Risk Screening Tools

Several validated tools exist to assist clinicians to screen athletes for risk injury and identify movements to be addressed in rehabilitation or strengthening programs. It is important to screen all athletes for risk of injury as many risk factors are modifiable in nature and can be addressed through a neuromuscular training program. All athletes can benefit from an injury prevention program but athletes with high-risk movements should be the focus of any training program as they are at highest risk for sustaining a lower extremity injury and have the potential to make the most gains from the program.

2.5 Theories of Health Behavior Change

Health behavior change theories were created as a means to assess the public health significance and success of interventions. Throughout their existence they have been used to assess interventions after their implementation, for example a community-based program to encourage the cessation of smoking, or encourage dietary changes.[135,136]

2.51 Health Belief & Stages of Change Models

One of first and most commonly used theories of health behavior is the Health Belief Model (HBM). The HBM states that people's beliefs on whether they are at risk for a disease/health problem in conjunction with their perceptions of the benefits of taking steps to avoid it influence their readiness to take action. [137] The key components of HBM are perceived susceptibility, severity, benefits, and barriers, cues to action, and self-efficacy. It is most often used for prevention-related and asymptomatic health concerns where beliefs are as important to the patient as symptoms. The Transtheoretical Model or Stages of Change Model proposes that people are at different stages of readiness to adopt healthful behaviors. The theory suggests that a person who has already contemplated changing a behavior is more ready to change and more apt to succeed. The Stages of Change model believes in letting a person discover and learn on his or her own. It describes a sequence of steps a person must go through for successful behavioral change; 1) *Precontemplation*: No recognition or need for or interest in change 2) *Contemplation*: Thinking about change 3) *Preparation*: Planning for change 4) *Action*: Adopting new habits and 5) *Maintenance*: Ongoing practice of new, healthier behavior.[138] These steps are not always completed in a linear fashion and an

individual may often repeat steps several times. This model is commonly used to identify an organization's readiness to change based on it's leaders' and members' readiness to change. This translates very well to injury prevention research, as we should assess an organization's (i.e. school, league or team) readiness to change prior to proceeding with an intervention. If a team has no interest in in an injury prevention program and does not see a need for it the program's potential for success is greatly diminished.

2.52 Social Cognitive Theory

Social Cognitive Theory (SCT) purposes that people not only learn via their own experiences but also through observing the actions of others.[139] Key constructs to utilize when using SCT for health behavior changes are observational learning, reinforcement, self-control, and self-efficacy. These constructs can be added to an injury prevention program as a method of increasing its efficacy. Athletes often learn how to do an injury prevention program by watching an instructor perform the desired exercises correctly and then receive feedback and reinforcement from the instructor. The concept of self-efficacy can also factor into an athlete's success in changing/improving their movement technique. Self-efficacy is defined as a person's confidence to perform a particular behavior. Confidence can be improved through several methods such as: setting small, achievable goals, monitoring and reinforcing the desired behavior. It is important to not overwhelm an athlete with too much feedback during implementation of an injury prevention program. Setting small, attainable goals such as "land softer" as well as giving positive reinforcement may help an athlete gain confidence in his or her newly learned movement techniques. The core belief in SCT is that a person can be both an

agent for change and a responder to change. Social Ecological Model uses several levels of influence (individual, interpersonal, organizational, community, and public policy) to emphasize the role social environment plays in shaping health behaviors and vice versa. Social Cognitive Theory shares some of its core components with the Social Ecological Model, chief among them is the idea that creating an environment that is conducive to change is crucial in order to facilitate the adoption of healthy behaviors.[139]

2.53 RE-AIM Framework

Health behavior researchers have raised concerns that theories of heath behavior change are being underutilized or are not being used properly which have resulted in health interventions that are largely ineffective. The success of an injury prevention programs is often measured by a reduction of injury rates, injury risk or of undesirable movement patterns. The RE-AIM framework was created as a way to evaluate the effectiveness and context of health behavior change programs after they have been implemented.[140] It was meant to assist with establishing the internal and external validity of the intervention as well as identify key issues pertinent to the dissemination and generalization of the intervention's results. Injury prevention researchers have recently identified it as a potential way to bridge the gap between research and successful implementation of injury prevention programs. Glasgow et al.[140] developed the RE-AIM framework as a method of evaluating the translatability and feasibility of an intervention program. RE-AIM consists of five dimensions: **R**each- Percentage and representativeness of individuals willing to participate, **E**ffectiveness- Effect of the intervention on the targeted outcomes, **A**doption- Extent to which the included settings represent the wider population and are adequately described,

Implementation- Degree to which the intervention is implemented as intended in the real world, and **M**aintenance- Extent to which the program is sustained over time.

2.54 Summary of Theories of Health Behavior Change

When designing an intervention to change health behaviors, theories and frameworks of health behavior change should be utilized to measure effectiveness and increase the interventions chances of success. Creating an injury prevention program based around a health behavior change framework helps the facilitators address every stage of the program (i.e. adoption, implementation, and retention) in the hopes that the program will continue after the initial implementation.

2.6 Patient Oriented Outcomes

2.61 Health–Related Quality of Life

Health–related quality of life (HRQOL) is an overarching term that encompasses all aspects of a person's health status and is an important healthcare outcome. Testa and Simonson[141] define HRQOL as "the physical, psychological, and social domains of health…influenced by a person's experiences, beliefs, expectation, and perceptions." Of all of the aspects of a patient's health, the physical aspects are often highlighted more than either mental or emotional health, which is unfortunate because all aspects have the potential of influencing an individual's HRQOL. This is especially true when dealing with the distinct healthcare needs of an athletic population, and even more apparent in those participating in high school athletics.

2.62 Generic Patient-Based Measures

HRQOL is measured through the use of generic patient-based outcomes, which are instruments or scales that a patient completes concerning his/her health status.

Generic scales provide a broad view of a patient's health status, are applicable to a variety of patient populations, injuries, or conditions, and allow for comparisons between the HRQOL of different groups. A commonly used generic measure is the Medical Outcomes 36-Item Short Form Health Survey (SF-36). The SF-36 has been used in individuals as young as 14 years of age but is more frequently utilized in an adult population.[142] A shortened version of the SF-36 called the SF-12 was created for ease of use in large-scale health measurement and monitoring.[143] The SF-12 consists of twelve questions and takes approximately two-three minutes to complete. It measures eight domains of health: physical function, role physical, bodily pain, general health, vitality, social function, role emotional and mental health. Responses are evaluated through Likert-style questions and a score ranging from 0-100 is given, with a higher score indicating higher HRQOL.

2.63 Specific Outcome Measures

Along with generic measures of overall patient HRQOL there are also disease and joint specific outcome measures that are able to allow a clinician a better picture of how a disease or injury is affecting a patient. The Knee Injury and Osteoarthritis Outcome Score (KOOS) is a self-administered measure of knee HRQOL.[144] It assesses five health outcomes; pain, symptoms, activities of daily living, sports and recreation function, and quality of life. Previous research has shown that patients who experienced bilateral ACL injuries reported lower scores for pain, sports and recreation and quality of life.[145] Another example of a joint specific outcome measure is the International Knee Documentation Committee (IKDC) Subjective Knee Form. It assesses the patient's

symptoms and functions in activities of daily living and is validated for use in a range of knee injury and disorders.[146]

2.64 Summary of Patient-Oriented Outcomes

Patient oriented outcomes can be another tool in a clinician's toolbox as they offer information that is meaningful to the patient that can supplement clinical tests and observations to give a more complete picture of the patient's health.

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MANSCRIPT I

Effects of a Shortened Duration Injury Prevention Program on Movement Technique in Female Adolescent Athletes

(American Journal of Sports Medicine)

ABSTRACT

Background: Injury prevention programs (IPP) decrease lower extremity injury rates and improve movement-based risk factors, but many coaches and players do not adopt these programs. The time required for these programs is frequently reported as a barrier to program adoption. It is not known if a shorter duration IPP can improve movement technique in a manner thought to reduce the risk of injury.

Purpose: To examine if a shorter duration IPP is able to elicit improvements in movement technique similar to the F11+ program in female, high school athletes. A secondary aim was to assess high-risk (LESS ≥ 5) participants' response to the intervention.

Study Design: Randomized controlled clinical trial

Methods: Seventy-six healthy, female athletes (Age=15±1 y, Mass: 59.9±10.4 kg, Height: 166.4±6.3 cm) (Field Hockey=21, Soccer=31, Volleyball=24). Participants were stratified by team and randomized into one of three warm-up interventions: Focused (N=25), F11+ (N= 24) or Control (N=27). Participants completed a test session before and after their 2014 Fall season (8-10 weeks). At each session they performed three trials of a jump-landing task. Each jump was scored using the Landing Error Scoring System (LESS). All participants performed their assigned warm-up program prior to sport practices. Separate 3x2 mixed model ANOVA or analysis of covariance (ANCOVA) tests for each dependent variable were used to evaluate differences between groups or test sessions.

Results: Participants improved their overall LESS scores (P=.002) regardless of group. High-risk participants reduced their LESS scores by nearly 2 errors (PRE: 7.00 ± 1.24, POST 5.06 ±1.74, P<.001).

Conclusions: All warm-up groups were able to decrease their risk of lower extremity injury as they improved their LESS scores. Participants with a LESS score ≥ 5 responded better as they had more to improve and should be a focus of clinicians implementing IPPs.

Key Words: jump-landing, injury prevention

Word Count: 293

INTRODUCTION

Exercise-based injury prevention programs (IPP) utilize sport-specific tasks to improve neuromuscular control, such as movement quality,[1,2] and decrease the risk of lower extremity injury.[3-5] Despite their success, less than 20% of high school coaches implement these programs even with high risk female athletes.[6,7] This poor adoption does not appear to be related to lack of knowledge about the positive benefits associated with injury prevention programs.[6,8] Instead, coaches frequently report that programs are too long,[6,7,9] are not necessary for their particular team,[6] or are too complicated.[6] Player and coach compliance are integral pieces in determining the success of an IPP because if a program is not performed as prescribed an athlete is unlikely to reap the benefits.[10,11]

In order to be successful, an IPP must be comprised of several exercise components. A recent systematic review reported that the use of multifaceted neuromuscular training programs consisting of stretching, proprioception, strength, plyometric and agility drills in addition to verbal and/or visual feedback on proper landing technique decrease the rate of anterior cruciate ligament (ACL) injuries in female athletes participating in team sports.[12] The most widely researched IPP is the FIFA 11+ (F11+). The F11+ was developed with soccer's governing body (FIFA) to prevent common soccer injuries. It consists of 15 exercises, divided into three parts including initial and final running exercises with a focus on cutting, jumping and landing techniques and strength, plyometrics, agility and field balance components.[13] In a study of female adolescent soccer players, the F11+ decreased the risk of overall injury by approximately 30% and the risk of severe injuries by as much as one half.[10] Despite these benefits, this program is still associated with poor compliance.[14-16]

The few coaches that do choose to adopt the programs frequently report modifying the original design to make the programs shorter.[9] Programs that have been shown to reduce injury rates and modifying neuromuscular control typically require at least twenty minutes of time per session to perform.[14,17,18] [19]Changing the program may interfere with program fidelity and result in poor outcomes. Studying if a shorter injury prevention program can yield equivalent results as longer programs with success in injury prevention could improve compliance and adherence.

The primary purpose of this study was to compare the effects of a multifaceted, shortened duration IPP, F11+ and a dynamic warm-up on movement control, as measured by the Landing Error Scoring System (LESS), three-dimensional hip and knee kinematics and peak vertical ground reaction force. All programs were performed over the course of the Fall interscholastic season. We hypothesized the F11+ and shortened program would result in similar effects, but greater than the effects associated with the dynamic warm-up program.

Athletes with risky movement patterns may demonstrate greater improvements in movement technique after exposure to an IPP as they have more room to improve. Using amount of knee abduction moment as a screening tool, Myer et al.[20] examined the effects of an IPP on individuals classified as high or low-risk and found that high-risk individuals responded better to the IPP. DiStefano et al.[21] reported a similar response in youth athletes participating in an IPP, players with a higher Landing Error Scoring System (LESS) movement score improved the after the intervention. Therefore, a secondary aim was to examine how participants with a “high-risk” LESS score, defined as a LESS ≥ 5, respond to the warm-up interventions.

METHODS

Design

We used a randomized controlled trial study design to compare the effects of a shortened duration IPP (Focused), the F11+ IPP, and an active control program (Dynamic) in high school female athletes. Participants completed two test sessions that evaluated their movement technique during a jump-landing task before (PRE) and after (POST) the season-long intervention (8-10 weeks). Participants completed the Knee Injury and Osteoarthritis Outcome Score (KOOS) survey at the beginning of the PRE.[22] After the first test session, participants were stratified by team (sport and level (Freshmen/JV/Varsity)) (e.g. Freshmen soccer) and their score on the function, sport and recreational activities (Sport/Rec) subscale of the KOOS and then randomized into one of three warm-up groups: Focused, F11+, or Dynamic. The KOOS is a patient-centered outcome measure that captures how a patient's knee may affect his or her life. We chose to use the Sport/Rec subscale as it is one the most sensitive and responsive subscales.[22] The average Sport/Rec subscale score for all participants was 90.6. Two participants fell more than 2 standard deviations away from 90.6 and they were placed into separate warm-up groups to keep the groups balanced.

Participants

Participants were recruited from female interscholastic teams at a local high school at high risk for sustaining a lower extremity injury. Seventy-six female athletes (n=21 field hockey players, 31 soccer players, 24 volleyball players; Age: 15 ± 1 yrs. Mass: 59.9 ± 10.4 kg, Height: 166.4 ± 6.3 cm) volunteered to participate in the study. All participants were free from injury that precluded them from athletic participation at each

test session. The study was approved by the university's Institutional Review Board and informed assent and consent was obtained from participants and their legal guardians, respectively.

Procedures

Participants wore a t-shirt, shorts, and athletic shoes to each test session (PRE, POST). The participants' height and mass were measured by a female research assistant and the participants' dominant limb was recorded (limb used to kick a ball for maximal distance) at the beginning of each test session. Participants completed the KOOS and a baseline health questionnaire prior to the PRE test session.

Participants performed three trials of a standardized jump-landing task. Two digital cameras (Canon FS400, Canon U.S.A. Inc., Lake Success, NY, USA) were placed in front of and to the side of the participants and captured both frontal and sagittal plane images of the jump-landing task. An electromagnetic motion analysis system (Trakstar; Ascension Technologies, Inc., Burlington, VT) synchronized with the force plate and controlled by Motion Monitor software (Innovative Sports Training, Inc.; Chicago, IL) measured three-dimensional lower extremity kinematics and kinetics at sampling frequencies of 150 Hz and 1500 Hz, respectively. Prior to completion of the jump-landing task, three electromagnetic sensors were placed and secured with double-sided tape on the participants' anteromedial tibia, distal lateral thigh, and sacrum. The medial and lateral femoral epicondyles, medial and lateral malleoli and bilateral ASIS were digitized using a stylus with a fourth sensor attached.[23]

Participants began the jump-landing task standing on a box 30-cm high and jumped forward, not vertically, from the box a distance of half the participant's body

height. Participants were instructed to land with their dominant foot in the center of a non-conductive force plate (model 4060-NC; Bertec Corporation, Columbus, OH) and immediately jump for maximum vertical height upon landing (Figure 1). Participants completed one practice jump and three trials. Participants were allowed as many familiarization trials as needed to ensure they could perform the task correctly and comfortably.

Program Implementation

Each of the three groups (Focused, F11+, Dynamic) performed their respective program prior to team practices for the duration of each team's fall season. Two research assistants who were athletic trainers, athletic training students or physical therapy students were assigned to each group and implemented the programs at a general location (track on campus) or at the team's practice location. Attendance was taken at each implementation session.

The **Focused program** was a ten-minute IPP based on previously published programs and consisted of flexibility, core, agility, plyometric, strengthening, and balance exercises. The Focused program incorporated exercises in three planes of motion (sagittal, frontal, and transverse) and involved cues, instruction, and feedback for correcting movement (i.e. "Bend your knees", "Keep your knees over your toes", "Keep your toes pointed straight ahead", "Hips square"). A progression to Phase 2 occurred at the halfway point of the season (approximately four weeks). The **F11+** program is a twenty-minute program developed to prevent lower extremity injuries in soccer players. The F11+ program progressed to Phase 2 at the same point in the season as the Focused program. The **Dynamic program** was a ten-minute dynamic

warm-up consisting of movements similar to what the teams were currently performing before practice: i.e. high knees, inchworms, butt kicks, and lunges.

Injury Reporting

The high school's athletic trainer was asked to record any injuries that occurred as a result of physical activity and restricted a participant from participating in her sport. Once a week during the study a member of the research team gathered injury information recorded for athletes who were participants in the study. The information included: mechanism of injury and type of injury sustained, but was not complete for every athlete. The data were checked against the abbreviated Injury History Questionnaire given at the post-test session.

Data Reduction and Analyses

The videos of the jump-landing task were scored using the Landing Error Scoring System (LESS) by a single rater blinded to group. The LESS is a valid and reliable clinical movement analysis tool that predicts ACL injury in youth soccer athletes.[24,25] The LESS evaluates the number of errors made during the jump-landing task with a high LESS score indicating more errors and greater injury risk than a low score. The average total LESS score was calculated from the three trials. Individual errors on the LESS were analyzed in order to examine which errors were improved or not improved after the programs. An individual error was determined as present if the participant demonstrated the error in at least two out of three trials. Participants were coded as "improved" if they exhibited the error at PRE, but not at POST. Participants were coded as "not improved" if they exhibited the landing error at both test sessions. There were a small number of participants who exhibited errors at POST that they did not

demonstrate at PRE.

Kinematics and Kinetics

Three-dimensional coordinates of the lower extremity were estimated using MotionMonitor software (Innovative Sports Technology, Chicago, IL). Joint angles were calculated using the MotionMonitor software as Euler angles rotated in a flexion/extension (x-axis), adduction (varus) / abduction (valgus) (y-axis), internal/external rotation (z-axis) sequence. Using standard inverse dynamics 3-dimensional hip and knee internal joint moments were calculated. All kinematic data were filtered with a fourth-order low-pass Butterworth filter at 14.5 Hz. Kinematic and vertical ground reaction force (VGRF) data were reduced using a customized software program to determine three-dimensional knee and hip joint angles at initial contact, as well as peak joint angles and VGRF. Peak values of each dependent variable were determined during the first 50% of the stance phase of the jump-landing task (deceleration phase). Stance phase was defined as the time from initial ground contact (VGRF>10N) to toe-off (VGRF<10N). Peak VGRF was normalized to body weight (N) for each participant (% body weight). The average across the trials was calculated for each dependent variable.

The exposure of each participant was calculated from the attendance log taken of the research assistants implementing the program each day. Compliance was calculated by dividing the number of sessions attended by the number of sessions an athlete had the potential to attend. Sessions missed due to injury or receiving treatment from the athletic trainer were not considered potentially attended sessions.

We used separate one-way analysis of variance (ANOVA) tests to evaluate any

group differences for each dependent variable or, age, height, mass, compliance and exposures at PRE. We conducted separate 3x2 mixed model ANOVA or analysis of covariance (ANCOVA) tests for each dependent variable to evaluate any differences between groups (Group: Focused, F11+, Dynamic) or test sessions (PRE, POST). Values at PRE were used as covariates when group differences existed on the PRE data. As a LESS score of 5 or greater is considered to increase the risk for an ACL injury[25], we performed a secondary analysis utilizing an analysis of variance (ANOVA) to examine how High-Risk (PRE LESS≥5) participants responded to the programs. A binomial proportion test (test proportion=0.5) was used to evaluate if individual items on the LESS improved from PRE to POST regardless of group (test proportion =0.50). All data were analyzed using SPSS (version 21.0, SPSS Inc., Chicago, Illinois) with an a-priori α level of significance of 0.05.

RESULTS

There were no differences between warm-up groups for height (P= .69), mass (P= .14), and age (P= .48) at baseline (Table 1). Sixty-two of the 76 participants completed the POST testing session (Focused: n=19/25 (76%), F11+: n=18/24 (75%), Dynamic: n=25/27 (93%)) (Figure 2). No participant sustained an injury while performing the IPP, but seven injuries (two concussions, one upper extremity injury, four lower extremity injuries) occurred over the intervention period. The lower extremities injuries by warm-up group were: (Focused=1; metatarsal stress fracture, F11+=1; lateral ankle sprain, Dynamic= 2; ankle fracture, knee sprain).

Participants had a median of 13 exposures (Range: 2-19) to programs. No significant differences were observed for the groups: Focused = 13 (3-17), F11+ =14 (3-

16), Dynamic = 12 (2-18) for exposure. Moderate compliance was observed overall and there were no significant differences for the warm-up groups; Median= 64% (10-95%) and for each group Focused= 69% (18-93%), F11+ = 73% (18-63%), Dynamic = 64% (11-95%).

LESS

Fifty-six (74%) participants had complete LESS score data available for analysis (Focused: n=18, F11+: n=15, Dynamic: n= 23). On average participants improved their LESS score from PRE (5.4 ± 1.9) to POST (4.3 ±1.4) (P=.002), but there were no significant differences in improvement observed between warm-up groups (P=0.32) (Table 2). Figure 3 depicts all participants LESS scores at PRE and POST. Binomial proportion tests demonstrated that the “Asymmetrical Contact” error was the only individual LESS error to significantly improve for all the groups (P=0.002)(Table 6).

Kinematics and Kinetics

Thirty-six participants had both PRE and POST kinematic and VGRF data and were included in the analyses (Focused: n=12, F11+ n=10, Dynamic n=14). There was one significant interaction at initial contact, the F11+ group exhibited significantly more hip internal rotation at initial contact at POST (P=.03) than the Focused or Dynamic groups (Table 3). All participants, regardless of group, landed with more knee external rotation (P=.001) and hip internal rotation (P=.003) at initial contact at POST compared to PRE. At POST all groups demonstrated less peak knee valgus (P=.003), greater peak external knee rotation (P=.003), and greater peak internal hip rotation (P=.01) during the deceleration phase of the jump-landing task(Table 4). No significant differences were observed in peak VGRF (Table 5).

High-Risk Analysis

Twenty-one of 76 participants had a LESS score of 5 or higher at PRE and were included in secondary LESS analyses. Median exposures for the high-risk participants was 13 $\pm$ 3.5 (Range=5-18) and median compliance was 64% $\pm$ 22 (Range=10-95%). High-risk participants reduced their LESS scores by nearly 2 errors (PRE: 7.00 $\pm$ 1.24, POST 5.06 $\pm$1.74, P<.001).

DISCUSSION

This study is unique as it is the first to examine for potential mechanistic changes in movement technique of the F11+ and compare the F11+ to a shortened neuromuscular training program. The most important finding from this study is that the shortened program yielded equivalent results as the longer duration, previously studied F11+ injury prevention program. Since coaches frequently report time as a barrier to program adoption and compliance, this finding may improve future implementation success. Further research is necessary to evaluate if the shortened program can also result in similar reductions in injury rates as the F11+, but was beyond the scope of the current study.

We observed lower LESS scores over the course of the season regardless of group assignment suggesting all participants reduced their risk for lower extremity injury.[25] As all of the warm-up groups improved their LESS scores it is possible that the improvements in movement technique are due to the natural effects of a season. Previous research made comparisons to passive control (group warms-up as they usually do) during an IPP warm-up intervention with female adolescent basketball players.[26] Lim et al.[26] found that the control did not exhibit improvements in strength,

flexibility, and sagittal plane motion that the IPP group demonstrated. In addition, other studies demonstrate that kinematics, evaluated through the LESS,[22] and VGRF are stable across time in physically active females. [27-30] Therefore, the changes observed in the current study are likely due to the effects of the intervention and not from the season, alone.

The similar nature of exercises in each program may have influenced the overall improvements observed even though each program had unique elements. Both the F11+ and the Focused program included specific cues, instruction and feedback designed to improve overall movement quality, and thus injury risk. While the Dynamic warm-up did not include these verbal inputs, it is possible that the exercises themselves in addition to the instruction to perform the Dynamic exercises correctly led to the improvements in movement observed. Similar to our findings, Klugman et al.[31] compared an active control to an IPP and also observed consistent improvements in movement quality, as measured by the tuck-jump score. Further research is needed to investigate if dynamic warm-ups can lead to similar protective effects in injury rates as formal “injury prevention programs”.

Participants who were deemed “high-risk” due to their LESS scores at PRE improved the most in both LESS score and kinematics. High-risk participants’ LESS scores improved almost 2 errors. This finding is similar to that of DiStefano et al.[21] in which high-risk participants improved their LESS scores after an IPP intervention. We did not expect to see the Dynamic warm-up group improve their LESS score as the program did not include plyometrics or feedback, which are both thought to be necessary to see changes in movement technique.[32] The program did, however, include

aspects of balance, strengthening, and stretching which are hallmarks of neuromuscular training programs. As all programs improved, we are unable to identify a mechanistic explanation for improvements in movement technique.

Participants improved their LESS scores at the end of the intervention but the greatest improvement was with the “Asymmetrical Contact” error. The majority of participants (77%) who landed with one foot before the either or with their heel first no longer displayed the error at post-testing. This improvement of landing technique is noteworthy as landing with one foot before the other can cause an athlete to shift their weight towards the leg that lands first, which is a movement very similar to the mechanism of many non-contact ACL injuries.[33-35]

Despite seeing improvements in LESS score we did not see substantial changes in participants’ landing kinematics or vertical ground reaction forces. It is important to note that the LESS is binary in nature and looks at global movement as opposed to discrete variables. Although there were no differences in kinematics between groups, all participants exhibited decreased peak knee valgus angle during the deceleration phase of the jump-landing. Myer et al.[27] and Chappell and Limpisvasti[2] utilized neuromuscular training programs with female athletes but only the intervention groups decreased their peak knee valgus, which is dissimilar from our findings. Knee external rotation and hip internal rotation are likely the same motion and are the result of a relatively more internally rotated hip. This motion may reduce overall displacement and rotation velocity occurring at the hip and knee thus placing less stress on the joints.

We also observed a trend (P= .06) of greater knee flexion during the deceleration phase of the jump-landing task at POST. This trend indicates that

participants are going through more knee flexion as they land from a jump than they displayed at PRE. Increased sagittal plane motion allows the body to dissipate the forces incurred during landing across the joints. The LESS error of "Knee Flexion Displacement" was eliminated at POST and may have been driven by the high-risk participants exhibiting significantly more knee flexion during deceleration at POST. These findings collectively with the reduced knee valgus are similar to those of Ortiz et al.[36] who reported that female adolescent soccer players demonstrated increased knee flexion and reduced knee valgus angles during a drop jump task after an IPP intervention. Together, these findings may help to explain part of the reduced injury risk observed with neuromuscular IPPs.

Compliance and adherence are critical to the success of an IPP. Soligard et al.[37] implemented the F11+ with a large cohort of female adolescent soccer players and found that players with high compliance had 35% lower injury risk than players with intermediate compliance. Our rate of compliance was higher than the average reported in the literature,[38] but our number of exposures may have been too small to change a specific dependent variable, such as vertical ground reaction forces. Our median exposure per athlete was 13 over an 8-10 week period and likely not enough to changes in movement technique. In a recent meta-analysis Sugimoto et al.[39] reported that there is a session dosage for IPPs that must be met before benefits are realized in the form of decreased injury rates. There was a large range reported but it was stated that about 70% of ACL injuries were avoided if preventative neuromuscular training was performed a total of more than 30 min per week during the in-season. The coaching staffs did not mandate participation in the warm-ups, but participants were strongly

encouraged to attend. In order to ensure that participants received as many warm-up sessions as possible research assistants accommodated changes in practice schedules as much as possible. Measures were also taken to speak to each team's captain to encourage their attendance at warm-up sessions as the team often followed their lead. This range is compliance is likely reflective of overall compliance of high school female athletes as a whole and should be a future aspect focused on in IPP research.

This study has several limitations. We were unable to blind the participants to the content of the other warm-ups as the warm-ups occurred at central locations. Although measures were taken to spread participants out across fields or courts, participants may have been influenced by what they observed in other warm-ups. While the range of LESS scores at PRE testing was wide, it is possible that the athletes in this study did not exhibit a large number of risky movements. Research has shown that athletes with the most risk show the most improvement during neuromuscular training.

CONCLUSION

Injury prevention programs used as a warm-up are able to improve the movement technique and decrease injury risk in female adolescent athletes as seen by a decrease in LESS score. It may be that athletes need to engage in a structured warm-up that consists of stretching, proprioception, strength, plyometric and agility drills in order to improve their movement technique. As a shortened duration neuromuscular training program was able to elicit movement technique benefits similar to the longer IPP, shorter programs should be utilized as a method to increase the buy in and potential adoption of IPPs with high school coaches.

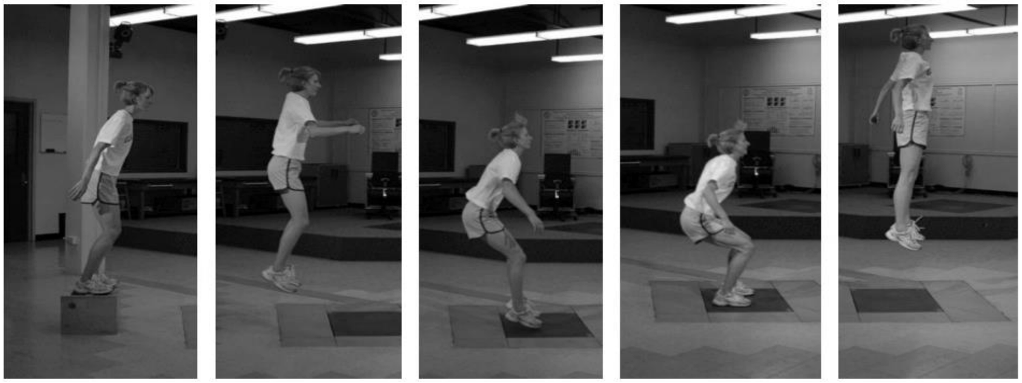

Figure 1. Jump-landing task

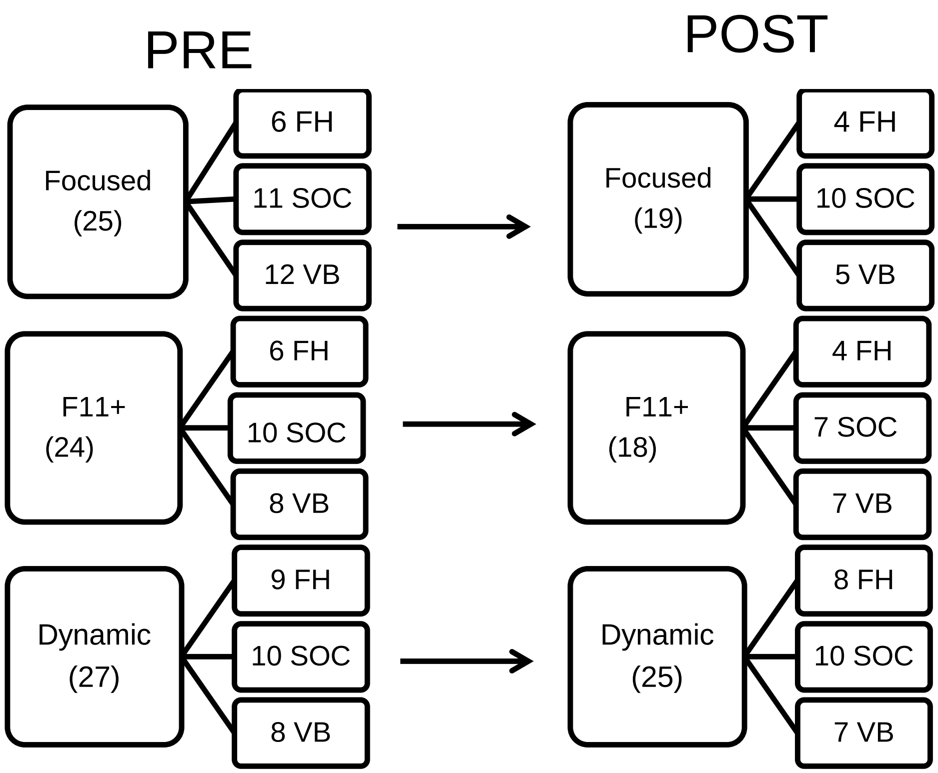

Figure 2. Distribution of Sport Between Warm-up Groups

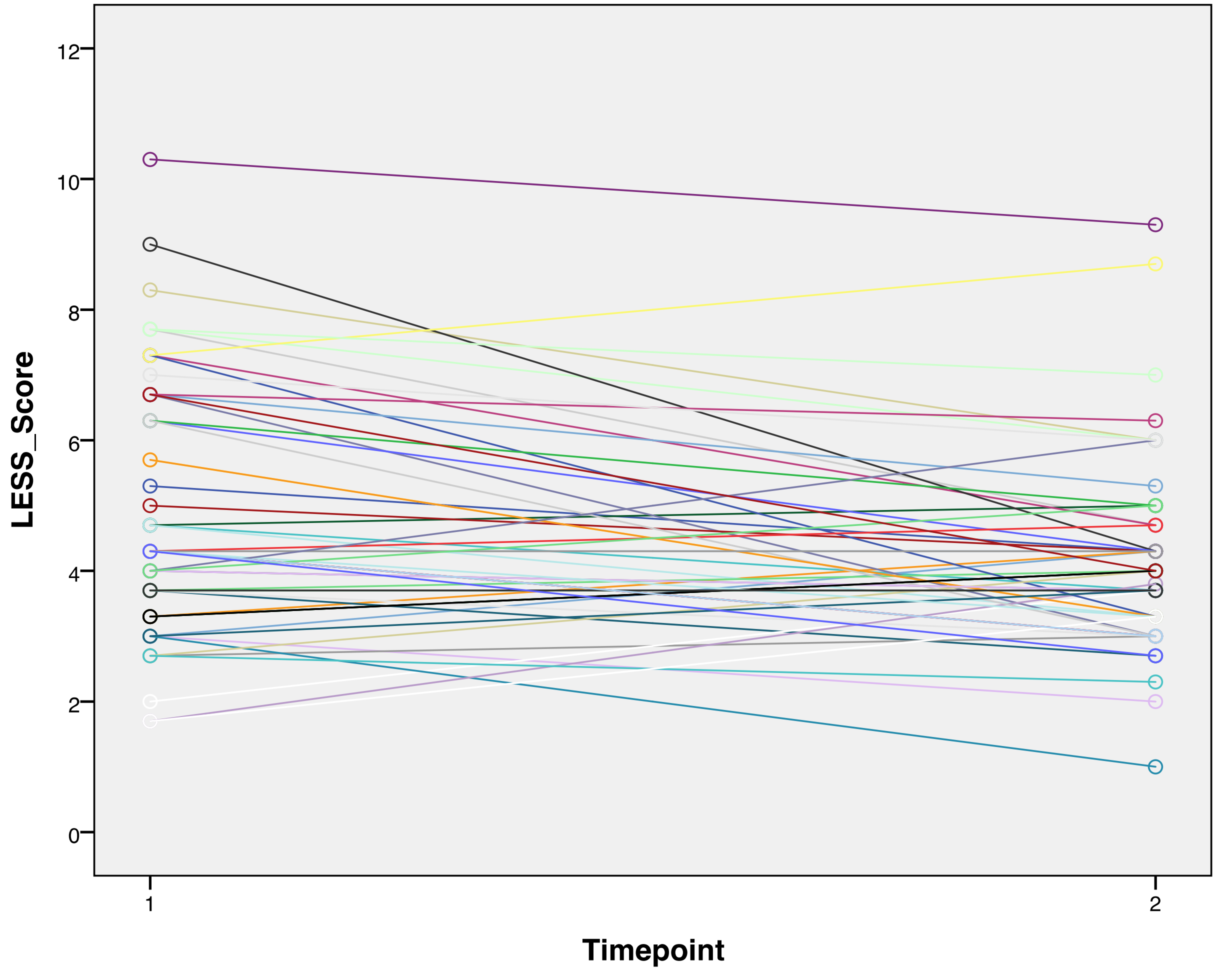

Figure 3. Participants' LESS Scores PRE to POST

Table 1. Participant Demographics By Warm-Up Group [Mean (SD)]

Group (n)	Age (years)	Height (cm)	Mass (kg)	KOOS(Sport/Rec)
Focused (25)	15 ± 1	165.4 ± 6.4	56.3 ± 7.5	89.2 ± 14.1
F11+ (24)	14 ± 1	166.3 ± 7.3	60.1 ± 9.4	94.2 ± 11.5
Dynamic (27)	15 ± 1	167.4 ± 5.3	63.0 ± 12.7	89.8 ± 11.6

Table 2. Average LESS Scores by Warm-up Group (Mean ± SD)

Program	PRE	POST	F	P
Focused	4.9 ± 2.1	4.3 ± 1.9	1.18	.32
F11+	5.4 ± 1.7	4.6 ± 0.8		
Dynamic	4.5 ± 2.0	3.9 ± 1.5		

Table 3. Kinematic Variables (º) at Initial Contact During the Jump Landing Task

Variable	Group	PRE	95% CI	POST	95% CI	F	P
Knee Flexion	Focused	12.14 ± 6.27	(8.03,16.26)	10.77 ± 6.24	(5.64,15.89)	1.24	.30
	F11+	13.60 ± 7.20	(9.10,18.11)	15.04 ± 9.49	(9.42, 20.65)		
	Dynamic	10.93 ± 7.45	(7.12, 14.74)	10.93 ± 7.45	(4.63, 14.12)		
Knee Valgus	Focused	1.89 ± 3.84	(-0.44, 4.22)	1.18 ± 5.24	(-1.72, 4.08)	0.13	.88
	F11+	2.55 ± 5.17	(0.003, 5.11)	-0.45 ± 5.12	(-3.63, 2.72)		
	Dynamic	1.71 ± 3.00	(-0.44, 3.87)	-0.01 ± 4.51	(-2.69, 2.68)		
Knee External Rotation	Focused	5.37 ± 7.56	(1.56, 9.18)	8.72 ± 9.20	(3.95, 13.49)	2.31	.12
	F11+	-1.73 ± 7.04	(-5.90,2.45)	9.36 ± 8.51	(4.13, 14.58)		
	Dynamic	0.75 ± 4.90	(-2.78, 4.28)	4.52 ± 6.76	(0.10, 8.93)		
Hip Flexion	Focused	24.23 ± 9.05	(19.00, 29.46)	23.07 ± 5.29	(17.35, 28.80)	1.1	.35
	F11+	28.90 ± 6.57	(23.18, 34.63)	27.04 ± 9.07	(20.77, 33.31)		
	Dynamic	27.28 ± 10.11	(22.44, 32.12)	23.66 ± 12.66	(18.36, 28.96)		
Hip Adduction	Focused	8.50 ± 8.90	(3.67, 13.34)	5.33 ± 5.50	(1.81, 8.84)	0.05	.95
	F11+	9.13 ± 8.08	(4.06, 14.20)	5.65 ± 4.15	(1.96, 9.33)		
	Dynamic	7.38 ± 6.83	(3.10, 11.67)	6.32 ± 6.74	(3.20, 9.43)		
Hip External Rotation	Focused	7.99 ± 10.23	(0.73, 15.25)	1.97 ± 6.61	(-4.51, 8.46)	3.79	.03*
	F11+	-0.81 ± 12.64	(-8.76, 7.13)	-8.63 ± 10.16	(-15.73, 1.52)		
	Dynamic	9.04 ± 13.73	(2.32, 15.76)	2.43 ± 14.17	(-3.57, 8.43)		

*= $\alpha<.05$

Table 4. Kinematic Variables (º) During the Deceleration Phase of the Jump Landing Task

Variable (Peak)	Group	Pre Test	95% CI	Post Test	95% CI	F	P
Knee Flexion	Focused	85.71 ± 14.79	(77.00, 94.42)	86.67 ± 8.07	(77.87, 95.47)	0.84	.44
	F11+	80.78 ± 15.36	(71.24, 90.31)	85.59 ± 17.00	(75.95, 95.24)		
	Dynamic	88.08 ± 14.47	(80.02, 96.14)	92.89 ± 17.75	(84.74, 101.04)		
Knee Valgus	Focused	8.61 ± 6.70	(4.25, 12.98)	5.54 ± 8.54	(0.96, 10.12)	1.01	.37
	F11+	6.65 ± 6.39	(1.61, 11.69)	1.07 ± 6.22	(-4.22, 6.36)		
	Dynamic	10.74 ± 8.52	(6.70, 14.78)	3.78 ± 7.98	(-0.46, 8.01)		
Int. Knee Rotation	Focused	5.54 ± 9.63	(1.21, 9.88)	1.64 ± 7.77	(-3.11, 6.39)	2.84	.07
	F11+	12.09 ± 5.81	(7.34, 16.84)	6.80 ± 7.59	(1.60, 12.00)		
	Dynamic	7.99 ± 6.04	(3.98, 12.00)	8.18 ± 8.65	(3.79, 12.58)		
Ext. Knee Rotation	Focused	0.27 ± 8.81	(-4.38, 4.92)	8.58 ± 8.00	(2.84, 14.32)	0.46	.64
	F11+	4.38 ± 5.69	(-0.05,8.81)	9.05 ± 10.85	(3.58, 14.53)		
	Dynamic	4.05 ± 6.94	(0.20, 8.29)	9.16 ± 7.48	(3.92, 14.40)		
Hip Flexion	Focused	70.19 ± 17.39	(60.14, 80.24)	68.04 ± 11.18	(57.52,78.56)	1.11	.34
	F11+	58.83 ± 16.63	(47.82, 69.84)	60.54 ± 21.74	(49.02, 72.07)		
	Dynamic	74.89 ± 17.21	(65.59, 84.20)	78.67 ± 19.53	(68.93, 88.41)		
Hip Adduction	Focused	5.02 ± 9.21	(0.14,9.90)	1.57 ± 6.86	(-2.50, 5.64)	0.01	.99
	F11+	5.59 ± 7.41	(0.47, 10.71)	1.73 ± 3.23	(-2.54, 6.01)		
	Dynamic	4.09 ± 7.22	(-0.23, 8.42)	3.03 ± 8.05	(-0.58, 6.64)		
Int. Hip Rotation	Focused	6.49 ± 8.72	(-0.08, 13.07)	6.34 ± 9.14	(1.14, 13.82)	0.48	.62
	F11+	4.95 ± 13.87	(-2.26, 12.15)	14.75 ± 11.48	(6.56, 22.94)		
	Dynamic	1.27 ± 10.99	(-4.82, 7.36)	11.57 ± 15.79	(4.64, 18.49)		
Ext. Hip Rotation	Focused	2.25 ± 6.85	(-4.34, 8.84)	0.76 ± 8.90	(-6.69, 8.20)	0.83	.44
	F11+	7.21 ± 15. 75	(0.33, 14.09)	-1.23 ± 15.77	(-9.01, 6.55)		
	Dynamic	10.71 ± 9.97	(4.61, 16.81)	2.25 ± 12.76	(-4.64, 9.15)		

Table 5. Peak Vertical Ground Reaction Force During Jump-Landing Task (Mean ± SD)

Variable	Group	PRE	95% CI	POST	95% CI	F	P
Peak VGRF	Focused	1.32 ± 0.22	(1.21,1.44)	1.25 ± 0.26	(1.14, 1.37)	1.58	.22
	F11+	1.42 ± 0.29	(1.31, 1.54)	1.39 ± 0.26	(1.27, 1.50)		
	Dynamic	1.32 ± 0.18	(1.22, 1.43)	1.29 ± 0.17	(1.18, 1.40)		

Table 6. LESS Items for All Participants PRE to POST

Landing Error	# With Error at PRE	Improved	Not Improved	Level of Significance
Knee flexion at initial contact	5	4 (80%)	1 (20%)	.38
Trunk flexion at initial contact	4	3 (75%)	1 (25%)	.63
Heel Toe	3	1 (33%)	2 (67%)	1.00
Asymmetrical contact	22	17 (77%)	5 (23%)	.02*
Lateral trunk flexion at initial contact	7	4 (57%)	3 (43%)	1.00
Medial knee displacement at initial contact	15	5 (33%)	10 (67%)	.30
Wide	5	1 (20%)	4 (80%)	.38
Narrow	14	3 (21%)	11 (79%)	.06
Feet external rotation	11	4 (36%)	7 (64%)	.55
Knee flexion displacement	5	5 (100%)	0	.06
Trunk flexion displacement	18	9 (50%)	9 (50%)	1.00
Excess trunk flexion displacement	4	2 (50%)	2 (50%)	1.00
Medial knee displacement	33	2 (6%)	31 (94%)	<.001*

Test proportion =0.50

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MANUSCRIPT II

Effects of a Shortened Duration Injury Prevention Program on Measures of Functional Performance in Female Adolescent Athlete Population (Journal of Strength & Conditioning Research)

ABSTRACT

The purpose of this study was to examine if a shorter duration injury prevention program (IPP) elicits improvements in power, agility and balance equivalent to, or greater than, a well-researched lower extremity IPP in female, adolescent athletes. A secondary aim was to examine if female, adolescent athletes with "high risk" Landing Error Scoring System (LESS) scores improve on measures of functional performance. Subjects were recruited from female interscholastic soccer, field hockey, and volleyball teams at a local high school. Seventy-six female athletes (Age= 15 ± 1 y, Mass: 59.9 ± 10.4 kg, Height: 166.4 ± 6.3 cm) (Field Hockey n=21, Soccer n=31, Volleyball n=24) were stratified by team (sport, level: Freshmen, JV, Varsity) and score on the Knee Injury and Osteoarthritis Outcome Score (KOOS)) and then randomized into one of three warm-up interventions that were conducted prior to practice during their Fall season. Subjects were tested before and after their season using a standing long jump, the Edgren Side Step Test (ESST) and the Y Balance Test in the anterior, posteromedial and posterolateral directions. Separate 2 (Time: PRE, POST) x 3 (Group: Focused, F11+, and Dynamic) mixed model univariate ANOVA tests were performed for long jump, ESST and the composite score of the Y Balance. No significant differences were observed in the standing long jump, ESST, and Y Balance Test for both all subjects and high-risk subjects. The performance benefits of a shortened duration IPP are equivalent to a well-researched IPP in performance in female, adolescent athletes.

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INTRODUCTION

Injury prevention programs (IPPs) decrease the risk of lower extremity injury,[1,2] particularly injuries to the anterior cruciate ligament.[3] Coaches and team administrators have indicated that injury prevention is a priority but, this is not reflected in the implementation and adoption of IPPs.[4,5] Less than 20% of high-risk girls sport coaches report implementing IPPs with their teams.[6,7] One of the barriers to adoption of injury prevention programs is time. Coaches implementing IPPs have reported that they run out of time trying to finish the exercises in the program and often modify the program which may impact program fidelity[2,7,8]. When exercises are cut out of an IPP, potential gains from the program may be limited. A possible solution to this adoption and implementation barrier is a shorter IPP, however research is limited about the effectiveness of this alternative.

Besides shortening the duration of the IPP, demonstrating improvements in athletic performance may also help to overcome implementation barriers and increase coach buy-in to IPP adoption. It is important to consider coaches as key stakeholders in IPP implementation as their attitudes towards the programs can affect their players' compliance.[9,10] Improvements in functional performance could be crucial in increasing buy-in from coaches and players but does not solve the barrier of not having enough time to perform the program. Previously studied programs that are performed correctly and with good compliance can improve measures of performance such as vertical jump, sprint time and hop distance.[11,12] However, it is unknown if a shortened duration IPP can elicit similar performance benefits as those illustrated in previous IPPs.[13,14]

The purpose of this study was to evaluate the effects of a shortened duration IPP on measures of functional performance in female, adolescent athletes. We hypothesized that the shortened duration IPP would result in equivalent functional performance benefits to a proven well-researched IPP. Previous research indicates that athletes with risky movement patterns experience greater improvements in movement technique and greater reduction of risk factors after exposure to an IPP as they have more room to improve.[15,16] Athletes with risky movement patterns are able to improve their movement after an IPP but it is not known if they also improve more on measures of performance. Therefore, a secondary purpose was to examine if female, adolescent athletes with high-risk Landing Error Scoring System (LESS) scores improve on measures of functional performance.

METHODS

Experimental Approach to the Problem

This study was designed to observe if the use of three warm-ups (Focused, F11+, and Dynamic) over an 8-10 week interscholastic sport season resulted in improvement in functional measures of performance. The warm-up intervention took place during the Fall 2014 scholastic athletic season and continued until the end of a team's season or post-season. We utilized a stratified, randomized controlled trial study design to compare the two IPPS (Focused and F11+) with an active control group (Dynamic) and each other.

Subjects

Subjects were recruited from female interscholastic soccer, field hockey, and volleyball teams at a local high school. Seventy-six female athletes (Age= 15 ± 1 y,

Mass: 59.9 ± 10.4 kg, Height: 166.4 ± 6.3 cm) (Field Hockey n=21, Soccer n=31, Volleyball n=24) volunteered to participate in the study. All athletes were free from injury that precluded them from athletic participation at the time of both test sessions. This study was approved by the university's Institutional Review Board and all parents and subjects provided consent and informed assent, respectively.

Procedures

Subjects wore a t-shirt, shorts, and athletic shoes to each test session (PRE, POST). The subjects' height, mass, and limb length (medial malleolus to ASIS while standing) were measured by a female research assistant and the subjects' dominant limb was recorded (limb used to kick a ball for maximal distance) at the beginning of each test session. Subjects completed two brief questionnaires prior to the first (PRE) testing session: a baseline health questionnaire and the Knee Injury and Osteoarthritis Outcome Score (KOOS).[17] At post-testing, subjects completed an abbreviated injury history questionnaire that asked about their injuries sustained over the course of the season.

At PRE and POST test sessions subjects performed three tests of functional performance in a random order: Y Balance Test, Edgren Side Step Test (ESST), and a Standing Long Jump. All research assistants conducting the tests of functional performance were blinded to group assignment. The Edgren Side Step Test (Figure 1) assesses both speed and agility and has been shown to be comparable to the T Test of agility, but can be performed in a smaller amount of space.[18] The test involves five cones at three-foot increments over a distance of twelve feet. Subjects stood feet shoulder width apart at the center cone and on "Go" (provided by a research assistant)

sidestepped to the right until her right foot crossed over the outside cone. The subject then sidestepped to the left until her left foot crossed over the outside cone. The subject sidestepped back and forth to the outside cones as quickly as possible for ten seconds. Each subject completed one submaximal practice trial and then threes trial at maximal effort. The trials were recorded from the front of the subject to be scored at a later date by a single rater blinded to group assignment.

The subjects also performed a standing long jump in order to assess power.[19] They were instructed to stand behind a designated starting line with feet together then to jump forward for maximal distance. The distance jumped (cm) was measured from the takeoff line to the point where the back of the heel nearest to the takeoff line landed. Each subject had one practice trial then three trials were recorded. If a subject stumbled or did not stick their landing the trial was repeated.

Subjects performed a standardized balance assessment called the Y Balance Test to evaluate dynamic balance ability. This test is a good measure of functional performance as it requires strength and mobility in addition to balance in order to perform a successful trial. The Y Balance Test (Figure 2) consists of balancing on one leg while reaching for maximal distance with the other leg in three directions. Subjects started with both feet in the center of the Y and were instructed that they must keep their hands on their hips, their stance foot in the same position, and their stance heel on the ground while they performed each reach. A research assistant marked the maximal distance reached for each trial. The three directions included: anterior, posterolateral and posteromedial. Subjects completed as many practice trials necessary to perform the task correctly and then performed two test trials in each direction. This assessment

was performed on the dominant limb. The Y Balance Test has been shown to be a reliable measure of balance ability and lower scores associated with increased risk of lower extremity injury.[20-22]

In addition to the measures of functional performance, subjects also completed a jump-landing task in order to determine which subjects were high-risk movers. Subjects began the jump-landing test standing on a box 30-cm high and jumped forward off the box a marked distance half the subject's body height away from the box. Subjects were instructed to leave the box with both feet at the same time, land, and then immediately perform a vertical jump for maximum vertical height upon landing. Subjects completed one practice jump and three trials.

Program Implementation

After the first test session (PRE) subjects were stratified by team (sport (field hockey, soccer, volleyball), level (Freshmen/JV/Varsity) and score on the Function in Sports and Recreation (Sport/Rec) section of the KOOS and then randomized into one of three warm-up groups: Focused, F11+ or Dynamic (described below). The KOOS is a patient-centered outcome measure that captures how a patient's knee may affect his or her life. We chose to use the Sport/Rec subscale as it is one the most sensitive and responsive subscales.[17] The average Sport/Rec subscale score for all subjects was 90.6. Two subjects fell more than 2 standard deviations away from 90.6 and they were placed into separate warm-up groups. Each of the three warm-up programs was implemented prior to team practices for the duration of the season. Implementation of the intervention occurred at a general location (track on campus) or at the team's practice location. The **Focused warm-up** was a <u>ten-minute</u> IPP based on previously published programs and consisted of flexibility, agility, plyometric, strengthening, and

balance exercises. The Focused program incorporated exercises in three planes of motion (sagittal, frontal, and transverse) and involved cues, instruction, and feedback for correcting movement in all planes (i.e. “Bend your knees”, “Keep your knees over your toes”, “Keep your toes pointed straight ahead”, “Hips square”). A progression to Phase 2 occurred at the halfway point of the season (approximately four weeks). One focus of the progression was moving double-leg exercises to a single leg position.

The **F11+ warm-up** was the FIFA 11+ (F11+) program. The F11+ is a twenty-minute program developed to prevent lower extremity injuries in soccer players. It consists of 15 exercises, divided into three parts including initial and final running exercises with a focus on cutting, jumping and landing techniques (Part 1 and 3) and strength, plyometrics, agility and field balance components (Part 2). We utilized Phase 1 and 2 of the F11+ with the progression occurring at the same time as the Focused program.

The **Dynamic warm-up** was a ten-minute dynamic warm-up consisting of movements similar to what the teams are currently preforming before practice: i.e. high knees, inchworms, butt kicks, and lunge stretches. This program was used as an active control to improve external validity. Program implementation and data collection occurred at the high school. Research assistants were responsible for implementation, instruction, and feedback during each training session. We did not rely on coaches for implementation or feedback of the programs in order to truly test the fidelity of the programs. Attendance was taken at each warm-up implementation session.

Data Reduction

The ESST score was calculated as the number of 3-foot cone segments a

subject completely passed through during each 10-second trial. A trial was scored as zero if the subject crossed her legs or did not keep her hips square to the cone course. Each reach distance of the Y Balance Test was normalized to the subject's dominant leg length (% leg length). Composite scores for the dominant leg were calculated by taking the average of the three normalized reach scores ([Normalized Anterior + Normalized Posteromedial + Normalized Posterolateral]/3). The best trial for each task (ESST, Y Balance Test and standing long jump) was used for analysis. The exposure of each subject was calculated from the attendance log taken of the research assistants implementing the program each day. Compliance was calculated by dividing the number of sessions attended by the number of sessions an athlete had the potential to attend. Sessions missed due to injury or receiving treatment from the athletic trainer were not considered potentially attended sessions.

The jump-landing task was video recorded using a two-camera system and then scored with a standardized clinical movement analysis tool (Landing Error Scoring System (LESS)). The LESS has been shown to be valid and reliable tool to assess movement technique.[23] A higher LESS score indicates poor technique in landing from a jump; a lower score indicates better technique. The LESS has been shown to identify high risk movement patterns during a jump-landing task.[23] Scoring was competed by a single rater blinded to group assignment. An average LESS score was calculated by taking the mean of the total LESS score from each jump-landing trial.

Statistical Analyses

We used separate one-way analysis of variance (ANOVA) tests to evaluate any group differences for each dependent variable, age, height, mass, compliance and

exposures at PRE. Separate 2 (Time: PRE, POST) x 3 (Group: Focused, F11+, and Dynamic) mixed model univariate ANOVA tests were performed for long jump, ESST and the composite score of the Y Balance. A 2 (Time: PRE, POST) x 3 (Group: Focused, F11+, and Dynamic) mixed model multivariate ANOVA was used to investigate differences in Y Balance reach distance as the three distances in the Y Balance are related and needed for dynamic balance. All data were analyzed using SPSS (version 21.0, SPSS Inc, Chicago, Illinois) and an a-priori α level of significance of 0.05. A secondary analysis using separate one-way ANOVA tests was performed to examine how subjects with a LESS score of greater or equal to five responded to the warm-up interventions. A LESS score of 5 or greater is considered to be at high risk for a lower extremity injury.[24]

RESULTS

When plotting compliance of all subjects a clear inflection point at 40% became apparent (Figure 3). As a result of this breaking point we did not include the 8 subjects whose compliance fell below the 40% break point in the analyses since the purpose of this study was to truly examine the effect of the program design in an optimal case on functional performance measures. There were no differences between groups for height (p= .69), mass (p= .14), and age (p= .48) at baseline (Table 1). Fifty-four of 68 (79%) of subjects completed both (PRE and POST) testing sessions. Twenty-nine subjects were scored as having a score of 5 or higher on the LESS at PRE and 22 completed POST testing and were included in the secondary analyses (Focused n=6, F11+ n= 9, Dynamic n= 7).

Functional Performance

No significant differences were observed in the standing long jump, ESST, and Y Balance Test for both all subjects and high-risk subjects (Tables 2, 3).

Compliance

Median compliance and program exposures of all subjects were 74% (42-95%) and 14 (8-19), respectively. Median compliance and exposures of high-risk subjects= 74% (47-94%) and 15 (9-17), respectively. Table 4 indicates the median compliance and program exposures for each warm-up group.

DISCUSSION

The most important finding of this study is that none of the warm-up activities had a negative impact on sport performance measures. Throughout the literature there is evidence that structured, dynamic warm-ups prepare an athlete for activity without impairing acute sport performance.[29,30] These findings extend this previous research by demonstrating there are also no long-term consequences on sport performance using a dynamic warm-up activity. Both of the injury prevention programs in this investigation were implemented as a dynamic warm-up and resulted in similar outcomes as the active control dynamic warm-up intervention. These findings suggest performing IPPs as a warm-up prior to sport participation will not harm athletic performance and may also reduce injury risk.

We hypothesized that the two injury prevention program warm-ups would result in similar performance benefits. While we did not observe any performance gains, we did find equivalent results between the two injury prevention programs. These findings are consistent with previous literature investigating the effect of similar types of IPPs on sport performance.[25-27] While some published IPPs have demonstrated improved

performance,[12,28] those interventions involved a younger population that may be more amenable to performance gains or a longer duration program with a heavier training load. An increased program volume/load may be necessary for an IPP to result in performance gains.

Our subjects had a median of 14 exposures to their warm-up program and this may not have resulted in enough program volume and intensity to induce changes in performance outcomes. Similar to the current findings, Steffen et al.[27] reported no improvements in measures of performance such as jumping ability, sprint time and long-distance kick following completion of F11+ training with adolescent female soccer players. Additionally, Lindblom et al.[26] implemented a 15-min IPP in female adolescent soccer players and also saw no improvements in performance measures after 11 weeks. Similarly to our findings, both authors hypothesized that the training volume and intensity of their programs was too low to cause changes in performance measures. Neuromuscular training programs that have demonstrated improvements in power and speed have been of a longer duration. One such program[11] was 90 minutes in duration featuring components similar to the Focused and F11+ warm-ups, (plyometrics, lower extremity and core strengthening and balance) which took 10 and 20 minutes respectively. If coaches want to elicit performance benefits from a warm-up, they may need to lengthen the duration of the warm-up program to increase the load of training, but this may not be desirable in many sport settings.[11]

The ability of the shortened duration warm-up program to change performance measures was equivalent to the longer duration IPP. This finding is encouraging as coaches indicate that time is a major barrier to IPP adoptions.[8] A shortened program

has the potential to yield improved compliance and adherence. A program length of 10 minutes is also more likely to be used as a pre-game warm-up, due to pre-game time limitations, in addition to pre-practice so athletes would increase their exposures to the program over the course of a season. Decreasing the number of exercises performed also makes the program easier for the coaches to administer as they have less to remember and demonstrate. This time reduction will hopefully ensure coaches maintain high fidelity with the program. Future research is needed to evaluate if the long and short duration programs also result in similar effects with injury reduction.

This study is not without limitations. We studied only female team sports so our results are not generalizable to males or individual sport athletes such as tennis or cross-country. We chose to include subjects who were above the 40% break point in compliance instead of utilizing an intent to treat analysis, as the purpose of this study was to examine the effect of the program design in an optimal case on functional performance measures. Solely looking at athletes who had the potential for improvement allowed us to assess the effects of each warm-up program. Future research should look to increase the number of exposures athletes have to IPPs in order to examine if a dose relationship exists with performance measures similar to what compliance and the risk of lower extremity injury.

PRACTICAL APPLICATIONS

The performance benefits of a shortened duration IPP are similar to a well-researched IPP in performance in female, adolescent athletes who participated in an 8-10 week warm-up intervention. A 10-mintute IPP achieving similar results to an IPP that can take 15-20 minutes to complete is important as a barrier to implementation and

adoption of IPPs is time. A shorter program has the potential to increase coach and player buy-in as to the use of IPPs. Using a 10-minute IPP as a warm-up does not appear to cause performance detriments in power, dynamic balance, and agility. IPP facilitators need to educate coaches that an IPP will not cause detriments to performance but can lead to gains.

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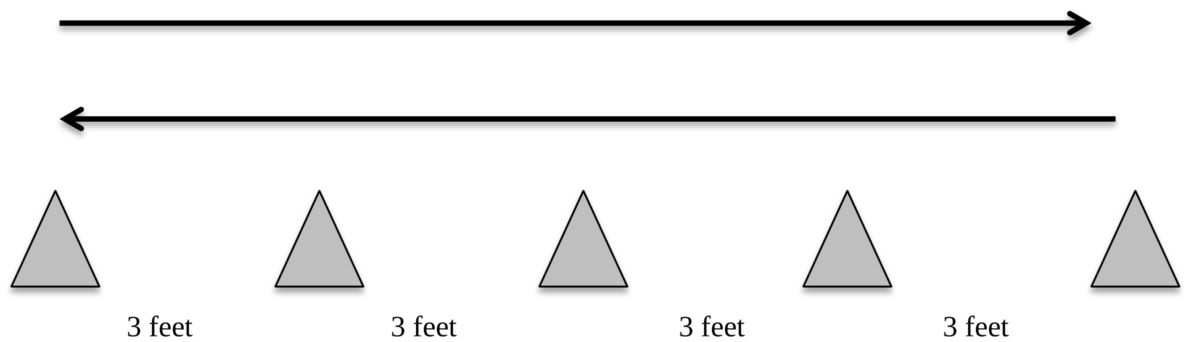

Figure 1. Edgren Side Step Test

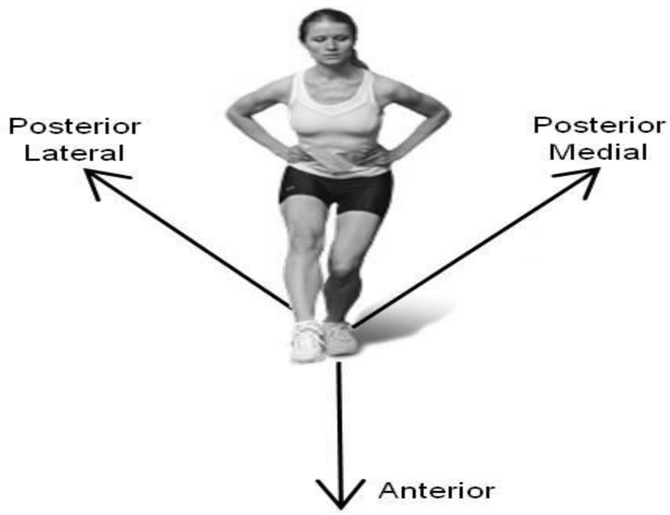

Figure 2. Y Balance Test

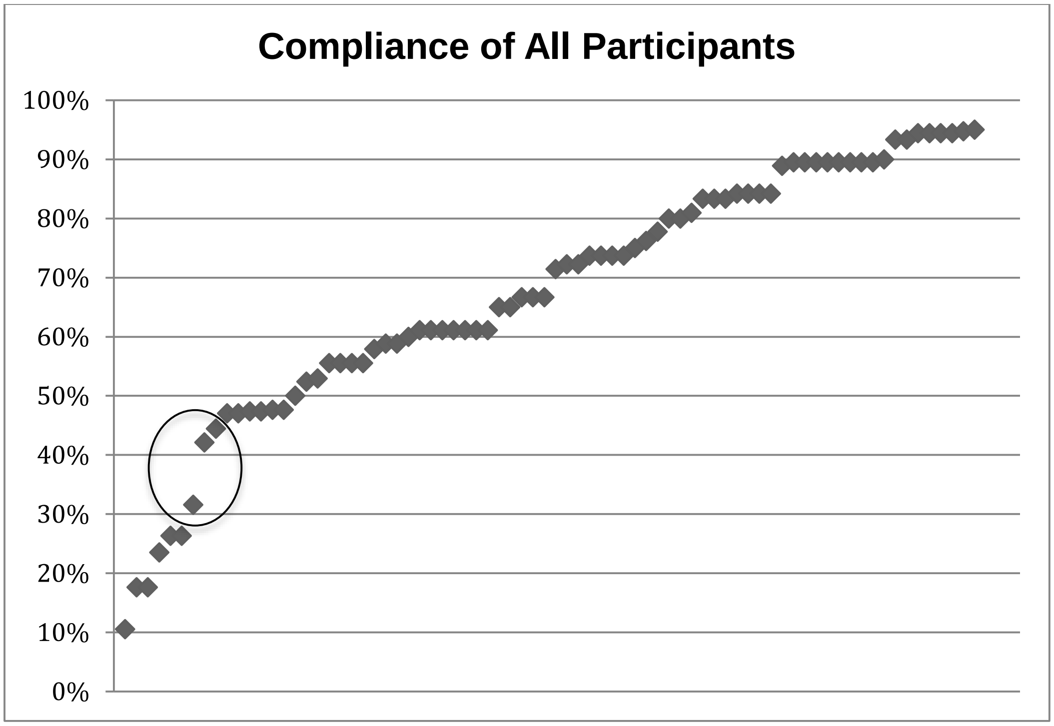

Figure 3. Compliance of all subjects with break point circled.

Table 1. Subject Demographics By Warm-Up Group [Mean (SD)]

Group (n)	Age (y)	Height (cm)	Mass (kg)
Focused (23)	15 ± 1	164.9 ± 6.4	55.6 ± 7.5
F11+ (20)	15 ± 1	166.4 ± 7.6	60.4 ± 9.9
Dynamic (25)	15 ± 1	167.4 ± 5.5	63.7 ± 12.9

Table 2. Performance Measures for All Subjects

Variable	Group (n)	Pre Test	95% CI	Post Test	95% CI	P
Long Jump (cm)	Focused (15)	146.39 ± 22.15	(133.66, 159.11)	147.32 ± 21.16	(135.52, 159.12)	.14
	F11+ (12)	143.72 ± 25.38	(129.49, 157.95)	152.08 ± 23.87	(138.89, 165.28)	
	Dynamic (19)	146.65 ± 25.52	(135.35, 157.96)	146.32 ± 23.03	(135.83, 156.81)	
ESST (segment)	Focused (17)	21.7 ± 2.4	(19.72, 23.69)	21.3 ± 2.2	(19.50, 23.09)	.34
	F11+ (14)	20.3 ± 2.7	(18.10, 22.47)	20.5 ± 1.7	(18.53, 22.47)	
	Dynamic (23)	21.4 ± 5.5	(19.64, 23.05)	20.6 ± 5.1	(19.07, 22.15)	
Composite (%LL)	Focused (19)	96.72 ± 12.90	(91.80, 101.64)	96.73 ± 8.68	(93.10, 100.36)	.39
	F11+ (15)	92.71 ± 10.49	(87.7, 98.25)	95.03 ± 7.83	(91.35, 98.72)	
	Dynamic (23)	93.45 ± 8.66	(88.97, 97.92)	95.61 ± 6.82	(92.49, 98.74)	

Table 3. Performance Measures of High-Risk Subjects

Variable	Pre Test	Post Test	95% CI of the Difference	P	d
Long Jump (cm)	133.67 ± 21.00	136.29 ± 21.87	(-2.74, 8.00)	.32	.12
ESST (segment)	19.7 ± 5.0	19.4 ± 4.6	(-1.10, 0.49)	.44	.06
Composite (%LL))	91.22 ± 9.48	93.36 ± 6.82	(-1.47, 4.73)	.16	.26

Table 4. Compliance and Exposures for All Subjects and High-Risk Subjects (Median (Range))

Group	Compliance (All)	Exposures (All)	Compliance (High Risk)	Exposures (High Risk)
Focused	74% (47-94%)	14 (8-17)	74% (48-94%)	15 (10-17)
F11+	76% (44-94%)	15 (8-17)	76% (47-94%)	16 (9-17)
Dynamic	67% (42-95%)	13 (8-19)	62% (47-89%)	13 (9-17)

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MANUSCRIPT III

Female Adolescent Athletes' Attitudes and Perspectives on Injury Prevention Programs
(Journal of Science and Medicine in Sport)

Abstract

Objectives: To examine what factors influence a high school female athlete's stated willingness to perform a lower extremity injury prevention program (IPP). A secondary aim was to examine if a participant's stated willingness affected her compliance with an IPP.

Design: Repeated measures

Methods: We surveyed high school female field hockey, soccer and volleyball athletes before and after a season-long IPP warm-up intervention. Participants completed the Injury Prevention Program Attitude Survey (IPPAS), a paper and pencil survey utilizing Likert-style and open-emended questions. It was used to assess the players' willingness to perform an IPP if the data proved the player would experience improved performance, fewer injuries and risk factors, what outside factors influence their willingness to perform an IPP, who they would feel comfortable leading their team in an IPP, and what they believe an IPP can improve.

Results: Participants' stated willingness and beliefs prior to the intervention did not appear to affect their compliance. Participants responded that they were willing to perform an IPP if data proved that they would have fewer injury risk factors (p=<.001) and be less likely to suffer an ACL injury (p<.001). Improved sport performance did not play a role in participants' willingness to perform an IPP. Before and after the warm-up

intervention, participants stated that stretching, strengthening, and cardiovascular activity should be included in an IPP.

Conclusions: Female adolescent athletes are willing to perform IPPs if data indicated that they would have fewer injury risk factors and suffer fewer ACL and leg injuries.

Keywords: injury prevention; high school; compliance

Word Count: 248

Introduction

Injury prevention programs (IPP) decrease lower extremity injury rates, improve movement technique and improve measures of performance.[1-5] Coaches and team administrators have indicated that injury prevention is a priority but, this is not reflected in the implementation and adoption of IPPs.[6,7] In a survey of Utah U-12 girls soccer coaches, only 19.8% of over 750 coaches surveyed had ever implemented an IPP.[8] The burden of adoption and implementation is not on the coaches alone, the players themselves are also key to the successful implementation of an IPP. Seventy-one percent of Australian netball coaches believed that players do not understand the value of IPPs and 83% of coaches cited poor concentration and motivation levels in their players as a barrier to implementation.[9] Players appear to not want to participate in an IPP and this may be because they do not know the associated benefits. If players knew that they may suffer fewer injuries and also improve performance factors, such as sprint time and vertical jump, that knowledge may increase their motivation and concentration when participating in an IPP.[5,10] It is crucial that players, coaches, and administrators not only adopt IPPs but also make them a regular part of training. It is important to understand what motivates the athletes we are trying to help so that we can target our education efforts and hopefully lead to widespread use of IPPs.

Increased motivation on the part of coaches and players can lead to an increase in compliance and adherence, as compliance plays a pivotal role in the success of an IPP. The literature indicates an inverse dose response relationship between compliance with an IPP and injury risk, a higher rate of compliance leads to a decreased risk of injury.[11,12] A major barrier to the success and continued adoption of an IPP is

compliance but we do not have a strong understanding of the factors resulting in low compliance. Low compliance may be due to low motivation on the part of the players, so it is necessary to find out what factors motivate athletes. A greater understanding of an athlete's motivation can lead to improved compliance and sustained use of IPPS. The purpose of this study was to examine what factors influence a high school female athlete's stated willingness to perform a lower extremity IPP. A secondary aim was to examine if a participant's stated willingness affected her compliance with an IPP.

Methods

This study utilized a repeated measures design to survey female adolescent athletes before and after participation in a season long IPP. Participants were recruited from female interscholastic soccer, field hockey, and volleyball teams at a local high school. Seventy-six female athletes (Age 15 ±1) (Field Hockey N=21, Soccer N =31, Volleyball N=24) volunteered to participate in the study. Ethics approval was obtained from The Institutional Review Board (the University of Connecticut IRB #H14-129). All participants and their legal guardians and provided assent and informed consent.

Participants preformed a prescribed warm-up before practice during the Fall 2014 scholastic season under the instruction of a research assistant who was an athletic trainer, athletic training student or physical therapy student. Prior to the intervention at the start of the season, participants completed the Injury Prevention Program Attitude Survey (IPPAS). The IPPAS is a paper and pencil survey that was adapted from a previously used survey created to assess determinants of soccer coaches' attitudes, subjective norms, perceived behavioral control, and behavioral intention regarding ACL IPP implementation.[7] The IPPAS utilizes both Likert scale and

open-ended questions. The questions utilizing a Likert Scale (1-Strongly Disagree through 5- Strongly Agree) were used to assess: 1) the players' willingness to perform an IPP if the data proved the player would experience improved performance, fewer injuries and risk factors 2) what outside factors influence their willingness to perform an IPP 3) who they would feel comfortable leading their team in an IPP, and 4) what they believe an IPP can improve. Participants also completed the IPPAS at the end of their season (POST), which occurred approximately 8-10 weeks after PRE.

Exposures were calculated from the attendance log taken by the research assistants implementing the warm-up each day. Compliance was calculated by dividing the number of sessions attended by the number of sessions an athlete had the potential to attend. Sessions missed due to injury or receiving treatment were not considered potentially attended sessions. Compliance rates were divided into quartiles and Low and High compliance groups were established using the bottom and top quartiles, respectively.

An open-ended question was used to ascertain what exercises or activities the participants believed should be included in an IPP. These responses were analyzed using open coding borrowing from the grounded theory method.[13] The survey responses were initially read for clarity and comprehension in order to gain a holistic view of data. Codes were assigned to words or phrases, and then these codes were formed into categories. If a participant's response included more then one code, (for example, stretching and strengthening), the response was counted for each code, but a single code was not counted more than once in the same response (for example, stretching hamstrings and stretching calves). Categories were totaled to determine

frequency of codes and similar categories were then organized into themes. The themes with the highest frequencies were considered emergent. Data analysis was guided by data redundancy. Following the methods above, two researchers who are certified athletic trainers experienced in lower extremity IPPs and qualitative researcher independently analyzed the data for emergent themes and met to discuss the findings. If and when a discrepancy occurred, the researchers negotiated the findings until they came to an agreement. A researcher with experience in qualitative methodology, who was otherwise uninvolved with data collection, was involved to ensure accuracy, credibility and trustworthiness with the data.[14,15]

Reponses to Likert scale questions were dichotomized into Yes or No, "5-Strongly Agree" was considered "Yes" and responses of 1 through 4 were considered "No". This dichotomization is often used in patient healthcare satisfaction surveys.[16] We wanted to ensure that the participant was in absolute agreement with the question posed. Chi square test of independence was used to examine if the participant responses in the High and Low compliance quartiles were statistically independent from each other at PRE and POST. If a difference between High and Low compliance quartiles was identified odds ratios were then calculated. If there was no difference between levels of compliance the groups were combined and χ^2 tests were utilized to identify differences between players' stated willingness and IPP beliefs.

Results

Median compliance was 69% (Range: 11-95%) and median exposures = 13 (Range: 2-19). Figure 1 depicts the distribution in compliance. Less than 56% compliance was considered Low compliance and greater than 83% was High

compliance.

At PRE three emerging themes became apparent (in order of prevalence): stretching, strengthening, and cardiovascular activity (Figure 2) in response to the question of what components should be included in an IPP. For example, varsity soccer player noted, “Stretching because you would want to stretch out your muscles before a game so you won't get an injury.” Similarly, a junior varsity (JV) field hockey player stated, “I think a lot of stretching should be included in an injury prevention program because it helps loosen your muscles.” A JV volleyball player explained, "Strengthening of legs, hips, and core because the lack of strength in these areas results in higher risk of injury.” A freshman volleyball player also said, “I think it should include lots of low impact strengthening exercises." One varsity soccer player explained, “Running/walking/stretching to make sure you don't pull anything when you go 100% in games or practices." Participants listed several components in their responses but stretching, strengthening and cardiovascular exercises were consistent throughout. “Stretching all parts of the body and a light jog. This way your heart starts pumping faster and your body isn't as tight” stated one of our participants and another noted the importance of strengthening, “… strengthening exercises and stretching should be included. I think this because you need to build your strength and keep your muscles warm so you can have a much lesser chance of getting injured.” These responses highlight the athletes’ view at PRE that stretching, strengthening and cardiovascular exercises were deemed important; nearly all participants mentioned stretching as a critical component in an IPP.

At POST the same three themes (stretching, strengthening, and cardiovascular activity) were present with the addition of two more: 1) focusing the warm-up on one body part and 2) agility/plyometrics (Figure 2b). A JV volleyball player felt “Stretching your hamstrings, calves, arm muscles.” should be included in an IPP. A varsity volleyball player was more specific naming particular exercises when she stated, “Planks to improve core so for some exercises you aren't depending on your legs. You should also do squats and lunges because they improve leg strength." Another participant had a more general response, “Any exercises that would warm-up your muscles." A varsity soccer player was focused singularly on injury prevention, stating "Exercises to prevent ACL injury.”

At both PRE and POST the most prevalent component that participants stated should be included in an IPP was stretching. At POST, participants listed more components in their responses than at PRE. For example, “stretching” was no longer given as a standalone response, which was common at PRE. A varsity soccer player explained, "I think that exercises that stretch your muscles/ simulate motions that you would make in a game to strengthen your muscles and get your heart pumping.” One participant suggested “plyometrics, running, and stretching to have variety in exercises” and another stated “stretches, strengthening exercises, balance exercises, and an aerobic warm-up to give the athlete a well balanced warm-up.”

There were no significant differences in stated willingness factors of performance (i.e. run faster, jump higher) at PRE or POST (Table 1). Participants indicated at PRE that they would be willing to perform an IPP if data proved they would have fewer injury risk factors ($p<.001$), be less likely to suffer an ACL injury ($p<.001$) and suffer fewer leg

injuries (p<.001) (Table 1). Participants responded similarly at POST; fewer injury risk factors (p= .02) and being less likely to suffer an ACL injury (p= .01) would make them more willing to perform an IPP. Participants often expressed their concern regarding injury in the open ended IPP component question. A JV soccer player stated “Stretching [should be included] to prevent hurting yourself." Another athlete made it clear that injuries were a concern stating, “Anything that helps prevent injuries.”

At PRE participants did not believe an IPP would improve their sport performance (p=.05), overall health (p=.008) or quality of life (p<.001). At POST participants with high compliance were more likely to believe an IPP would improve their overall health (p=.04, OR: 4.4 (1.04, 18.60)) and their quality of life (p=.01, OR: 4.4(1.29, 111.32)). Participants indicated that if they were the only team (p<.001), if other teams in their conference (p=.001), a local college/university (p<.001) or their favorite athlete were also doing it (p<.001)(Table 1) Their stated influences did not change at POST; other teams (p=.001), my team (p<.001), local college (p=.002) and favorite athlete (p=.005).

At PRE the participants were not willing to have any of the listed IPP facilitators lead them in an IPP. Participants indicated that they would not feel comfortable with themselves (p<.001), a teammate (p<.001), or their coach (p=.005) leading them in an IPP. There was no significant difference for an athletic trainer leading the IPP (p=.12)(Table 1). Participants felt the same at POST with regards to not feeling comfortable with themselves (p<.001), a teammate (p<.001) or their coach (p=.004) leading their team in an IPP, although they did respond at POST that they were comfortable with their athletic trainer leading an IPP (p=.01). The only question on the

IPPAS that changed significantly PRE to POST was the participants responding that they feeling more comfortable with their athletic trainer leading their team in an IPP ($p=.007$).

Discussion

Our rate of compliance is within the range reported in the literature and higher than average with a compliance rate of 40.5%.[17] These results are encouraging, as coaches did not mandate participation in the warm-up; every athlete was only encouraged to participate in their respective warm-up. Even though compliance among our study population was high our results indicate that female adolescent athletes' beliefs and attitudes towards an IPP did not affect their compliance. McKay et al.[18] reported similar findings when studying preseason and postseason knowledge and beliefs of Canadian adolescent, female soccer players.

At both PRE and POST participants believed an IPP should consist of components similar to their previous warm-up; running and stretching. McKay et al.[18] also found stretching to be the leading prevention strategy response from players after participating in an IPP. It may be difficult to overcome the common routine of running a lap then static stretching as it may be what athletes have been taught since they were children. Players need to be educated on the components of a warm-up and when static stretching can be beneficial. Female players should also be educated about the importance of strengthening and proprioception on injury prevention. Lauersen et al.[19] found that strengthening and proprioception were favorable in IPPs, as opposed to stretching. At POST, however, our participants appeared to be aware of the importance of a multifaceted approach. This concept is supported by a recent systematic review by

Stojanvic et al.[20], which reported that the use of a multifaceted training intervention decreased the rate of ACL injury in female athletes. The evidence indicated that an intervention consisting of stretching, proprioception, strength, plyometric and agility drills resulted in the greatest reduction of ACL injuries.[20] These were the exercises and components our athletes deemed important.

Female athletes are more willing to perform an IPP if the data proved to them that they would suffer fewer injuries as opposed to experiencing performance benefits. This is an interesting finding, given that the current literature indicates that male athletes are primarily concerned with performance benefits.[21] As we strive to implement IPPs within the adolescent athletic population, we should focus our educational and marketing techniques what motivates each specific group. For example, highlighting the injury prevention benefits an IPP should be a point of emphasis when working with female athletes. If we are able to speak to factors that matter most to a team the hopes are a team will continue to use an IPP as part of their regular practice or game preparation protocol.

In a recent survey of female youth soccer players, most players believe that injuries could be prevented but only 20% believed that knee injuries were preventable.[18] There appears to be a gap in knowledge on the effect IPPs can have on knee injuries. Female athletes are witnessing the effects of knee injuries on a more regular basis due to an increased incidence of knee injuries coupled with increased media coverage. An athlete may believe that sustaining a knee injury is a consequence of playing sports and is therefore not preventable. We need to educate athletes that this is not the case.

One of the key findings of this study was that after the intervention participants were comfortable with their athletic trainer leading their team in an IPP. Prior to the intervention participants indicated that they were not comfortable letting any of the entities we listed lead their team in an IPP. This may indicate that the athletes in our study have confidence in their athletic trainer's ability to guide them through the exercises. Another important finding was that our participants not feel comfortable with their coach leading an IPP. White et al.[22] surveyed netball coaches in Australian and found that the coaches had strong positives attitudes towards teaching correct landing technique. There appears to be a disconnect between the players' confidence in their coach's ability and the coaches' confidence in their ability to effectively implement an IPP.

A limitation of our study is that we only surveyed female, high school aged athletes and as such our findings may not be applicable to other age groups. We did not measure the participants' knowledge of IPPs prior the warm-up intervention. Level of IPP knowledge could positively or negatively impact what influences their willingness to participate in an IPP. There is also potential for a sample bias as the warm-up programs were not mandatory, participants who consented for the study may have been more apt to participate in the warm-up. We also did not measure if an individual's willingness changed from PRE to POST so it is unknown if the same participants said Yes at PRE and POST or if some changed their response to unwilling at POST.

Conclusion

Female adolescent athletes are willing to perform IPPs if the data indicated that they would have fewer risk factors when they moved, suffer fewer leg injuries and be

less likely to suffer an ACL injury. Athletic trainers and other facilitators need to understand what factors are most important to their athletes and take them into consideration when educating their athletes. Participants believed an IPP should include stretching, strengthening and cardiovascular activities. While this view is not incorrect, it is not inclusive of all activities the evidence shows should be included in an IPP to order see a decrease in lower extremity injuries. The activities stated most often were exercises that athletes are potentially more accustomed to. It is important to educate athletes on the components of an IPP and the benefits of each component.

Practical Implications

1. Female and male athletes may have different motivating factors and clinicians need to keep this in mind when implementing an IPP.
2. Female athletes have some knowledge on what components should be in an IPP but facilitators need to educate athletes as to the benefits of a multi-faceted approach to an IPP.
3. Female athletes have confidence in their athletic trainer's ability to lead their team in an IPP so athletic trainers and other healthcare professionals should be more involved in delivery and implementation of IPPs.

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APPENDIX A: BASELINE HEALTH QUESTIONNAIRE

ID _________

University of Connecticut: Injury Prevention Research Study

BASELINE PRE-SEASON QUESTIONNAIRE

DEMOGRAPHIC INFORMATION

1. What is your child's date of birth? _____/_____/_____
2. What is your child's gender? (Please circle) M F
3. Which leg does your child prefer to kick a ball with? Ie. Which leg would he/she use to kick for maximum distance. (Please circle)

   Leg Left   Right Leg   Either

Please answer the following questions to the best of your ability regarding your child.

HISTORY OF KNEE INJURY

4. Has your child ever had an injury to a ligament in either (or both) knee(s)?

- No *If no, go to Question 9.*
- Yes

5. Has your child ever had an Anterior Cruciate Ligament (ACL) injury?

- No *If No, Go to Question 6.*
- Yes

5a. If YES to ACL injury, which knee(s):

- Left
- Right
- Both

5b. When (what year or years) did the injury occur?

5c. Did this ACL injury require surgery?

- No
- Yes

6. Has your child ever had an injury to the Medial Collateral Ligament (MCL)?

- No *If No, Go to Question 7.*
- Yes

6a. If YES to MCL injury, which knee(s):

- Right
- Left
- Both

6b. When (what year or years) did the injury occur?

6c. Did this MCL(s) injury require surgery?

- No
- Yes

7. Has your child ever had an injury to the Lateral Collateral Ligament (LCL)?

No *If No, Go to Question 8.*
Yes

7a. If yes to LCL injury, which knee(s):

Right   Left   Both

7b. When (what year or years) did the injury occur?

7c. Did this LCL injury require surgery?

No
Yes

8. Has your child ever had a Posterior Cruciate Ligament (PCL) injury?

No *If No, Go to Question 9.*
Yes

8a. If yes to PCL injury, which knee(s):

Right   Left   Both

8b. Did this PCL injury require surgery?

No
Yes

9. Has your child ever had an injury to the meniscus of the knee or knees?

No *If NO, Go to Question 10.*
Yes

9a. If yes, which knee(s)?

Right   Left   Both

9b. When (what year or years) did the injury occur?

9c. Did this injury (or injuries) require surgery?

No
Yes

10. Has your child had knee surgery, <u>within the past 10 years</u>, other than that listed in the previous questions?

No *If NO, Go to Question 11.*
Yes

10a. If yes, which knee(s)?

Right   Left   Both

10b. When (what year or years) did the surgery occur?

11. Within the <u>past six months</u>, has your child had episodes of *severe* pain in his/her knee(s)?
Severe means pain that would make you stop what you were doing, or limit or interfere with your activities.

No *If NO, Go to Question 12.*
Yes

11a. Which knee(s)?

Right   Left   Both

11b. Was/Is it worse when you exercise?

No
Yes

11c. Does your child currently have this problem or has it resolved?

Still a problem
Resolved

11d. At its worst, how would your child rate the pain?

1 (mild)
2 (moderate)
3 (severe)
4 (debilitating)

ID __________

HISTORY OF LOWER EXTREMITY INJURY

Within the **past 5 years**, has your child experienced **any** of these leg injuries?

12. Shin splints within the past 5 years?

✐ No *If NO, go to Question 13*
✐ Yes

12a. *If yes,* which leg(s)?

✐ Right ✐ Left ✐ Both

12b. *If yes,* does it currently interfere with physical activity?

✐ No
✐ Yes

13. Lower limb stress fracture within the past 5 years?

✐ No *If NO, go to Question 14*
✐ Yes

13a. *If yes,* which leg(s)?

✐ Right ✐ Left ✐ Both

13b. *If yes,* does it currently interfere with physical activity?

✐ No
✐ Yes

14. Other lower limb bone fracture within the past 5 years?

✐ No *If NO, go to Question 15*
✐ Yes

14a. *If yes,* which leg(s)?

✐ Right ✐ Left ✐ Both

14b. *If yes,* does it currently interfere with physical activity?

✐ No
✐ Yes

15. Ankle sprain within the past 5 years?

✐ No *If NO, go to Question 16*
✐ Yes

15a. *If yes,* which ankle(s)?

✐ Right ✐ Left ✐ Both

15b. *If yes,* does it currently interfere with physical activity?

✐ No
✐ Yes

16. Hip injury within the past 5 years?

✐ No *If NO, go to Question 17*
✐ Yes

16a. *If yes,* which leg(s)?

✐ Right ✐ Left ✐ Both

16b. *If yes,* does it currently interfere with physical activity?

✐ No
✐ Yes

ID _________

17. Patello-femoral pain syndrome (severe knee pain or runner's knee) within the past 5 years?

No *If NO, go to Question 18*
Yes

17a. *If yes,* which knee(s)?

Right Left Both

17b. *If yes,* does it currently interfere with physical activity?

No
Yes

18. Swelling, clicking, or popping, or feeling the knee giving way within the past 5 years?

No
Yes

18a. *If yes,* which knee(s)?

Right Left Both

18b. *If yes,* does it currently interfere with physical activity?

No
Yes

END
Thank you very much!

BASELINE QUESTIONNAIRE

Please complete the table below to list the sports your child has participated in at any time in their life and how long your child participated in them.

Sport	Age at Start (approximate)	Age at End (approximate) or, if applicable, write "present"

Please answer the following questions to the best of your ability regarding your child.

1. Has your child ever sustained an injury (injuries) to the lower body that prevented him/her from playing sports for at least one day? Yes / No

   If yes, please provide a brief description of the injury including approximate date of injury, mechanism of injury (what was your child doing at the time of injury) and treatment.

2. Are there any other injuries, conditions, or illnesses you feel the researchers of this study should be aware of because they may influence how your child performs the tasks in this study?

PUBERTAL MATURATION OBSERVATIONAL SCALE

Please mark an "X" next to any statement in the appropriate checklist (Female OR Male) that you agree with regarding your child.

Female Checklist

Agree?	Characteristic
	The adolescent has grown 3 to 3.5 inches in the past 6 months or is past the growth spurt.
	The adolescent has begun breast development.
	The adolescent has begun menarche.
	The adolescent has evidence of darker underarm hair or shaves.
	The adolescent's calves are becoming defined.
	The adolescent has evidence of acne.
	There was evidence of sweating after physical activities.

Male Checklist

Agree?	Characteristic
	The adolescent has evidence of darkening of facial hair or shaves.
	The adolescent's voice has gotten deeper or is currently breaking.
	The adolescent has grown 3 to 4 inches in the past 6 months or is past the growth spurt.
	The adolescent's biceps are becoming defined.
	The adolescent's calves are becoming defined.
	The adolescent has evidence of acne.
	There was evidence of sweating after physical activities.
	There is darkened underarm hair.

Please answer the following questions to the best of your ability regarding your child.

1. Do you feel your child has experienced a major growth spurt in the past year?

   Yes No

   a. If yes, approximately how many inches do you think he/she has grown in the past year?

2. If known, how tall is your child's biological mother?

3. If known, how tall is your child's biological father?

APPENDIX B: ABBREVIATED INJURY HISTORY QUESTIONNAIRE

ID __________

Injury History Questionnaire

1. Did your child sustain an injury (injuries) to the lower body that prevented her from playing sports for at least one day?

   ____ Yes ____ No

   If yes, please provide a brief description of the injury including approximate date of injury, mechanism of injury (what was your child doing at the time of injury) and treatment.

2. Are there any other injuries, conditions, or illnesses you feel the researchers of this study should be aware of because they may influence how your child performs the tasks in this study?

   ____ Yes ____ No

   If yes, please provide a brief description.

KOOS KNEE SURVEY

Today's date: _____/______/______ Date of birth: _____/______/______

Name: ____

INSTRUCTIONS: This survey asks for your view about your knee. This information will help us keep track of how you feel about your knee and how well you are able to perform your usual activities.
Answer every question by ticking the appropriate box, only one box for each question. If you are unsure about how to answer a question, please give the best answer you can.

Symptoms
These questions should be answered thinking of your knee symptoms during the **last week**.

S1. Do you have swelling in your knee?

Never	Rarely	Sometimes	Often	Always
☐	☐	☐	☐	☐

S2. Do you feel grinding, hear clicking or any other type of noise when your knee moves?

Never	Rarely	Sometimes	Often	Always
☐	☐	☐	☐	☐

S3. Does your knee catch or hang up when moving?

Never	Rarely	Sometimes	Often	Always
☐	☐	☐	☐	☐

S4. Can you straighten your knee fully?

Always	Often	Sometimes	Rarely	Never
☐	☐	☐	☐	☐

S5. Can you bend your knee fully?

Always	Often	Sometimes	Rarely	Never
☐	☐	☐	☐	☐

Stiffness
The following questions concern the amount of joint stiffness you have experienced during the **last week** in your knee. Stiffness is a sensation of restriction or slowness in the ease with which you move your knee joint.

S6. How severe is your knee joint stiffness after first wakening in the morning?

None	Mild	Moderate	Severe	Extreme
☐	☐	☐	☐	☐

S7. How severe is your knee stiffness after sitting, lying or resting **later in the day**?

None	Mild	Moderate	Severe	Extreme
☐	☐	☐	☐	☐

Pain

P1. How often do you experience knee pain?

Never	Monthly	Weekly	Daily	Always
☐	☐	☐	☐	☐

What amount of knee pain have you experienced the **last week** during the following activities?

P2. Twisting/pivoting on your knee

None	Mild	Moderate	Severe	Extreme
☐	☐	☐	☐	☐

P3. Straightening knee fully

None	Mild	Moderate	Severe	Extreme
☐	☐	☐	☐	☐

P4. Bending knee fully

None	Mild	Moderate	Severe	Extreme
☐	☐	☐	☐	☐

P5. Walking on flat surface

None	Mild	Moderate	Severe	Extreme
☐	☐	☐	☐	☐

P6. Going up or down stairs

None	Mild	Moderate	Severe	Extreme
☐	☐	☐	☐	☐

P7. At night while in bed

None	Mild	Moderate	Severe	Extreme
☐	☐	☐	☐	☐

P8. Sitting or lying

None	Mild	Moderate	Severe	Extreme
☐	☐	☐	☐	☐

P9. Standing upright

None	Mild	Moderate	Severe	Extreme
☐	☐	☐	☐	☐

Function, daily living

The following questions concern your physical function. By this we mean your ability to move around and to look after yourself. For each of the following activities please indicate the degree of difficulty you have experienced in the **last week** due to your knee.

A1. Descending stairs

None	Mild	Moderate	Severe	Extreme
☐	☐	☐	☐	☐

A2. Ascending stairs

None	Mild	Moderate	Severe	Extreme
☐	☐	☐	☐	☐

For each of the following activities please indicate the degree of difficulty you have experienced in the **last week** due to your knee.

A3. Rising from sitting

None	Mild	Moderate	Severe	Extreme
☐	☐	☐	☐	☐

A4. Standing

None	Mild	Moderate	Severe	Extreme
☐	☐	☐	☐	☐

A5. Bending to floor/pick up an object

None	Mild	Moderate	Severe	Extreme
☐	☐	☐	☐	☐

A6. Walking on flat surface

None	Mild	Moderate	Severe	Extreme
☐	☐	☐	☐	☐

A7. Getting in/out of car

None	Mild	Moderate	Severe	Extreme
☐	☐	☐	☐	☐

A8. Going shopping

None	Mild	Moderate	Severe	Extreme
☐	☐	☐	☐	☐

A9. Putting on socks/stockings

None	Mild	Moderate	Severe	Extreme
☐	☐	☐	☐	☐

A10. Rising from bed

None	Mild	Moderate	Severe	Extreme
☐	☐	☐	☐	☐

A11. Taking off socks/stockings

None	Mild	Moderate	Severe	Extreme
☐	☐	☐	☐	☐

A12. Lying in bed (turning over, maintaining knee position)

None	Mild	Moderate	Severe	Extreme
☐	☐	☐	☐	☐

A13. Getting in/out of bath

None	Mild	Moderate	Severe	Extreme
☐	☐	☐	☐	☐

A14. Sitting

None	Mild	Moderate	Severe	Extreme
☐	☐	☐	☐	☐

A15. Getting on/off toilet

None	Mild	Moderate	Severe	Extreme
☐	☐	☐	☐	☐

For each of the following activities please indicate the degree of difficulty you have experienced in the **last week** due to your knee.

A16. Heavy domestic duties (moving heavy boxes, scrubbing floors, etc)

None	Mild	Moderate	Severe	Extreme
☐	☐	☐	☐	☐

A17. Light domestic duties (cooking, dusting, etc)

None	Mild	Moderate	Severe	Extreme
☐	☐	☐	☐	☐

Function, sports and recreational activities

The following questions concern your physical function when being active on a higher level. The questions should be answered thinking of what degree of difficulty you have experienced during the **last week** due to your knee.

SP1. Squatting

None	Mild	Moderate	Severe	Extreme
☐	☐	☐	☐	☐

SP2. Running

None	Mild	Moderate	Severe	Extreme
☐	☐	☐	☐	☐

SP3. Jumping

None	Mild	Moderate	Severe	Extreme
☐	☐	☐	☐	☐

SP4. Twisting/pivoting on your injured knee

None	Mild	Moderate	Severe	Extreme
☐	☐	☐	☐	☐

SP5. Kneeling

None	Mild	Moderate	Severe	Extreme
☐	☐	☐	☐	☐

Quality of Life

Q1. How often are you aware of your knee problem?

Never	Monthly	Weekly	Daily	Constantly
☐	☐	☐	☐	☐

Q2. Have you modified your life style to avoid potentially damaging activities to your knee?

Not at all	Mildly	Moderately	Severely	Totally
☐	☐	☐	☐	☐

Q3. How much are you troubled with lack of confidence in your knee?

Not at all	Mildly	Moderately	Severely	Extremely
☐	☐	☐	☐	☐

Q4. In general, how much difficulty do you have with your knee?

None	Mild	Moderate	Severe	Extreme
☐	☐	☐	☐	☐

Thank you very much for completing all the questions in this questionnaire.

APPENDIX D: INJURY PREVENTION PROGRAM ATTITUDE SURVEY (IPPAS)

Pre: _______ Post: _______ ID: _______

Injury Prevention Program Attitude Survey

1) **Have you ever performed/participated in an ACL/Lower Extremity injury prevention program?**

☐ **Yes** ☐ **No**

   a. **If yes, what was the name of the program?**

   ____

   b. **If yes, who instructed you in the program?**

   ____

2) **What do you think of when you hear the term injury prevention program?**

____

____

____

3) **What do you believe are the major goals of an injury prevention program?**

____

____

____

4) **I would be willing to…**

	Strongly Disagree	**Disagree**	**Neither Agree nor Disagree**	**Agree**	**Strongly Agree**
…perform a lower extremity injury prevention program if data proved I would **run faster** after completing the program for a season.	☐	☐	☐	☐	☐
…perform a lower extremity injury prevention program if data proved I would **jump higher** after completing the program for a season.	☐	☐	☐	☐	☐
…perform a lower extremity injury prevention program if data proved I would **change direction faster** after completing the program for a season.	☐	☐	☐	☐	☐
…perform a lower extremity injury prevention program if data proved I would have **fewer injury risk factors when I move** after completing the program for a season.	☐	☐	☐	☐	☐

…perform a lower extremity injury prevention program if data proved I would **be less likely to suffer an ACL injury** after completing the program for a season.	☐	☐	☐	☐	☐
…perform a lower extremity injury prevention program if data proved I would **suffer fewer leg injuries** after completing the program for a season.	☐	☐	☐	☐	☐

5) I would be willing to…

	Strongly Disagree	Disagree	Neither Agree nor Disagree	Agree	Strongly Agree
…perform a lower extremity injury prevention if **other teams in my conference were also doing it.**	☐	☐	☐	☐	☐
…perform a lower extremity injury prevention if **my team was the only team in my conference doing it.**	☐	☐	☐	☐	☐
…perform a lower extremity injury prevention if **a college/university near me was also doing it.**	☐	☐	☐	☐	☐
…perform a lower extremity injury prevention if **my favorite athlete was also doing it.**	☐	☐	☐	☐	☐

6) For each question indicate your best answer

	Strongly Disagree	Disagree	Neither Agree nor Disagree	Agree	Strongly Agree
I would feel comfortable **leading** my team in an injury prevention program.	☐	☐	☐	☐	☐
I would feel comfortable with **a teammate leading** my team in an injury prevention program.	☐	☐	☐	☐	☐
I would feel comfortable with **my coach leading** my team in an injury prevention program.	☐	☐	☐	☐	☐
I would feel comfortable with **my athletic trainer** leading my team in an injury prevention program.	☐	☐	☐	☐	☐

7) I believe an injury prevention program can…

	Strongly Disagree	Disagree	Neither Agree nor Disagree	Agree	Strongly Agree
...improve my sport performance.	☐	☐	☐	☐	☐
…improve my overall health.	☐	☐	☐	☐	☐
…improve my quality of life.	☐	☐	☐	☐	☐

8) What do you think should be included in an injury prevention program? Why?

____

____

____

____

____

APPENDIX E. FOCUSED PROGRAM EXERCISE SHEET

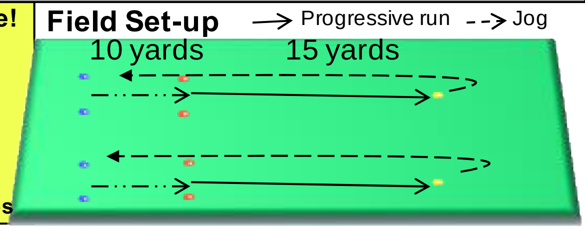
EO WARM-UP FOCUSED PROGRAM

PHASE 1

Key Points to Emphasize for EVERY Exercise!

Toes straight ahead, Knees over toes, Bend your knees

Field Set-up



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. FORWARD HOP TO BALANCE 2 times 	▪ Hands on hips standing on one leg ▪ Hop forward ▪ Land softly on opposite leg with trunk, hip, and knee flexed ▪ Hold for 5 seconds	▪Land as softly toe to heel ▪Bend your knees, hips and trunk
5. DOUBLE LEG SQUAT 5, rest, 5 	▪ Hands on hips ▪ Feet shoulder width apart ▪ Squat down like sitting in a chair	▪Toes straight ahead ▪Knees over toes ▪Sit back
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	Description	Key Points
7. SIDE PLANK 30 seconds each side 	▪ Lay on side, elbow under shoulder, feet stacked. ▪ Lift hips bringing them in a straight line with shoulder and feet.	▪Stay "straight as an arrow" ▪Draw your belly button towards your spine while breathing
8. SINGLE LEG REACH 5 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

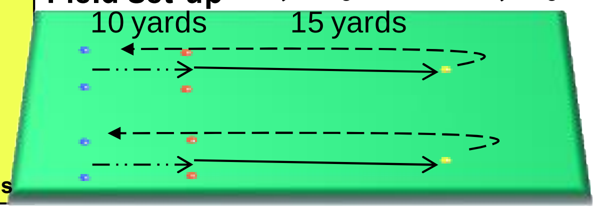
EO WARM-UP FOCUSED PROGRAM

PHASE 2

Key Points to Emphasize for EVERY Exercise!

Toes straight ahead, Knees over toes, Bend your knees

Field Set-up → Progressive run - -> Jog



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	Description	Key Points
7. SIDE PLANK 30 seconds each side 	▪ Lay on side, elbow under shoulder, feet stacked. ▪ Lift hips bringing them in a straight line with shoulder and feet.	▪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

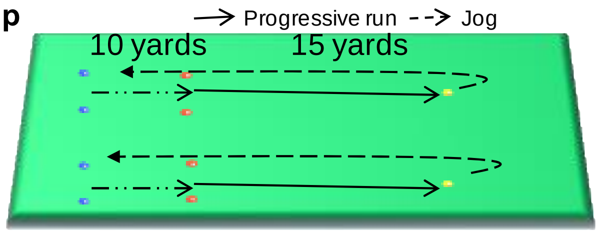
Always emphasize soft landings, knees over toes, & toes ahead

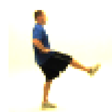
APPENDIX F. F11+ PROGRAM MANUAL

APPENDIX G: DYNAMIC PROGRAM EXERCISE SHEET

EO SMITH DYNAMIC WARMUP

Field Set-Up



Exercise	Description	CUES
1. WALKING QUAD PULL 	▪ 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	▪ 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	**Description**	**Key Points**
8. HIGH KNEES	▪ Jog quickly to the second cone with knees reaching hip height or higher.	
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!