Published in final edited form as:

Scand J Med Sci Sports. 2018 December ; 28(12): 2592–2603. doi:10.1111/sms.13278.

CHANGES IN BIOMECHANICAL KNEE INJURY RISK FACTORS ACROSS TWO COLLEGIATE SOCCER SEASONS USING THE 11+ PREVENTION PROGRAM

Amelia J.H. Arundale^{1,*}, Holly J. Silvers-Granelli², Adam Marmon¹, Ryan Zarzycki¹, Celeste Dix¹, and Lynn Snyder-Mackler²

¹Biomechanics and Movement Science Program, University of Delaware, Newark, Delaware

²Department of Physical Therapy, University of Delaware, Newark, Delaware

Abstract

The 11+ injury prevention program effectively reduces injuries in high school aged female soccer player, but the mechanism of the 11+ is unknown, particularly whether it impacts biomechanical risk factors associated with knee injuries. The purpose was to report the changes in hip and knee biomechanics with use of the 11+ over two soccer seasons. Two collegiate women's soccer teams performed the 11+ for two soccer seasons. A control team was followed for one season. Athletes performed motion analysis of a drop vertical jump during preseason and postseason. Both groups had meaningful increases in peak knee abduction angle over the first season, and there were no meaningful changes in peak knee abduction moment over either season. The control group had bilateral decreases in knee flexion angle. The program did not seem to systematically impact biomechanical risk factors associated with knee injuries, with increase in peak knee abduction angle no bilateral changes in frontal or transverse hip motion. The 11+ may have mitigated clinically meaningful decreases in knee flexion, however as ACL injuries do not occur purely in the sagittal plane, it is unclear the impact of these changes. The results of this study indicate that the 11+ may require some modifications to impact landing biomechanics and potentially risky movement patterns, particularly when used in collegiate women over multiple seasons.

Keywords

Football; Prevention; Anterior Cruciate Ligament; Injury; Neuromuscular Training

Introduction

The 11+ (previously the FIFA11+), is a neuromuscular injury prevention program involving running, strengthening, balance, and plyometric exercises.^{1,2} The 11+ focuses on proper lower extremity alignment and landing technique with emphasis on avoiding valgus movement patterns (knee abduction, hip adduction, and hip internal rotation). The 11+ was

*Corresponding Author: Amelia J.H. Arundale, arundale@udel.edu.

Address: Biomechanics and Movement Science Program, University of Delaware, 540 S. College Ave, Newark, DE, 19711, USA, Telephone: +1-971-409-6134

designed to be implemented by coaches, parents, or athletes with limited or no knowledge of exercise progression.^{3,4} Further, as most teams do not have access to staff who can tailor athlete exercise progressions, the 11+ was developed intended to be used over multiple seasons.

In collegiate male soccer players the 11+ reduced lower extremity injuries by 92%, knee injuries by 58%,¹ and ACL injuries by 76%.⁵ High school age women soccer players also seemed to benefit from the program demonstrating a 32% reduction in lower extremity injury risk, and although not statistically significant a 38% reduction in knee injury risk.² The efficacy of the 11+ has not been tested in collegiate women soccer players, however they are at a known high risk for ACL injuries. With a rate of 0.26 injuries per 1,000 athletic exposures, collegiate female soccer players are at a four times higher risk for an ACL injury than their male counterparts,⁶ with ACL injuries accounting for 7% of all injuries.⁷

Valgus collapse, particularly large or asymmetrical peak knee abduction moments and knee abduction angles/medial knee displacements during drop vertical jump (DVJ) landings, have been associated with increased risk of primary and secondary ACL injuries^{8–10} and may contribute to anterior knee pain.¹¹ Although the DVJ has been criticized as a method for assessing movement,⁹ it remains one of the most published and clinically feasible assessments of jump landings and knee mechanics.^{12–20}

Neuromuscular injury prevention programs can change movement patterns such as valgus collapse.^{17,21–24} The Sportsmetrics™ program was reported to decrease peak knee abduction moments during jump landings by approximately 50%,²¹ and after a season performing the Prevent Injury and Enhance Performance Program (also known as the PEP program) female soccer players landed DVJs in less hip internal rotation and adduction.²² However, there have been no studies examining the biomechanical effects of the 11+. Given the focus of the 11+ on proper landing technique, it is unknown whether the 11+ changes athletes' movement patterns. Further, no studies of the 11+ have reported results over multiple seasons. Understanding if the 11+ changes movement patterns will help determine the mechanism of the program, inform clinicians and researchers regarding the program's effect on potentially risky knee and hip biomechanics, and lead to information on if such mechanical changes are different from one season to the next. Changes, or lack thereof in movement patterns over multiple seasons are important to inform program implementation as well as exercise or progression modification for athletes' continued benefit and protection.

Thus, the purpose of this study was to explore the changes in hip and knee biomechanics, particularly those associated with valgus collapse, over two soccer seasons using the 11+ injury prevention program. Our hypotheses were 1) after using the 11+ for one season athletes in the intervention group would have smaller peak knee abduction, hip adduction, and hip internal rotation angles and moments than athletes in the Control group, and 2) after using the 11+ for a second season athletes would have further decreases in peak knee abduction, hip adduction, and hip internal rotation angles and moments compared to the first season of 11+ use. This study aimed to place biomechanical changes in the context of

clinically meaningful alterations in movement patterns through comparisons to smallest detectable change (SDC) and minimum important differences (MID) values.

Methods

Participants:

The coaches of all 10 National Collegiate Athletics Association (NCAA) women's soccer teams located within an hour driving distance of the testing location were contacted regarding study participation. Three teams (NCAA Division I and II) agreed to participate. Two teams were selected as intervention teams (11+ group) based on their willingness to implement the 11+. The third team agreed to participate but only as a control. All athletes gave written informed consent prior to participating and the study was approved by the University of Delaware human subjects review board. Athletes were included regardless of position, academic year, or injury and surgery history, but excluded if they were unable to perform a DVJ.

Sixty-eight athletes (11+ = 48, Control = 20) were enrolled and participated in at least one testing time point (Figure 1). Fifteen Control group and twenty two 11+ group athletes had complete biomechanical data for all time points and were included in the biomechanical analyses (Figure 1).

Intervention:

Led by their coaches or athletic trainers the intervention group performed the 11+ (http://fifamedicinediploma.com/cdn/11plus_workbook_e.pdf) for two consecutive seasons (Figure 1). The coaches and athletic trainers of the 11+ teams were educated about the 11+ in person and over the phone as well as provided with written material and a program DVD. None of the teams had used or were familiar with the program prior to the study. The teams instituted the 11+ during preseason and continued to perform the program prior to training sessions or games at least three times per week throughout both seasons. No interventions were performed during the off-season. Compliance was reported to one researcher (HSG) by the coaches at the end of each season. The Control team was followed for one season (Figure 1). The Control team performed their standard warm-up involving dynamic stretching of the lower extremities, running, and passing a soccer ball while stationary and running.

Motion Analysis:

Details of the DVJ, motion analysis, and post-processing methods are described in Appendix A. Motion analysis of a DVJ was performed in preseason and postseason (Figure 1), using an eight camera motion system (VICON; Oxford Metrics Ltd, London, England) sampling at 240Hz, and two 6 component embedded force plates (Bertec, Worthington, Ohio, USA) sampling simultaneously at 1080Hz. Twenty two retro-reflective markers were affixed to the acromion, pelvis, and lower extremities, and six rigid shells were affixed to the trunk, pelvis, thighs, and shanks (Appendix A). All markers were placed by one researcher (AA).

The DVJ was performed similar to Hewett et al.²⁵ Athletes dropped from a 40 cm box, landing with one foot on each force plate. Upon landing athletes immediately jumped up and

landed again with one foot on each force plates. Analysis focused on the first jump, with initial contact defined as when the vertical force exceeded 5N. Athletes were given verbal instructions and allowed to practice the DVJ before three trials were recorded. Only the second and third trials were analyzed (Appendix A).

Rigid-body analysis and inverse dynamics post-processing were performed using Visual 3D (C-Motion Inc., Germantown, Maryland, USA). Kinematic and kinetic data were low pass filtered at 6 Hz and 40 Hz respectively.²⁶ External moments were calculated and in accordance with the right hand rule hip flexion, adduction, and internal rotation, as well as knee extension and adduction, were represented as positive values. Variables of interest were the peak hip flexion, adduction, and internal rotation angles and moments, as well as peak knee flexion and abduction angles and moments. Limb dominance was determined through athlete self-report of their preferred kicking leg.

Smallest Detectable Change (SDC) and Minimum Important Differences (MID):

Smallest detectable change (SDC, also known as the minimum detectable change) and minimum important difference (MID, also known as the minimum clinically important difference) were calculated to help establish whether observed changes hold measureable and clinical impact.²⁷ SDC and MID methods are detailed in Appendix A. Using the preseason data from all athletes with complete 1st season data (N=54, 11+ and Control groups combined, Figure 1), Intraclass Correlation Coefficient (ICC)(2,1) were used to examine the reliability of all knee and hip variables. All variables had good to excellent reliability (ICCs from 0.63 to 0.92), thus, standard error of the mean and SDC values were calculated (Table 1, Appendix A). MID values were calculated using a hybrid of anchor and distribution based methods.²⁸ The preseason DVJ measurements of athletes in the Control group who went on to incur a non-contact lower extremity injury during the season (N=11) were compared to those who did not have an injury (N=9) using a MANOVA. A non-contact lower extremity injury was defined as a physical complaint regarding the foot, ankle, shank, knee, thigh, hip, or groin, that caused an athlete to miss one or more training sessions/games and were not the result of a collision with another player or object.²⁹ The mean difference between the injured and uninjured athletes was compared to the SDC. Where the mean difference between injured and uninjured Control group athletes exceeded the SDC, the mean difference value was taken as an MID (Table 1, Appendix A).

Valgus Collapse Values:

Valgus collapse is often studied by looking at its components (hip adduction, hip internal rotation, and knee abduction) individually. However, none of these motions occur in isolation, so to examine these variables together, a measure of valgus collapse was created. The hip adduction, hip internal rotation, and knee abduction angles were calculated at the time of peak knee flexion and the following equation was used: Valgus Collapse Value = hip adduction angle + hip internal rotation angle + (knee abduction angle x -1). Thus, negative valgus collapse values indicate an athlete is in more varus pattern involving hip abduction, external rotation and knee adduction, where as positive valgus collapse values indicates more valgus and hip adduction, internal rotation and knee abduction (Figure 2).

Statistical Analysis:

Demographic and anthropometric variables were compared between groups using t-tests and Fischer's exact tests. To examine changes in biomechanics over the first season, 2×2 (time x group) repeated measures ANOVAs with planned least squared comparisons assessed if the Control group and the 11+ group changed differently over the first season. Planned comparisons were the interaction effect, change over the season for each variable of interest in the Control and 11+ groups, and differences between groups at pre- and postseason. The mean change over the season for each group was compared to the SDC and MID values (Table 1, Appendix A). Only statistically significant changes greater than the SDC were considered meaningful, and changes greater than the MID considered clinically meaningful.

Analysis of peak knee abduction angles bilaterally over the first season found main effects of group. To investigate this between-group effect further, the authors performed a one-way ANOVA comparing the postseason peak knee abduction angle of 11+ and Control groups, including preseason peak knee abduction angle in the model as a covariate. A 2×2 (time x group) ANOVA was also used to determine if the 11+ and Control groups' valgus collapse value changed differently across the first season.

Changes over the second season of 11+ use were compared to the changes over the first season using a 2×2 (time x seasons) repeated measures ANOVA with planned least squares comparisons. Again, planned comparisons were the interaction effect and the mean change across seasons were compared to the proposed SDC and MID values, and difference between the 1st and 2nd season at pre- and postseason.

Power Analysis:

An a priori power analysis was performed using G*Power software v 3.1.0 (Universität Düsseldorf, Düsseldorf, Germany). The preseason mean dominant peak knee abduction angles for the Control and 11+ groups were used to establish an effect size sensitive enough to detect a change larger than the SDC. These calculations indicated that an effect size of $f = 0.53$ (partial eta squared [η_p^2] = 0.22) was needed. Power calculations subsequently indicated that using a repeated measures ANOVA, with alpha set at $p=0.05$, and power = 0.80, a total sample size of 30 would be needed detect such an effect size. Partial eta squared (η_p^2) values were considered small 0.01, medium 0.06, or large 0.14.³⁰

Results

There were no differences between groups in any demographic or anthropometric variables (Table 2).

First season (Table 3):

There were significant main effects of time for non-dominant peak hip adduction angle ($F(1,35) = 4.51$, $p = 0.04$, $\eta_p^2 = 0.11$) and peak hip internal rotation angle ($F(1,35) = 5.33$, $p = 0.03$, $\eta_p^2 = 0.13$), but only the 11+ group had a meaningful change (Table 3). There were also significant main effects of time and group on both the dominant (main effect of time $F(1,35) = 19.00$, $p < 0.01$, $\eta_p^2 = 0.36$; main effect of group $F(1,35) = 18.49$, $p < 0.01$, $\eta_p^2 =$

0.59) and non-dominant (main effect of time $F(1,35) = 4.01$, $p = 0.05$, $\eta_p^2 = 0.10$; main effect of group $F(1,35) = 25.58$, $p < 0.01$, $\eta_p^2 = 0.42$) for knee abduction angle (Table 3). On the dominant limb both groups had clinically meaningful increases in knee abduction angle. On the non-dominant limb both groups had meaningful increases. To investigate the main effect of group further, the authors performed one-way ANOVAs comparing postseason peak knee abduction angles between groups, controlling for preseason peak knee abduction angle. There were no significant differences between groups in postseason peak knee abduction on either the dominant ($F(1,35) = 1.60$, $p = 0.21$) or non-dominant limb ($F(1,35) = 2.01$, $p = 0.17$) when controlling for preseason peak knee abduction angle, meaning that when controlling for baseline differences between groups there was no difference between the Control and 11+ groups at postseason.

There were no significant time x group interactions for the valgus collapse value for either limb (Dominant $F(1,35) = 0.75$, $p = 0.39$, $\eta_p^2 = 0.02$; Non-dominant $F(1,35) = 0.01$, $p = 0.91$, $\eta_p^2 = 0$), however there were main effects of time (Dominant $F(1,35) = 9.43$, $p < 0.01$, $\eta_p^2 = 0.23$; Non-Dominant $F(1,35) = 6.56$, $p = 0.02$, $\eta_p^2 = 0.18$). From pre- to postseason both groups moved more towards a more varus landing pattern (Figure 3).

In addition to the motions related to valgus collapse, both groups had meaningful decreases in dominant peak hip flexion angle (main effect of time $F(1,35) = 4.85$, $p = 0.04$, $\eta_p^2 = 0.13$). There was also a significant time x group interaction for dominant peak knee flexion angle ($F(1,35) = 7.64$, $p = 0.05$, $\eta_p^2 = 0.18$) (Table 3). Both groups had decreases in peak knee flexion angle, but the Control group had a clinically meaningful decrease, where the 11+ group did not have a meaningful change (Supplemental Figure 1A). On the non-dominant limb there was no significant time x group interaction ($F(1,35) = 2.93$, $p = 0.10$, $\eta_p^2 = 0.08$), however there was a significant main effect of time ($F(1,35) = 4.25$, $p = 0.05$, $\eta_p^2 = 0.11$) (Table 3). Both groups had decreases in peak knee flexion angle, but this decrease was only meaningful in the Control group (Supplemental Figure 1B).

Second Season (Table 4):

There was a significant time x season interaction in non-dominant peak hip adduction angle ($F(1,42) = 1.40$, $p = 0.02$, $\eta_p^2 = 0.13$) (Table 4). During the first season the peak hip adduction angle moved meaningfully into more hip abduction, however during the second season there was no meaningful change (Figure 4 A and B). There was also a time x season interaction for non-dominant peak hip internal rotation angle ($F(1,42) = 6.69$, $p = 0.01$, $\eta_p^2 = 0.14$) (Table 4). During the first season the peak hip internal rotation angle moved meaningfully into more hip external rotation, but no meaningful change occurred in the second 11+ season (Figure 4 C and D).

There was a significant time x season interaction for dominant peak knee abduction angle ($F(1,42) = 5.04$, $p = 0.03$, $\eta_p^2 = 0.11$) (Table 4). There was an increase in peak knee abduction angle over both seasons, however this increase was only clinically meaningful during the first season (Figure 4 E). On the non-dominant side there was a main effect of time ($F(1,42) = 5.32$, $p = 0.05$, $\eta_p^2 = 0.11$) (Figure 4 F), with meaningful increases in peak knee abduction angle over both seasons.

There were no significant time x season interactions in valgus collapse value for either the dominant ($F(1,42) = 1.02$, $p = 0.33$, $\eta_p^2 = 0.05$) or non-dominant limbs ($F(1,42) = 1.24$, $p = 0.28$, $\eta_p^2 = 0.06$). There was a significant main effect of season on the non-dominant limb ($F(1,42) = 6.33$, $p = 0.02$, $\eta_p^2 = 0.23$), with the athletes on average staying in a more varus pattern over the course of the second 11+ season (Preseason $-6.83 \pm 7.22^\circ$, Postseason $-6.24 \pm 8.15^\circ$) compared to the first season (Preseason $-3.46 \pm 7.43^\circ$, Postseason $-4.90 \pm 7.62^\circ$). There was no main effect of season ($F(1,42) = 1.43$, $p = 0.24$, $\eta_p^2 = 0.06$) on the dominant limb (1st season Preseason $-1.57 \pm 7.20^\circ$, Postseason $-1.49 \pm 5.90^\circ$; 2nd season Preseason $-3.62 \pm 7.42^\circ$, Postseason $-1.50 \pm 7.45^\circ$).

In addition to the motions related to valgus collapse, there was a significant time x season interaction ($F(1,42) = 3.98$, $p = 0.05$, $\eta_p^2 = 0.09$) in non-dominant peak hip flexion angle (Table 4). During the first season there was a meaningful decrease in peak hip flexion angle, however during the second season there was a meaningful increase (Supplemental Figure 2A). This pattern was similar on the dominant limb, however the interaction was not significant ($F(1,42) = 3.33$, $p = 0.08$, $\eta_p^2 = 0.08$) (Table 4, Supplemental Figure 2 B).

Discussion

The 11+ encourages proper lower extremity alignment and jump landing technique. Theoretically, teaching players appropriate technique should influence biomechanical risk factors, such as valgus collapse and peak knee abduction moment,²⁵ and ideally lead to a reduction in knee and ACL injuries. This study did not find any meaningful changes in peak knee abduction moment over either season of 11+ use, and both Controls and 11+ athletes had increases in peak knee abduction angles. Over the course of the first season, the 11+ and Control groups had similar changes in valgus collapse values, and neither had bilateral changes in frontal or transverse plane hip mechanics. As neither of the study hypotheses were supported, the results of this study indicate that the mechanism by which the 11+ reduces non-contact lower extremity injuries may not be via avoiding valgus movement patterns, and that in collegiate women the 11+ may need to be modified so that it can make a greater impact on biomechanics associated with higher knee injury risk.

A primary focus of this study was changes in valgus collapse, the combined motion of hip adduction, internal rotation, and knee abduction. Knee abduction angle and moment, in particular, have been associated with both primary and secondary ACL injury risk.^{9,10,25} In the first season both Control and 11+ athletes experienced a bilateral increase in peak knee abduction angle. Of particular concern, both groups experienced a clinically meaningful increase in dominant peak knee abduction angle. The 11+ athletes also had meaningful increase in non-dominant peak knee abduction angle over the second season. The 11+ group did not experience a meaningful change in peak knee abduction moment over either season, but these results would seem to indicate that the 11+ may actually be accentuating movement patterns at the knee that were previously identified as risky during a drop jump.

There were interesting results when examining the other two components of valgus collapse, peak hip adduction and internal rotation angles. Over the course of the first season, the 11+ athletes landed in more hip abduction and external rotation on their non-dominant limb.

They did not, however, have any meaningful changes on their dominant limb. In contrast, although there were no statistically significant interactions or main effects, the Control group athletes had meaningful increases in hip abduction and external rotation on their dominant limbs, with no meaningful changes on the non-dominant limb. It is unclear the reason for or impact of these results. It could be that the 11+ has unilateral effects, however how or why the program would only impact one limb is uncertain. Collegiate women soccer players have biomechanical asymmetries, as was seen in establishing SDC values (Table 1 in Appendix A). However, at baseline the athletes were already in more hip abduction and external rotation on their non-dominant limbs compared to their dominant (Table 1 in Appendix A). For a soccer player, the non-dominant limb is their stance leg, meaning it is the foot planted on the ground during kicking. It has been proposed that the non-dominant limb of women soccer players may be at a higher risk for non-contact ACL injuries,³¹ in which case the unilateral effects of the 11+ may have been helpful in protecting these athletes, however this is only hypothetical. More research is needed into the mechanism of the 11+ and investigate if the program indeed has unilateral effects.

A unique aspect of this study was the creation of a valgus collapse measure. Hip adduction, hip internal rotation, and knee abduction do not occur in isolation and from a clinical standpoint knowing if a change is occurring specifically in hip abduction or external rotation may be less important than knowing whether the overall movement pattern is improving. Thus, use of this measure may be helpful to both summarize the results of the individual joint measures, and to frame a more global picture for change, or lack thereof, in movements these athletes are performing. In the present results the mean valgus collapse value at baseline on the dominant limb was around zero for both groups, and slightly negative (indicating more hip abduction, external rotation, and knee adduction) on the non-dominant. Such a baseline indicates that the mean across athletes was not in a valgus collapse. Further work examining the valgus collapse value could explore if athletes who had positive valgus collapse values changed differently over the course of the season from those closer to neutral. The results of this study do indicate that although both the 11+ and Control group athletes landed in more knee abduction at postseason, the valgus collapse values indicate that such changes at the knee may have been countered by the changes at the hip, as both groups bilaterally land in a more varus pattern after the first season. Additional work examining the valgus collapse value could further justify its clinical utility as well as identify athletes who might gain more benefit biomechanically from the 11+ program.

In addition to avoiding knee valgus, the 11+ encourages “soft landings,” or landings with greater hip and knee flexion.³ Although the 11+ group was not different from the Controls in peak hip flexion angle (both groups had bilateral meaningful decreases), they did not have meaningful decreases in peak knee flexion angle on either limb. Sagittal plane forces alone do not cause ACL injuries, but a more extended knee position in combination with transverse and frontal plane forces may place the ACL at greater risk for injury.³² Thus, the 11+ may have mitigated clinically meaningful decreases in knee flexion, however such changes may have been less important in regards to preventing knee injuries than influencing frontal and transverse plane mechanics at the knee and hip.

A strength of this study was the calculation of SDC and MID values. SDC and MID provide clinical context to changes seen in response to an intervention. Previous studies have found that motion analysis of a DVJ is reliable,^{15,16,33} but none have used SDC or MID values to provide context for the amount of change needed to exceed the measurement error (SDC) and be clinically meaningful (MID). Further, unlike previous studies that have used a 31cm step, this study used a 40cm step, potentially serving as a reference for future work. Unfortunately, due to the step height difference the SDC and MID values from this study can't be used compare the results of this study to others, but previous biomechanical studies have shown neuromuscular prevention programs to change movement patterns. One study examining the PEP program (an 11+ predecessor), in high school age women athletes found increases in hip abduction and external rotation angles.²² The study only examined the dominant limb though.²² Given the asymmetries between limbs and unilateral effects of the 11+ observed in this study, information on the non-dominant limb effects of the PEP program would be valuable. Differences in external moment calculations, particularly the way moments were normalized, makes comparison of this study to the outcomes of the Sportsmetrics™ program difficult.^{17,21,23,24} Sportsmetrics is a 90–120 minute injury prevention program, performed two times per week for six weeks, has reported changes in frontal plane knee mechanics.^{17,21,24} Future research is needed investigate if the longer duration and higher intensity, particularly the higher dosage of plyometric exercises and close supervision, involved in the Sportsmetrics program as compared to the 11+, may be necessary to change biomechanical knee injury risk factors and preventing knee injuries in women.

Overall, the results of this study indicate that changing DVJ landing biomechanics may not be the mechanism by which the 11+ prevents non-contact injuries. The 11+ has been shown to improve dynamic balance and agility in soccer players.³⁴ Thus, it seems plausible that the 11+ changes neuromuscular control, potentially without changing an athlete's biomechanics as captured by a traditional kinematic and kinetic viewpoint. For example, other biomechanical methods such as examining changes in power, or neuromuscular techniques such as electromyography could show changes as a result of the 11+ that were not seen in this study. It is also possible that another movement, such as a single leg cutting or jumping task, might better reflect changes. The DVJ is not a soccer movement and is artificial when performed in a laboratory as there is no ball, opponent, or game-play,, all variables that could make movement in a lab different from that during training or games. Further, although the efficacy of the 11+ have been demonstrated in college age men^{1,5} and high school age women soccer players,² the efficacy in college age women is not yet known. The authors expect that the program helps prevent lower extremity and knee injuries, but large scale prospective studies are needed to determine the program's protective effects in college age women soccer players.

This study has limitations. Each exercise in the 11+ has three, progressively more difficult, stages. Unfortunately, neither progression through the 11+, nor the number of times each individual player performed the 11+ were recorded. The program was run and progressed by coaches/athletic trainers, and the researchers only received verbal confirmation of compliance from the coaching staff at the end of the season. Future research must include details of progression through the 11+ stages and investigate compliance on an individual

rather than team level. Future studies should also include site visits to ensure fidelity of the intervention. None of the coaches, athletic trainers, or athletes were familiar with or had performed the 11+ prior to this study, but future studies should explore whether athletes who progress to the most difficult level of exercises then plateau, potentially effecting the program's efficacy over multiple seasons. In addition, future studies should also include blinding and randomization.

To those unfamiliar with US collegiate sports it may seem that this study had a very large loss to follow-up. Difficulties associated with studying NCAA athletes over multiple seasons include injuries, graduation, scheduling conflicts, and university transfers, are common. Unfortunately, adding to these usual difficulties, this study also encountered marker drop out due to the athletes' arm swing obstructing cameras (Appendix A). The researchers chose not to limit arm motion to preserve the sport-like quality of the task. This decision meant the loss of six players' data. However, the authors found no differences in first season biomechanics between 11+ athletes with two seasons of complete data versus only first season data (data not shown). Therefore, while future studies with smaller loss to follow-up are needed, the authors believe that this study stands as strong preliminary data.

In conclusion, this study found both the 11+ and Control groups had bilateral increases in peak knee abduction angle, coupled with unilateral increases in hip abduction and external rotation on the non-dominant side for the 11+ group and dominant for the Control group. Although the 11+ may have mitigated bilateral decreases in knee flexion angle, it is unclear the overall effects of the program on the variables that have been previously associated with knee and ACL injury risk. Due to the program's effectiveness in other cohorts^{1,2,5,35} the authors emphasize that this study should not dissuade clinicians, coaches, or athletes from implementing the 11+. Rather, this study stands as one of the first in many investigations of the program's mechanism, so that researchers and clinicians can continue to optimize the 11+; keeping future generations of athletes healthy and on the field.

Brief Perspectives

The 11+ (previously known as the FIFA11+), is a neuromuscular injury prevention program involving running, strengthening, balance, and plyometric exercises. The program is effective in reducing lower extremity injuries in collegiate age men and high school age women.^{1,2,5} The 11+ program focuses on proper lower extremity alignment and landing technique with emphasis on avoiding valgus movement patterns (knee abduction, hip adduction, and hip internal rotation). This study found both the 11+ and Control groups had bilateral increases in peak knee abduction angle, coupled with unilateral increases in hip abduction and external rotation on the non-dominant side for the 11+ group and dominant for the Control group. Although the 11+ may have mitigated bilateral decreases in knee flexion angle, it is unclear the overall effects of the program on the variables that have been previously associated with knee and ACL injury risk. Due to the program's effectiveness in other cohorts^{1,2,5,35} the authors emphasize that this study should not dissuade clinicians, coaches, or athletes from implementing the 11+, but provides support for future research into the mechanism and efficacy of the program.

Supplementary Material

Refer to Web version on PubMed Central for supplementary material.

Acknowledgements

The authors would like to thank the women's soccer coaching, athletic training, and strength and conditioning staff at the University of Delaware, Temple University, and Wilmington University for their support and participation in this study. The authors would also like to thank Kelsey O'Donnell and Elise Krause for their help with data processing.

The work of Amelia Arundale was supported by the National Institutes of Health [R01 AR048212 and R44 HD068054]. The work of Holly Silvers was supported in part by the National Institutes of Health [R44 HD068054]. The work of Ryan Zarzycki was supported by the National Institutes of Health [R37 HD037985]. Amelia Arundale also received support for some of her work from a Foundation for Physical Therapy Promotion of Doctoral Studies I Scholarship.

Appendix A.

Motion Analysis

Motion analysis of a drop vertical jump (DVJ) was performed using an eight camera motion system (VICON; Oxford Metrics Ltd, London, England) sampled at 240Hz, and two 6 component embedded force plates (Bertec, Worthington, Ohio, USA) sampled simultaneously at 1080Hz. Athletes wore their own athletic shoes and clothes. Twenty two retro-reflective markers were affixed, using double sided tape, on the acromion, pelvis, and lower extremities (medial and lateral metatarsal heads, medial and lateral malleoli, medial and lateral femoral condyles, the greater trochanters of each hip, and each acromion) to identify joint centers. Six rigid shells were affixed, using elastic wraps, on the trunk, pelvis, thighs, and shanks, to track segment motion. Previous research, including a reliability study that calculated SDC and MID values for walking gait,¹⁴ has used this marker set.^{21,22} All markers were placed by one researcher (AA) who had excellent inter-rater (against others who regularly use this marker set, ICC >0.95) and intra-rater reliability (ICC >0.97).

Appendix A, Figure 1.

Marker set used in this study

Marker set used for study. Individual markers affixed medially and laterally to identify joint centers (medial and lateral metatarsal heads, medial and lateral malleoli, medial and lateral femoral condyles, the greater trochanters of each hip, and each acromion). Six rigid shells were affixed to the trunk, pelvis, thighs, and shanks, to track each segment.

The DVJ was performed similar to Hewett et al.¹² Athletes dropped from a 40 cm box, landing with one foot on each force plate. Upon landing they immediately jumped up and again landed with one foot on each force plate. Analysis focused on the first landing, with initial contact defined by when the vertical force exceeded 5N. Athletes were given verbal instructions and allowed to practice the DVJ. Three trials of the DVJ were then performed with no standardization of the time between jumps.

Post-processing

Markers were labeled using Vicon Nexus software (v 1.8.5, VICON, Oxford Metrics Ltd, London, England) and gaps in the signal caused by marker drop out were filled using the program's spline filling algorithm (maximum five frames). Trials with gaps > 5 frames were excluded from analysis. In the first season 65 athletes (11+ = 46, Control = 19) participated in preseason motion analysis testing of the DVJ. Of those, 54 had usable 1st season DVJ

biomechanical data (11+ = 39, Control = 15) (Figure 1 of main text). The primary reasons for exclusion in the first season were injury (11+ = 4, Control = 4) and marker drop out (11+ = 3). Marker drop out was caused by the athlete's arms swing obstructing the thigh shells from camera view. This issue was not experienced in piloting with non-athletes. The authors chose to sacrifice the data points in favor of limiting arm motion to preserve the sport-like aspects of the movement.

Rigid-body analysis and inverse dynamics post-processing was performed using Visual 3D (C-Motion Inc., Germantown, Maryland, USA). Kinematic and kinetic data were low pass filtered at 6 Hz and 40 Hz respectively.¹³ External moments were calculated and in accordance with the right hand rule hip flexion, hip adduction, hip internal rotation, knee extension, and knee adduction, were presented as positive values. Moments were normalized to body weight x height. Variables of interest were the peak hip flexion, adduction, and internal rotation angles and external moments, as well as peak knee flexion and abduction angles and external moments. In keeping with the methods of previous studies^{9–11} the peak angles and moments were used as opposed to the angle and moments at initial contact or peak knee flexion.

Smallest Detectable Change (SDC)

Smallest detectable change (SDC, also known as the minimum detectable change) and minimum important difference (MID, also known as the minimum clinically important difference) provide clinical context to changes seen in response to an intervention. Previous studies have found that motion analysis of a DVJ is reliable,^{17–19} but none have used SDC or MID values to provide context for the amount of change needed to exceed the measurement error (SDC) and be clinically meaningful (MID).

To determine SDC and MID values the biomechanical data from all athletes (Control and 11+ athletes, N=54) at preseason of the first season was used. All statistical analyses were performed in SPSS version 24 (Microsoft, Redmond, Washington, USA) and Microsoft Excel 2013 (Redmond, Washington, USA). Paired *t* tests were performed to determine if SDC values could be applied bilaterally. There were significant differences between the dominant and non-dominant limbs in hip adduction angle ($p=0.02$), hip internal rotation angle ($p<0.01$) and moment ($p<0.01$), knee flexion angle ($p<0.04$) and knee abduction moment ($p<0.01$) (Appendix Table 1); as a result, separate dominant and non-dominant ICCs, SEMs, and SDCs were calculated. (Dominance was determined via athlete self-report of their preferred kicking leg. Only five athletes were left-foot dominant.)

Appendix A Table 1

Results of paired *t* tests (N=54)

Variable	Dominant (Mean $\pm$ Standard Deviation)	Non-Dominant (Mean $\pm$ Standard Deviation)	p-value	Cohen's D
Peak Hip Flexion Angle	88.72 $\pm$ 13.51°	89.33 $\pm$ 13.73°	0.29	0.04
Peak Hip Flexion Moment	-1.10 $\pm$ 0.26 Nm/kgm	-1.10 $\pm$ 0.26 Nm/kgm	0.93	0.00

Variable	Dominant (Mean $\pm$ Standard Deviation)	Non-Dominant (Mean $\pm$ Standard Deviation)	p-value	Cohen's D
Peak Hip Adduction Angle [*]	-2.19 $\pm$ 5.15°	-4.21 $\pm$ 4.45°	0.02	0.42
Peak Hip Adduction Moment	-0.16 $\pm$ 0.10 Nm/kgm	-0.15 $\pm$ 0.10 Nm/kgm	0.29	0.10
Peak Hip Internal Rotation Angle ^{**}	-5.11 $\pm$ 6.47°	-8.08 $\pm$ 5.98°	<0.01	0.48
Peak Hip Internal Rotation Moment	-0.19 $\pm$ 0.08 Nm/kgm	-0.16 $\pm$ 0.08 Nm/kgm	<0.01	0.38
Peak Knee Flexion Angle	-105.33 $\pm$ 12.14°	-106.76 $\pm$ 12.14°	0.04	0.12
Peak Knee Flexion Moment	0.98 $\pm$ 0.15 Nm/kgm	0.95 $\pm$ 0.16 Nm/kgm	0.29	0.19
Peak Knee Abduction Angle	-1.76 $\pm$ 3.76°	-1.79 $\pm$ 4.76°	0.96	0.01
Peak Knee Abduction Moment	0.26 $\pm$ 0.12 Nm/kgm	0.17 $\pm$ 0.10 Nm/kgm	<0.01	0.81

In accordance with the right hand rule, hip flexion, adduction, internal rotation, knee extension, and adduction are presented as positive.

^{*} Some athletes performed the DVJ in hip adduction (+) others in hip abduction (-). As a result the mean peak hip adduction angle was negative, and actually represents a small hip abduction angle.

^{**} Similar to the peak hip adduction angle, some athletes performed the DVJ in hip internal rotation (+) some in hip external rotation (-). As a result the mean peak hip internal rotation angle was negative, and actually represents a small hip external rotation angle.

Intraclass Correlation Coefficients (ICC)(2,1)ⁱ was selected for analysis.^{23,24} The standard error of the mean (SEM) was calculated using the equation $SEM = \text{Standard Deviation} \times (1 - ICC)$. The SDC was calculated using the equation $SDC = SEM \times 1.96 \times (2)$.²³ ICCs were classified as either excellent (>0.75), good (0.60–0.75), fair (0.40–0.59), or poor (<0.40).²⁵ Effect sizes (Cohen's D) were classified as small (0.2), medium (0.5), and large (0.8).²⁶ ICC analyses were performed on all three DVJ trials for each variable (data not shown), but there were significant inter-trial differences for peak hip flexion angle (dominant $p < 0.01$, non-dominant $p < 0.01$), non-dominant peak hip flexion moment ($p = 0.05$) and peak hip adduction moment ($p = 0.04$), dominant peak hip internal rotation angle ($p = 0.02$), non-dominant peak knee flexion angle ($p = 0.02$), and peak knee flexion moment (dominant $p = 0.01$, non-dominant $p = 0.02$). Previous work by James et al²⁷ found that ground reaction force measures don't stabilize until after at least two trials. Thus, the analysis was repeated using only the second and third trials.ⁱⁱ

ⁱThis study used ICC (2,1), meaning the analysis used a two-way model (keeping variability between trials and error separate), that assessed single scores from each athlete for each trial, and assumed the rater was a random sample from a population of raters.²³ In other words, the person who placed the markers was considered to be one of many people who could have placed the markers. In this study even though only one researcher placed all of the markers, that researcher was highly reliable to a larger group of investigators, and thus could have been replaced by any other reliable researcher. In contrast, previous studies^{17,19} used ICC (3,k), a two-way model, that uses an average score across trials from each subject, and assumes that the rater(s) is/are the only rater(s) of interest.²³ In other words, the results are only applicable to the raters or researchers who placed the markers in the study.²³ Therefore, although the differences in ICCs are minimal and all studies indicate good to excellent reliability, the implications of the ICC models means the results of this study are more generalizable. By using ICC (2,1) the SDCs produced from this study can be used anywhere. Clinicians and researchers can apply similar methods and evaluate athlete's movement to determine if meaningful changes have occurred.

ⁱⁱAn argument could be made that higher reliability was found assessing two trials as opposed to three because variability was reduced by removing a trial. The authors acknowledge this possibility, and hope that further research designed specifically to assess and calculate SDC and MID values may clarify the exact methods needed to perform and analyze a DVJ. However, given that previous research²⁷ found that measures related to ground reaction force during jumping require 2–8 trials to stabilize, we feel using the second

Using only the second and third trials all variables had excellent ICCs with the exception of two which had good ICCs (Appendix Table 2). There was a significant difference between trials in non-dominant knee abduction angle, however, the effect size for this inter-trial difference was small ($p = 0.05$, Cohen's $D = 0.13$). The SDC values are presented in Appendix A Table 2.

Appendix A Table 2

Reliability analysis (N=54)

	Dominant			Non-Dominant		
	ICC	95% CI	SEM	ICC	95% CI	SEM
Hip Flexion Angle (°)	0.94 (excellent)	0.90 – 0.97	0.80	0.94 (excellent)	0.91 – 0.97	0.79
Hip Flexion Moment (Nm/kgm)	0.67 (good)	0.49 – 0.79	0.10	0.82 (excellent)	0.71 – 0.89	0.05
Hip Adduction Angle (°)	0.91 (excellent)	0.85 – 0.95	0.49	0.84 (excellent)	0.74 – 0.90	0.75
Hip Adduction Moment (Nm/kgm)	0.79 (excellent)	0.67 – 0.87	0.07	0.82 (excellent)	0.71 – 0.89	0.06
Hip Internal Rotation Angle (°)	0.91 (excellent)	0.86 – 0.95	0.58	0.87 (excellent)	0.79 – 0.92	0.76
Hip Internal Rotation Moment (Nm/kgm)	0.65 (good)	0.47 – 0.78	0.03	0.75 (excellent)	0.60 – 0.85	0.02
Knee Flexion Angle (°)	0.86 (excellent)	0.77 – 0.92	1.70	0.86 (excellent)	0.76 – 0.91	1.82
Knee Flexion Moment (Nm/kgm)	0.78 (excellent)	0.64 – 0.86	0.03	0.85 (excellent)	0.75 – 0.91	0.03
Knee Abduction Angle (°)	0.95 (excellent)	0.92–0.97	0.18	0.96 (excellent)	0.93–0.97	0.23
Knee Abduction Moment (Nm/kgm)	0.76 (excellent)	0.61–0.85	0.03	0.73 (excellent)	0.58–0.84	0.03

Abbreviations: ICC: Intra-class Correlation Coefficient, 95% CI: 95% confidence interval, SEM: standard error of the mean.

Minimal Important Differences (MID)

As the 11+ teams participated in the intervention, they could not be used in the MID calculations. Control group athletes were monitored throughout the soccer season by a certified athletic trainer and all injuries/complaints reported to the athletic trainer were recorded. At the conclusion of the season Control athletes were categorized as to whether they experienced a non-contact lower extremity injury²⁸ (Injured) or not (Uninjured). In accordance with the United European Football Associations' consensus statement, a lower extremity injury was defined as any physical complaint relating to the hip, groin, thigh, knee, shank, ankle, or foot, sustained by the player during a soccer game or training session.²⁸ This study used a time-loss definition of injuries, meaning only injuries that resulted in the player being unable to take full part in a future soccer game or training session, were

and third recorded trial is justified, as these trials likely represent the most stable values. Athletes took one practice trial before the three recorded trials, thus the second and third recorded trials are equivalent to the third and fourth times the athlete performed the jump. Further, the authors specifically chose an ICC (2,1) rather than an ICC (2,k), to try and address the concern of the number of trials. An ICC (2,1) uses each individual trial, where an ICC (2,k) uses the average of the trials for each subject. Thus, even though an ICC (2,k) would have produced higher ICCs, an ICC(2,1) was more appropriate. Further, although recording three DVJ trials is common in the literature,^{12,17–19,31} more research may be needed to explore if there is a learning effect and the impact of performing more than three trials.

recorded.²⁸ A non-contact injury was defined as an injury that did not result from a collision with another player or object.²⁸ Non-contact lower extremity injuries were examined as they are the target of the 11+ prevention program. A MANOVA was used to assess if there were differences between the Injured and Uninjured groups in the variables of interest at preseason. The mean difference between the Injured and Uninjured groups was compared to the SDC. Where the mean difference between the Injured and Uninjured groups was greater than the SDC it was chosen as the MIDⁱⁱⁱ.²⁹

Ten of the 19 Control group athletes who participated in preseason DVJ testing experienced non-contact lower extremity injuries (Injured). Injuries included: Achilles pain/calf tightness, lateral ankle sprains, groin, hamstring and quadriceps strains, patellofemoral pain, peroneal tendonitis, and iliotibial band syndrome. There were ten measures where the mean differences between groups exceeded the SDC, these were chosen as MID values.

Appendix A Table 3

Results of MANOVA comparing Injured (N=10) and Uninjured (N=9) athletes

Variable	Smallest Detectable Change	Mean Difference between Injured and Uninjured groups	p-value	Effect size (Cohen's D)	Smallest Detectable Change	Mean Difference between Injured and Uninjured groups	p-value	Effect size (Cohen's D)
	Dominant				Non-Dominant			
Peak Hip Flexion Angle (°)	2.21	5.82 *	0.44	0.41	2.20	2.69 *	0.73	0.18
Peak Hip Flexion Moment (Nm/kgm)	0.27	0.11	0.42	0.43	0.14	0.03	0.81	0.13
Peak Hip Adduction Angle (°)	1.37	1.29	0.59	0.29	2.08	1.96	0.30	0.55
Peak Hip Adduction Moment (Nm/kgm)	0.19	0.03	0.55	0.32	0.17	0.03	0.47	0.38
Peak Hip Internal Rotation Angle (°)	1.61	4.73 *	0.20	0.69	2.10	2.21 *	0.40	0.45

ⁱⁱⁱThere are numerous methods for establishing MIDs.²⁹ Anchor-based methods compare a change in the outcome score to an external criteria, such as a global rating of change.²⁹ Distribution-based methods compare the score to a measure of variability such as the SEM or SDC.²⁹ In establishing MID values for gait biomechanics after ACL reconstruction, Di Stasi et al.¹⁴ used a hybrid of these approaches by comparing the knee extension range of motion loss known to effect patient function as a clinical anchor, and comparing this clinical anchor to a distribution measure, the SDC.¹⁴ The present study aimed to be conservative in proposing preliminary MID values, and thus used a similar hybrid method. As in an anchor-based method where a global rating of change score is used to dichotomize athletes and then the differences between groups in the variable of interest is used as an MID,²⁹ this study categorized Control group athletes as Injured or Uninjured and examined the mean difference in each variable of interest between groups. This anchor-based approach was taken one step further. The mean difference between the Injured and Uninjured Control athletes was compared to both the SEM and SDC, distribution-based methods. MID values were proposed only where the mean difference between the Injured and Uninjured Control athletes exceeded the SEM and SDC. These MID values should not be considered definitive, and future research should examine SDC and MID values more rigorously in the DVJ.

Variable	Smallest Detectable Change	Mean Difference between Injured and Uninjured groups	p-value	Effect size (Cohen's D)	Smallest Detectable Change	Mean Difference between Injured and Uninjured groups	p-value	Effect size (Cohen's D)
Peak Hip Internal Rotation Moment (Nm/kgm)	0.09	0.02	0.40	0.45	0.06	0.03	0.32	0.53
Peak Knee Flexion Angle (°)	4.71	8.44 *	0.19	0.70	5.06	9.92 *	0.09	0.93
Peak Knee Flexion Moment (Nm/kgm)	0.10	0.12 *	0.06	1.04	0.07	0.08 *	0.27	0.59
Peak Knee Abduction Angle (°)	0.49	0.99 *	0.68	0.22	0.62	3.05 *	0.29	0.56
Peak Knee Abduction Moment (Nm/kgm)	0.09	0.01	0.88	0.09	0.08	0.07	0.13	0.83

* The mean difference between the Injured and Uninjured Control group athletes was greater than the SDC and thus selected to be a MID value

Power for SDC calculations

Power calculations were performed similar to Mok et al.¹⁹ using sample size calculations specifically designed for reliability studies.³⁰ Using a confidence interval width of 0.2, a mean ICC value of 0.80, $p = 0.05$, with two trials of the DVJ a minimum sample size of 50 was needed to establish SDC values.

References

1. Silvers-Granelli H, Mandelbaum B, Adeniji O, et al. Efficacy of the FIFA 11+ Injury Prevention Program in the Collegiate Male Soccer Player. *Am J Sports Med.* 2015;43(11):2628–2637. [PubMed: 26378030]
2. Soligard T, Myklebust G, Steffen K, et al. Comprehensive warm-up programme to prevent injuries in young female footballers: cluster randomised controlled trial. *Br Med J.* 2008;337.
3. Bizzini M, Dvorak J. FIFA 11+: an effective programme to prevent football injuries in various player groups worldwide—a narrative review. *Br J Sports Med.* 2015;49(9):577–579. [PubMed: 25878073]
4. Steffen K, Meeuwisse WH, Romiti M, et al. Evaluation of how different implementation strategies of an injury prevention programme (FIFA 11+) impact team adherence and injury risk in Canadian female youth football players: a cluster-randomised trial. *Br J Sports Med.* 2013;47(8):480–487. [PubMed: 23486935]
5. Silvers-Granelli H, Bizzini M, Arundale A, Mandelbaum B, Snyder-Mackler L. Does the FIFA11+ Injury Prevention Program Reduce Incidence of ACL Injury in Male Soccer Players? *Clin Orthop Rel Res.* 2017.
6. Stanley LE, Kerr ZY, Dompier TP, Padua DA. Sex Differences in the Incidence of Anterior Cruciate Ligament, Medial Collateral Ligament, and Meniscal Injuries in Collegiate and High School Sports. *Am J Sports Med.* 2016;44(6):1565–1572. [PubMed: 26940226]

7. NCAA. NCAA Women's Soccer Injuries; Data from the 2004/5– 2008/9 Seasons In: NCAA, ed. NCAA Injury Surveillance Program. Datalysicenter.org: NCAA, StopInjuries, Datalysicenter; 2010.
8. Hewett TE, Myer GD, Ford KR, et al. Biomechanical Measures of Neuromuscular Control and Valgus Loading of the Knee Predict Anterior Cruciate Ligament Injury Risk in Female Athletes: A Prospective Study. *Am J Sports Med.* 2005;33(4):492–501. [PubMed: 15722287]
9. Krosshaug T, Steffen K, Kristianslund E, et al. The Vertical Drop Jump Is a Poor Screening Test for ACL Injuries in Female Elite Soccer and Handball Players: A Prospective Cohort Study of 710 Athletes. *Am J Sports Med.* 2016;44(4):874–883. [PubMed: 26867936]
10. Paterno M, Schmitt L, Ford K, et al. Biomechanical measures during landing and postural stability predict second anterior cruciate ligament injury after anterior cruciate ligament reconstruction and return to sport. *Am J Sports Med.* 2010;38:1968–1978. [PubMed: 20702858]
11. Biomechanics Associated with Patellofemoral Weiss K, Whatman C. Pain and ACL Injuries in Sports. *Sports Med.* 2015;45(9):1325–1337. [PubMed: 26130304]
12. Barber-Westin SD, Smith ST, Campbell T, Noyes FR. The drop-jump video screening test: retention of improvement in neuromuscular control in female volleyball players. *J Strength Cond Res.* 2010;24(11):3055–3062. [PubMed: 20940643]
13. Herrington L, Munro A. Drop jump landing knee valgus angle; normative data in a physically active population. *Phys Ther Sport.* 2010;11(2):56–59. [PubMed: 20381002]
14. Kristianslund E, Krosshaug T. Comparison of Drop Jumps and Sport-Specific Sidestep Cutting: Implications for Anterior Cruciate Ligament Injury Risk Screening. *Am J Sports Med.* 2013;41(3):684–688. [PubMed: 23287439]
15. Malfait B, Sankey S, Azidin RFR, et al. How reliable are lower-limb kinematics and kinetics during a drop vertical jump. *Med Sci Sport Exer.* 2014;46(4):678–685.
16. Mok K-M, Petushek E, Krosshaug T. Reliability of knee biomechanics during a vertical drop jump in elite female athletes. *Gait Posture.* 2016;46:173–178. [PubMed: 27131197]
17. Myer G, Ford K, Brent J, Hewett T. Differential neuromuscular training effects on ACL injury risk factors in "high-risk" versus "low-risk" athletes. *BMC Musculoskelet Disord.* 2007;8(1):39. [PubMed: 17488502]
18. Myer G, Ford K, McLean S, Hewett T. The Effects of Plyometric Versus Dynamic Stabilization and Balance Training on Lower Extremity Biomechanics. *Am J Sports Med.* 2006;34(3):490–498. [PubMed: 16382007]
19. Nilstad A, Andersen TE, Kristianslund E, et al. Physiotherapists Can Identify Female Football Players With High Knee Valgus Angles During Vertical Drop Jumps Using Real-Time Observational Screening. *J Orthop Sports Phys Ther.* 2014;44(5):358–365. [PubMed: 24730435]
20. Paterno MV, Ford KR, Myer GD, Heyl R, Hewett TE. Limb asymmetries in landing and jumping 2 years following anterior cruciate ligament reconstruction. *Clin J Sports Med.* 2007;17(4):258–262.
21. Hewett T, Stroupe A, Nance T, Noyes F. Plyometric training in female athletes. Decreased impact forces and increased hamstring torques. *Am J Sports Med.* 1996;24(6):765–773. [PubMed: 8947398]
22. Pollard C, Sigward S, Ota S, Langford K, Powers C. The influence of in-season injury prevention training on lower-extremity kinematics during landing in female soccer players. *Clin J Sports Med.* 2006;16(3):223–227.
23. Lim B-O, Lee YS, Kim JG, An KO, Yoo J, Kwon YH. Effects of Sports Injury Prevention Training on the Biomechanical Risk Factors of Anterior Cruciate Ligament Injury in High School Female Basketball Players. *Am J Sports Med.* 2009;37(9):1728–1734. [PubMed: 19561174]
24. Myer G, Ford K, Palumbo J, Hewett T. Neuromuscular training improves performance and lower-extremity biomechanics in female athletes. *J Strength Cond Res.* 2005;19(1):51–60. [PubMed: 15705045]
25. Hewett T, Myer G, Ford K, et al. Biomechanical Measures of Neuromuscular Control and Valgus Loading of the Knee Predict Anterior Cruciate Ligament Injury Risk in Female Athletes: A Prospective Study. *Am J Sports Med.* 2005;33(4):492–501. [PubMed: 15722287]
26. Roewer BD, Ford KR, Myer GD, Hewett TE. The 'impact' of force filtering cut-off frequency on the peak knee abduction moment during landing: artefact or 'artificiality'? *Br J Sports Med.* 2014;48(6):464–468. [PubMed: 22893510]

27. Wilken JM, Rodriguez KM, Brawner M, Darter BJ. Reliability and minimal detectable change values for gait kinematics and kinetics in healthy adults. *Gait Posture*. 2012;35(2):301–307. [PubMed: 22041096]
28. Di Stasi SL, Hartigan EH, Snyder-Mackler L. Unilateral stance strategies of athletes with ACL deficiency. *J Applied Biomech*. 2012;28(4):374. [PubMed: 22983931]
29. Fuller CW, Ekstrand J, Junge A, et al. Consensus statement on injury definitions and data collection procedures in studies of football (soccer) injuries. *Br J Sports Med*. 2006;40(3):193–201. [PubMed: 16505073]
30. Cohen J A power primer. *Psychological Bulletin*. 1992;112(1):155. [PubMed: 19565683]
31. Brophy R, Silvers HJ, Gonzales T, Mandelbaum BR. Gender influences: the role of leg dominance in ACL injury among soccer players. *Br J Sports Med*. 2010;44(10):694–697. [PubMed: 20542974]
32. McLean S, Huang X, Su A, van den Bogert A. Sagittal plane biomechanics cannot injure the ACL during sidestep cutting. *Clin Biomech*. 2004;19:828–838.
33. Ford K, Myer G, Hewett T. Reliability of landing 3D motion analysis: implications for longitudinal analyses. *Med Sci Sport Exer*. 2007;39(11):2021–2028.
34. Impellizzeri FM, Bizzini M, Dvorak J, Pellegrini B, Schena F, Junge A. Physiological and performance responses to the FIFA 11+(part 2): a randomised controlled trial on the training effects. *J Sports Sci*. 2013;31(13):1491–1502. [PubMed: 23855764]
35. Thorborg K, Krommes KK, Esteve E, Clausen MB, Bartels EM, Rathleff MS. Effect of specific exercise-based football injury prevention programmes on the overall injury rate in football: a systematic review and meta-analysis of the FIFA 11 and 11+ programmes. *Br J Sports Med*. 2017;51(7):562–571. [PubMed: 28087568]

Figure 1:
CONSORT diagram of study, including testing time points and intervention

Figure 2:
Visual representation of positive and negative valgus collapse values

Figure 3:
Change in valgus collapse value over the first season on the dominant and non-dominant limbs in the Control and 11+ groups.

Figure 4:

Changes in hip adduction, hip internal rotation, and knee abduction angles over the first and second season of 11+ use. A) Dominant hip adduction angle (time x season interaction $p = 0.85$), B) Non-dominant hip adduction angle (time x season interaction $p = 0.02$), C) Dominant hip internal rotation angle (time x season interaction $p = 0.43$) D) Non-dominant hip internal rotation angle (time x season interaction $p = 0.01$, E) Dominant limb (time x season interaction ($p = 0.03$), F) Non-dominant limb (time x season interaction $p = 0.46$, main effect of time $p = 0.03$). Legend: The light grey line represents the 1st 11+ season, the dark grey line represents the 2nd 11+ season. * indicates the mean change across the season was meaningful and greater than the SDC, ** indicates the mean change across the season was clinically meaningful and greater than the MID. Note: In accordance with the right had rule hip adduction, hip internal rotation, and knee adduction are represented as positive. As many athletes landed and remained in hip abduction (–) rather than hip adduction (+), the mean peak hip adduction angle is actually in hip abduction. Similarly for peak hip internal rotation, as many landed and remained in hip external rotation (–), the mean peak hip internal rotation angle is actually in hip external rotation.

Table 1

Smallest Detectable Change and Minimal Important Difference

Variable	Side	SDC	MID
Peak Hip Flexion Angle (°)	Dominant	2.21	5.82
	Non-Dominant	2.20	2.69
Peak Hip Flexion Moment (Nm/kgm)	Dominant	0.10	
	Non-Dominant	0.14	
Peak Hip Adduction Angle (°)	Dominant	1.37	
	Non-Dominant	2.08	
Peak Hip Adduction Moment (Nm/kgm)	Dominant	0.19	
	Non-Dominant	0.17	
Peak Hip Internal Rotation Angle (°)	Dominant	1.61	4.73
	Non-Dominant	2.10	2.21
Peak Hip Internal Rotation Moment (Nm/kgm)	Dominant	0.09	
	Non-Dominant	0.06	
Peak Knee Flexion Angle (°)	Dominant	4.71	8.44
	Non-Dominant	5.06	9.92
Peak Knee Flexion Moment (Nm/kgm)	Dominant	0.10	0.12
	Non-Dominant	0.07	0.08
Peak Knee Abduction Angle (°)	Dominant	0.49	0.99
	Non-Dominant	0.62	3.05
Peak Knee Abduction Moment (Nm/kgm)	Dominant	0.09	
	Non-Dominant	0.08	

Abbreviations: SDC: smallest detectable change, MID: minimal important difference. MID values were only established for variables where the mean difference between Control athletes who experienced a non-contact lower extremity injury and those who did not was greater than the SDC (See Appendix A for details).

Table 2

Anthropometric and demographic comparison between groups

	11+ (N=22)	Control (N=15)	p-value
Age (years)	19.4 ± 1.3	19.4 ± 1.2	0.85
Height (m)	1.7 ± 0.1	1.6 ± 0.1	0.15
Weight (kg)	60.9 ± 2.0	63.7 ± 8.5	0.30
Limb Dominance Right Left	20 2	14 1	1.00
Position Goalkeeper Defender Midfielder Forward	2 4 10 6	1 6 5 3	0.54
Academic Year First Second Third Fourth	11 7 4 0	6 1 6 2	0.06

Table 3
Results of time x group ANOVAs comparing change across first season in the Control and 11+ groups

Variables	Dominant					Non-dominant				
	Time x Group Interaction	Main Effect of Time	Main Effect of Group	Preseason	Postseason	Time x Group Interaction	Main Effect of Time	Main Effect of Group	Preseason	Postseason
Peak Hip Flexion Angle (°)	0.98	0.04 [†]	0.59	Control: 85.31 ± 13.03 11+: 87.17 ± 12.34 p = 0.67 ₋	Control: 81.01 ± 11.16 [*] 11+: 82.94 ± 10.41 [*] p = 0.60	0.81	0.09	0.60	Control: 85.08 ± 15.17 11+: 87.58 ± 13.00 p = 0.60	Control: 82.44 ± 13.46 [*] 11+: 84.08 ± 10.57 [*] p = 0.68
Peak Hip Flexion Moment (Nm/kgm)	<0.01 [†]	0.90	0.09	Control: -0.99 ± 0.25 11+: -0.98 ± 0.19 p = 0.91	Control: -0.85 ± 0.30 [*] 11+: -1.11 ± 0.22 [*] p < 0.01	<0.01 [†]	0.28	0.03 [†]	Control: -0.97 ± -0.28 11+: -1.03 ± 0.22 p = 0.53	Control: -0.81 ± 0.29 [*] 11+: -1.09 ± 0.25 p < 0.01
Peak Hip Adduction Angle (°)	0.06	0.34	0.23	Control: -2.65 ± 4.85 11+: -2.03 ± 4.53 p = 0.69	Control: -4.45 ± 4.99 [*] 11+: -1.43 ± 4.77 p = 0.08	0.42	0.04 [†]	1.00	Control: -4.60 ± 3.87 11+: -3.99 ± 4.77 p = 0.68	Control: -5.55 ± 2.76 11+: -6.15 ± 5.11 [*] p = 0.68
Peak Hip Adduction Moment (Nm/kgm)	0.74	0.03 [#]	0.75	Control: -0.18 ± 0.09 11+: -0.18 ± 0.09 p = 0.88	Control: -0.22 ± 0.09 11+: -0.20 ± 0.11 p = 0.69	0.08	0.97	0.03 [#]	Control: -0.18 ± 0.07 11+: -0.11 ± 0.09 p = 0.02	Control: -0.16 ± 0.06 11+: -0.13 ± 0.07 p = 0.19
Peak Hip Internal Rotation Angle (°)	0.19	0.42	0.10	Control: -6.38 ± 7.86 11+: -4.59 ± 5.25 p = 0.42	Control: -8.48 ± 6.09 [*] 11+: -4.09 ± 5.46 p = 0.03	0.20	0.03 [†]	0.93	Control: -8.53 ± 5.23 11+: -7.54 ± 6.20 p = 0.61	Control: -9.42 ± 5.79 11+: -10.73 ± 6.52 [*] p = 0.54
Peak Hip Internal Rotation Moment (Nm/kgm)	<0.01 [#]	0.42	0.01 [#]	Control: -0.17 ± 0.05 11+: -0.18 ± 0.06 p = 0.40	Control: -0.13 ± 0.06 11+: -0.20 ± 0.06 p < 0.01	0.71	0.25	0.12	Control: -0.14 ± 0.05 11+: -0.17 ± 0.07 p = 0.20	Control: -0.15 ± 0.07 11+: -0.19 ± 0.08 p = 0.16
Peak Knee Flexion Angle (°)	0.05 [†]	<0.01 [†]	0.85	Control: -107.69 ± 12.67 11+: -103.39 ± 13.80 p = 0.35	Control: -99.14 ± 11.10 ^{**} 11+: -102.08 ± 8.68 p = 0.38	0.10	0.05 [†]	0.94	Control: -107.36 ± 12.18 11+: -104.80 ± 13.97 p = 0.57	Control: -101.15 ± 10.17 [*] 11+: -104.22 ± 10.66 p = 0.39
Peak Knee Flexion Moment (Nm/kgm)	0.25	0.45	0.77	Control: 1.01 ± 0.12 11+: 0.98 ± 0.14 p = 0.41	Control: 0.93 ± 0.28 11+: 0.99 ± 0.11 p = 0.38	0.09	0.54	0.60	Control: 0.98 ± 0.17 11+: 0.96 ± 0.16 p = 0.69	Control: 0.90 ± 0.34 [*] 11+: 0.99 ± 0.16 p = 0.28
Peak Knee Abduction Angle (°)	0.86	<0.01 [†]	<0.01 [†]	Control: -5.51 ± 4.43 11+: -0.43 ± 3.15	Control: -8.11 ± 4.58 ^{**}	0.85	0.05 [†]	<0.01 [†]	Control: -5.40 ± 5.92 11+: -0.11 ± 3.77	Control: -6.77 ± 5.64 [*]

Variables	Dominant					Non-dominant				
	Time x Group Interaction	Main Effect of Time	Main Effect of Group	Preseason	Postseason	Time x Group Interaction	Main Effect of Time	Main Effect of Group	Preseason	Postseason
				p < 0.01	11+: -2.83 ± 3.82 ^{**} p < 0.01				p < 0.01	11+: -1.76 ± 3.91 [*] p < 0.01
Peak Knee Abduction Moment (Nm/kgm)	0.50	0.51	0.53	Control: 0.26 ± 0.13 11+: 0.23 ± 0.09 p = 0.37	Control: 0.24 ± 0.15 11+: 0.23 ± 0.08 p = 0.80	0.07	0.78	0.28	Control: 0.16 ± 0.09 11+: 0.16 ± 0.09 p = 0.91	Control: 0.13 ± 0.09 11+: 0.19 ± 0.11 p = 0.10

[†] indicates significance and a meaningful or clinically meaningful change in one or both groups

[#] indicates significant but no meaningful change in either group.

^{*} indicates a meaningful change across the season

^{**}

indicates a clinically meaningful change across the season. In accordance with the right hand rule hip flexion, adduction, and internal rotation as well as knee extension and adduction are represented as positive values. As some athletes landed in hip adduction (+) while others landed in hip abduction (−) the mean peak hip adduction angle is negative as it is in hip abduction. Similarly for hip internal rotation, the mean peak hip internal rotation angle is actually in hip external rotation

Table 4
Results of time x group ANOVAs comparing the change across the first and second seasons of 11+ use

Variables	Dominant					Non-dominant				
	Time x Group Interaction	Main Effect of Time	Main Effect of Group	Preseason	Postseason	Time x Group Interaction	Main Effect of Time	Main Effect of Group	Preseason	Postseason
Peak Hip Flexion Angle (°)	0.08	0.76	0.55	1st Season: 87.17 ± 12.34 2nd Season: 85.54 ± 11.56 p = 0.66	1st Season: 92.94 ± 10.41* 2nd Season: 88.55 ± 15.18* p = 0.17	0.05 [†]	0.99	0.73	1st Season: 87.58 ± 13.00 2nd Season: 85.26 ± 11.11 p = 0.53	1st Season: 84.08 ± 10.57* 2nd Season: 88.70 ± 14.44* p = 0.23
Peak Hip Flexion Moment (Nm/kgm)	0.12	<0.01 [†]	0.70	1st Season: -0.98 ± 0.19 2nd Season: -1.04 ± 0.20 p = 0.33	1st Season: -1.11 ± 0.22* 2nd Season: -1.09 ± 0.17 p = 0.79	0.77	0.12	0.87	1st Season: -1.03 ± 0.22 2nd Season: -1.02 ± 0.22 p = 0.98	1st Season: -1.09 ± 0.25 2nd Season: -1.07 ± 0.23 p = 0.78
Peak Hip Adduction Angle (°)	0.85	0.24	0.43	1st Season: -2.03 ± 4.53 2nd Season: -2.53 ± 4.27 p = 0.71	1st Season: -1.43 ± 4.77 2nd Season: -1.71 ± 3.58 p = 0.83	0.02 [†]	0.24	0.70	1st Season: -3.99 ± 4.77 2nd Season: -5.95 ± 4.29 p = 0.16	1st Season: -6.15 ± 5.11* 2nd Season: -5.18 ± 4.36 p = 0.50
Peak Hip Adduction Moment (Nm/kgm)	0.48	0.24	0.43	1st Season: -0.18 ± 0.09 2nd Season: -0.18 ± 0.08 p = 0.84	1st Season: -0.20 ± 0.11 2nd Season: -0.28 ± 0.46 p = 0.44	0.10	0.71	0.14	1st Season: -0.11 ± 0.09 2nd Season: -0.17 ± 0.10 p = 0.06	1st Season: -0.13 ± 0.07 2nd Season: -0.16 ± 0.12 p = 0.42
Peak Hip Internal Rotation Angle (°)	0.43	0.16	0.83	1st Season: -4.59 ± 5.25 2nd Season: -5.48 ± 5.17 p = 0.57	1st Season: -4.09 ± 5.46 2nd Season: -3.77 ± 4.03 p = 0.83	0.01 [†]	0.10	0.65	1st Season: -7.54 ± 6.20 2nd Season: -10.22 ± 5.84 p = 0.15	1st Season: -10.73 ± 6.52* 2nd Season: -9.57 ± 5.76 p = 0.54
Peak Hip Internal Rotation Moment (Nm/kgm)	0.71	0.28	0.34	1st Season: -0.18 ± 0.06 2nd Season: -0.17 ± 0.07 p = 0.45	1st Season: -0.20 ± 0.06 2nd Season: -0.18 ± 0.12 p = 0.40	0.62	0.21	0.03 [#]	1st Season: -0.17 ± 0.07 2nd Season: -0.13 ± 0.08 p = 0.11	1st Season: -0.19 ± 0.08 2nd Season: -0.14 ± 0.05 p = 0.03
Peak Knee Flexion Angle (°)	0.98	0.35	0.42	1st Season: -103.39 ± 13.80 2nd Season: -101.10 ± 8.65 p = 0.52	1st Season: -102.08 ± 8.68 2nd Season: -99.72 ± 9.81 p = 0.41	0.71	0.42	0.20	1st Season: -104.80 ± 13.97 2nd Season: -101.09 ± 9.42 p = 0.31	1st Season: -104.22 ± 10.66 2nd Season: -99.52 ± 12.13 p = 0.18

Variables	Dominant					Non-dominant				
	Time x Group Interaction	Main Effect of Time	Main Effect of Group	Preseason	Postseason	Time x Group Interaction	Main Effect of Time	Main Effect of Group	Preseason	Postseason
Peak Knee Flexion Moment (Nm/kgm)	0.57	0.81	0.87	1st Season: 0.98 ± 0.14 2nd Season: 0.98 ± 0.15 p = 0.91	1st Season: 0.99 ± 0.11 2nd Season: 0.97 ± 0.18 p = 0.69	0.03	0.80	0.78	1st Season: 0.96 ± 0.16 2nd Season: 0.96 ± 0.16 p = 0.54	1st Season: 0.99 ± 0.16 2nd Season: 0.94 ± 0.15 p = 0.26
Peak Knee Abduction Angle (°)	0.03 [‡]	0.01 [‡]	0.74	1st Season: -0.43 ± 3.15 2nd Season: -1.81 ± 2.99 p = 0.15	1st Season: -2.83 ± 3.82 ^{**} 2nd Season: -2.03 ± 2.94 p = 0.44	0.46	0.03 [‡]	0.44	1st Season: -0.11 ± 3.77 2nd Season: -1.32 ± 3.82 p = 0.29	1st Season: -1.76 ± 3.91 [*] 2nd Season: -2.16 ± 4.18 [*] p = 0.74
Peak Knee Abduction Moment (Nm/kgm)	0.75	0.74	0.77	1st Season: 0.23 ± 0.09 2nd Season: 0.22 ± 0.09 p = 0.62	1st Season: 0.23 ± 0.08 2nd Season: 0.23 ± 0.13 p = 0.98	0.60	0.07	0.03	1st Season: 0.16 ± 0.09 2nd Season: 0.11 ± 0.09 p = 0.09	1st Season: 0.19 ± 0.11 2nd Season: 0.13 ± 0.08 p = 0.04

[‡] indicates significance and a meaningful or clinically meaningful change in one or both groups

[#] indicates significant but no meaningful change in either group.

^{*} indicates a meaningful change across the season

^{**} indicates a clinically meaningful change across the season. Note: In accordance with the right hand rule hip flexion, adduction, and internal rotation as well as knee extension and adduction are represented as positive values. As some athletes landed in hip adduction (+) while others landed in hip abduction (-) the mean peak hip adduction angle is negative as it is in hip abduction. Similarly for hip internal rotation, the mean peak hip internal rotation angle is actually in hip external rotation