Influence of Age, Sex, Technique, and Exercise Program on Movement Patterns After an Anterior Cruciate Ligament Injury Prevention Program in Youth Soccer Players
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More than 3 million youth are currently registered to take part in organized soccer within the United States, and participation grows approximately 20% every year.1 While soccer is a very popular sport among youth, there is a high incidence of injury associated with participation in soccer.16,25,39,57,59 Rupture of the anterior cruciate ligament (ACL) is one of the common lower extremity injuries that may occur during soccer. A recent study demonstrated soccer to be the most frequent activity to cause ACL injury in Norway.25 There are an estimated 200 000 anterior and posterior cruciate ligament injuries in the United States each year, with an associated cost of more than $3 billion.32,45 The frequency of ACL injuries appears to increase in soccer athletes around age 11 or 12 with a steady rise until age 18.59 Not only are ACL injuries in youth soccer common and a financial burden, they are also detrimental to long-term health as radiographic signs of osteoarthritis development were present in 80% of soccer players less than 15 years after an ACL injury, regardless of the treatment received.41 While these results were from surgeries performed 2 decades ago, it is unknown if any recent improvements in surgical technique have ameliorated these long-term effects. These consequences demonstrate the immediate need for effective ACL injury prevention, especially in young soccer athletes.
Approximately 70% of all ACL injuries are the result of a noncontact mechanism of injury and usually occur as an individual is planting, cutting, or jumping. Lower extremity movement patterns during these activities play a critical role in injury mechanism because they influence the load and deformational forces on ligaments, meniscus/cartilage, and bone. Specific movement patterns commonly occurring during ACL and lower extremity injury include knee varus, excessive leg rotation, and decreased knee flexion. Knee flexion angle influences ACL stress as vigorous quadriceps contractions at low knee flexion angles (0°–30°) generate anterior tibial shear force that may strain the ACL. Large amounts of ACL loading occur during the combined loading state of tibial rotation and knee varus. As such, lower extremity rotation (tibial rotation) and knee varus occurring during cutting and jumping maneuvers are viewed to be of large enough magnitude to generate extreme loads within the ACL, causing spontaneous rupture of the ligament. It is during this combined loading state of excessive tibial rotation and knee varus that researchers have described the ACL to be at greatest risk.

All previous research investigating injury prevention exercise interventions has used a “one-size-fits-all” (generalized) approach to exercise prescription where all individuals performed the same set of exercises without regard to the individual's specific needs. The effectiveness of injury prevention exercise interventions may be improved by developing individualized interventions and collecting data to understand the mechanisms for an intervention’s success. None of the research investigating injury prevention exercise interventions has incorporated an initial assessment to identify specific deficiencies for an individual. Currently, training programs for elite athletes are developed from an initial assessment and customized to meet the specific needs of the individual, and as a result, there have been tremendous gains in individual physical performance. Similarly, rehabilitation and reconditioning programs for individuals recovering from physical and/or medical disability are based on an initial assessment and customized for the patient. A similar approach may need to be taken with injury prevention to maximize the effectiveness of injury prevention exercise interventions in reducing the risk of injury during sport and recreational activity. In support of this concept, it has recently been indicated that customized injury prevention exercise interventions are the next phase of the research in this area of injury prevention.

Individuals displaying various potentially injurious movement patterns may respond differently to an injury prevention program. Recent research supports this theory as it has been shown that an individual's initial biomechanical profile influences the effectiveness of an injury prevention program. In this study, those individuals displaying large external knee abduction moments were classified as “high risk,” and conversely, those with small knee abduction moments were classified as “low risk.” Subjects in the high-risk group were able to reduce their knee abduction moments greater than those in the low-risk group. These results highlight the potential importance for evaluating subjects’ improvement based on their initial profile. The subjects in the “high-risk” group had greater moments to reduce so it is not surprising that this group improved, but these changes may have been obscured if the subjects were not divided into risk categories before the analysis. These findings also suggest that an initial movement assessment to identify individuals with varying levels of movement quality may improve the effectiveness of injury prevention programs. Individuals with poor movement technique may respond more favorably than those with good movement technique, which may suggest the need to place a greater training emphasis on those individuals with poor movement technique. However, more research is necessary to investigate whether individuals with varying levels of movement quality respond differently to an injury prevention program.

There is minimal information regarding how different populations respond to an ACL injury prevention program. The rate of ACL injury is 2 to 5 times greater in female than male athletes in comparable sports, but due to greater exposure to sports, the absolute number of ACL injuries in male athletes is greater than the absolute number in female athletes. To our knowledge, female athletes are often evaluated before and after an injury prevention program, but only 1 study has evaluated how male athletes respond to an injury prevention program, and no studies have compared results between sexes. Besides focusing primarily on female athletes, the majority of previous research on injury prevention programs used either adult or high school–aged subjects. Outcomes of injury prevention programs may be enhanced if the programs are implemented to individuals before they reach the age associated with the highest injury risk. However, minimal research has been conducted with youth athletes less than 14 years of age to evaluate if they are able to respond to an injury prevention program.

The primary purpose of this study was to compare changes in landing technique between subjects with different baseline levels of movement error after completion of an injury prevention program. A secondary objective of this study was to evaluate if injury prevention programs stratified to specific movement errors, compared with a generalized (“one-size-fits-all”) program, would result in different improvements between pretraining and postraining measurements. Our final objective was to compare improvements from an injury prevention program between sexes and age groups. We hypothesized high school–aged female subjects with poor landing technique would improve the most after completing the stratified program.

**MATERIALS AND METHODS**

We conducted a cluster-randomized controlled trial to study the effect of a stratified versus generalized neuromuscular injury prevention program in changing landing technique in youth male and female soccer players during the course...
TABLE 1

Subject Demographics*

<table>
<thead>
<tr>
<th>Sex</th>
<th>Group</th>
<th>Age (years ± SD)</th>
<th>Height (cm ± SD)</th>
<th>Mass (kg ± SD)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Male</td>
<td>General Program</td>
<td>13 ± 2</td>
<td>164 ± 13</td>
<td>51 ± 14</td>
</tr>
<tr>
<td></td>
<td>MKD</td>
<td>12 ± 1</td>
<td>153 ± 17</td>
<td>41 ± 14</td>
</tr>
<tr>
<td></td>
<td>TO</td>
<td>14 ± 2</td>
<td>171 ± 12</td>
<td>60 ± 13</td>
</tr>
<tr>
<td></td>
<td>NA</td>
<td>13 ± 1</td>
<td>173 ± 5</td>
<td>56 ± 8</td>
</tr>
<tr>
<td>Female</td>
<td>General Program</td>
<td>14 ± 2</td>
<td>162 ± 8</td>
<td>51 ± 10</td>
</tr>
<tr>
<td></td>
<td>MKD</td>
<td>13 ± 2</td>
<td>160 ± 9</td>
<td>50 ± 9</td>
</tr>
<tr>
<td></td>
<td>TO</td>
<td>13 ± 2</td>
<td>159 ± 7</td>
<td>49 ± 10</td>
</tr>
<tr>
<td></td>
<td>NA</td>
<td>13 ± 2</td>
<td>155 ± 8</td>
<td>47 ± 10</td>
</tr>
</tbody>
</table>

*SD, standard deviation; MKD, medial knee displacement; TO, toe out; NA, neutral alignment.

of a soccer season. The stratified injury prevention program consisted of a group of exercises stratified to correct certain movement errors as well as a set of team exercises. In contrast, the generalized program only involved a larger set of team exercises. We chose to randomize at the team level because randomization of players on the same team to different injury prevention programs would probably result in contamination. This randomization technique permits teams to perform a warm-up together, which is common practice in the general population and enhances the external validity.20

We recruited 27 youth soccer teams from the under-11 (10 years old) to the under-18 (17 years old) divisions of an area soccer association. All teams were in the competitive division of the soccer association, and players were placed on the teams through a selection process based on their skill level before the season. The teams were randomly assigned using a coin flip to either a stratified (13 teams) or generalized (14 teams) injury prevention program after stratifying the teams by sex and age group. All of the teams chose to adopt the injury prevention program as a replacement for their normal warm-up routine. As a result, all players performed the injury prevention program, but movement assessment was only conducted on players who volunteered to participate in the study. Before the season, players and their parents were informed about the study and asked for their voluntary participation. University-approved informed assent and consent forms were completed by players and their parents, respectively, if they chose to participate. Table 1 provides detailed demographic information of players who chose to participate in this study.

Movement Assessment

Subjects had no symptoms of injury limiting soccer participation at the time of movement assessment and were evaluated at the beginning (pretest) and the end (posttest) of their season. Teams between the ages of 10 and 13 years (under-11 to under-14 team divisions) participated in a 9-month season (August to May), while the older age groups, between the ages of 14 and 17 years (under-15 to under-18 team divisions), only performed the programs for 4 months (females: August to December; males: January to May) due to conflicts with their high school soccer seasons. Both movement assessments (pretest and posttest) occurred before the start of a soccer practice so fatigue did not influence the results.

Subjects performed 3 trials of a standardized jump-landing task during both movement assessments. Subjects jumped forward from a 30-cm high box a distance of half of their body height, which was marked using a line placed on the ground according to each subject’s height. Upon landing on both feet, subjects were instructed to jump vertically for maximal height and land in approximately the same location. All subjects received the same oral instructions before the jump-landing task, which included “jump forward from the box with both feet so that you land with both feet just after the line” and “as soon as you land, jump up for maximum height and land back down.” A research assistant demonstrated the maneuver once for each team to minimize coaching effects. The subjects were instructed to perform the task as naturally as possible and not to be influenced by the demonstration. Subjects were permitted to practice the jump-landing task until they felt comfortable with the task and performed it correctly. Trials were excluded and repeated if subjects jumped vertically from the box instead of forward or if the subjects did not jump for maximal height on landing. Two video cameras (Sony DCR-HC30, Park Ridge, NJ) were positioned 10 ft in front of and to the right of the subject to record all 3 jump-landing task trials. The camera positioning allowed capture of both frontal and sagittal plane images.

Movement technique was assessed during the jump-landing task before and after the season through the Landing Error Scoring System (LESS), which will be discussed further in the Data Reduction/Analysis section. In addition to the 3 jump-landing task trials, subjects also completed a double-legged squat task during the pretest session. Subjects in the stratified injury prevention program performed a specific set of exercises based on their movement patterns during the double-legged squat task (described further in Stratified Intervention). The double-legged squat task required subjects to stand with their feet shoulder-width apart, toes pointing straight ahead, hands straight up in the air, while they slowly squatted toward the ground as far as comfortably possible and returned to the starting position.
Implementation of Injury Prevention Programs

Research assistants trained the teams on their program at the beginning of a practice within 1 week of the pretest session. Coaches received training materials explaining their team’s respective injury prevention program, attended a brief lesson on their team’s program, and were taught the exercises by the research staff before this practice. All teams completed their respective program within 10 to 15 minutes at the start of every soccer training session, approximately 3 to 4 times per week, throughout the season. Proper technique was emphasized to the subjects for all of the exercises. Subjects received a constant set of instructions and oral cues to remember while performing the exercises. These instructions and oral cues consisted of “keep your toes pointed straight ahead,” “keep your knees over your toes,” and “land softly on your toes while bending your knees.” Coaches were instructed to increase the number of exercise repetitions as the players progressed with the program.

Stratified Intervention

Subjects on teams in the stratified program were further assigned to 1 of 3 groups (medial knee displacement, toe out, normal) based on their individual movement assessment during the double-legged squat task. Using the videotapes of the double-legged squat task recorded during the pretest session, a single individual assessed the frontal plane image of the double-legged squat task to assign stratified group subjects to 1 of the 3 stratified exercise categories. The same individual assessed all of the double-legged squat tasks. Only subjects on teams randomized to the stratified program were assessed with the double-legged squat because their exercises were dependent on their group assignment in contrast to subjects on teams assigned to the generalized program. Subjects who demonstrated excessive medial knee displacement, which was defined as the patella moving medial to the great toe at any point during the squat descent, were assigned to the medial knee displacement (MKD) exercise group (Figure 1A). Subjects whose feet rotated outward during any point of the squat descent were assigned to the toe-out (TO) exercise group (Figure 1B). Participants who displayed both medial knee displacement and toe out were assigned to the TO group. The neutral alignment (NA) exercise group consisted of subjects who did not demonstrate either medial knee displacement or toe out during the double-leg squat task (Figure 1C).

A detailed description of the stratified injury prevention program is provided in Appendix 1 (available online at http://ajs.sagepub.com/supplemental/). The stratified program was developed from previous ACL injury prevention programs but expanded to include multiplanar exercises, as well as exercises designed to target the specific movement patterns (MKD, TO, or NA).22,32,42,49-51 At the beginning of each practice, teams in the stratified groups first

Figure 1. A, Medial knee displacement during double-legged squat task. B, Toe out during double-legged squat task. C, Neutral alignment during double-legged squat task.
divided into their 3 separate subgroups, MKD, TO, or NA, and completed the stratified exercises. Both the MKD and TO stratified exercises consisted of a static stretching exercise to lengthen the muscle thought to be influencing their movement pattern, as well as an exercise to activate the muscle that may be able to correct their movement pattern. To address medial knee displacement, the MKD group strengthened and stretched the hip abductor and adductor muscles, respectively. The TO group performed exercises to strengthen and stretch the lower leg muscles. The NA group performed exercises to improve their core and lower extremity stability and strength. After the group exercises, all of the individual groups came together to perform a set of team exercises.

Generalized Intervention

A detailed description of the generalized injury prevention program is provided in Appendix 2 (available online at http://ajs.sagepub.com/supplemental/). The athletes on teams randomized to the generalized intervention were assigned a set of exercises to strengthen and stretch several lower extremity muscle groups and were provided with training in good postural alignment during physical activity. This intervention is modified from previous ACL injury prevention programs that have been shown to be effective with reducing injury rates and modifying neuromuscular injury risk factors. The generalized intervention maintained the overall types of exercises included in these previous studies but abbreviated the program to make it more feasible as a warm-up.

Compliance Monitoring

Research assistants visited each team at least once a week during the season to monitor compliance and correct exercise technique. Coaches and players also recorded program compliance and informed the research assistant about the team’s participation during the previous week. Compliance records were completed after every visit by the research assistant and used to produce a team compliance score after completion of the season. Four possible scores (1, 2, 3, or 4) could be received for the team compliance score, and the score was related to what percentage (100% = 4, 75% = 3, 50% = 2, 25% = 1) of the time the team was performing the exercises correctly with no encouragement needed by the research assistant. For example, a score of 4 indicated the team achieved 100% compliance according to coaches, players, and research assistants’ observations. In contrast, teams with 25% compliance, or a score of 1, only performed the programs when the research assistants were present. Observations that rated compliance between these percentages were rounded down as a conservative estimate.

Data Reduction/Analysis

LESS. All jump-landing and squat trials were transferred from standard videotapes to a videoediting software package (Windows Media Player, Microsoft, Redmond, Washington) after data collection was complete. All jump-landing trials were scored using the LESS by 1 of 2 different researchers who were blinded to group assignment and testing session. The LESS is a standardized clinical movement assessment tool for identifying improper movement patterns during the jump-landing tasks. The LESS uses a binary system (0,1) to evaluate landing technique based on nine jump-landing characteristics: knee flexion angle, knee valgus angle, trunk flexion angle, ankle plantarflexion angle, foot position, stance width, foot contact (heel or toe first), overall joint motion, and overall impression of landing “quality.” A higher LESS score indicates a greater number of landing errors committed and thus poor jump-landing technique.

The LESS has been shown to be a reliable (intrarater: intraclass correlation coefficient [ICC] 1,1 = .90, standard error of the mean [SEM] = 1.08; interrater: ICC 2,1 = .83, SEM = 1.50) tool to assess landing errors in large populations of subjects efficiently. In addition to reliability, predictive and concurrent validity of the LESS has also been established. Female subjects have consistently been shown to demonstrate different movement patterns, such as reduced knee flexion and greater knee valgus, compared with male subjects during sports maneuvers, such as the jump-landing task. The LESS was able to differentiate between sexes in both collegiate and youth athletes as LESS scores were significantly higher in female athletes. The LESS and an electromagnetic motion analysis tool yield comparable conclusions about specific landing errors, such as knee flexion, knee valgus torque, and vertical ground-reaction forces. Predictive validity of the LESS has been established in prospective research that has been conducted comparing LESS scores between ACL-injured and noninjured individuals. The results revealed that ACL-injured subjects demonstrated less knee flexion motion and less flexion in all lower extremity joints compared with the noninjured subjects.

LESS variables. We calculated an average total LESS score by taking the mean of the total LESS scores from the 3 jump-landing trials to analyze overall landing technique during both testing sessions. Next, we calculated a change score for the average total LESS score (posttest-pretest), causing a negative change score to indicate the subject improved after completion of the program. We created 2 independent variables to allow us to evaluate changes in LESS score between ages (age group) and levels of baseline movement error (baseline movement error). To determine if age influenced the program’s effectiveness, we compared changes in LESS scores between pre–high school (ages 10-13 years) and high school (ages 14-17 years) age subjects. This age grouping accounted for the fact that the pre–high school group performed the program for a longer duration (9 months) than the high school–age group (4 months) because the high school–age group teams did not practice regularly during the high school soccer season.

To examine the influence of an individual’s baseline movement patterns, we formed groups based on quartiles from the pretest LESS scores. Subjects whose LESS scores were in the first quartile (LESS range, 0-3.67 points)
demonstrated “excellent” landing technique. Those in the second quartile (LESS range, 3.68-5.0 points) were considered to have “good” landing technique. The subjects in the third quartile (LESS range, 5.1-6.3 points) were considered to display “moderate” landing technique. Individuals in the fourth quartile had the highest scores (LESS range, 6.33-11.0 points) and demonstrated “poor” landing technique. We then compared changes in LESS scores between groups.

Statistical Analysis

We used a generalized linear model, with the team compliance score as a covariate to compare the change score between sex, age group, baseline movement error, and program. Only main effects were included in the model as our primary research questions involved determining if program type mattered, if girls or boys were more sensitive to the program, if age influenced the ability to change, and if baseline scores affected improvement. Complete separation of confidence intervals was used to evaluate pairwise comparisons for post hoc testing.

Individual items on the LESS were analyzed to determine which specific movement patterns changed or failed to change after subjects performed the injury prevention programs. First, we produced a composite score for individual landing characteristics. Subjects were scored with an “error” if the subject demonstrated the specific landing characteristic error during 2 or more of the 3 trials; otherwise, that individual item was coded as “no error.” Next, we devised a coding scheme to identify subjects who improved their landing error versus those who did not improve after completing the program. Subjects who demonstrated a specific landing error at pretest, but not at posttest, were scored with a binary response of “improve.” Subjects who displayed the landing error at pretest but still possessed the error at posttest received a “no improvement” score. Only a small percentage of subjects demonstrated an error at posttest but no error at pretest. For the 6 main variables examined for improvement, 3 variables had between 5% to 10% of subjects demonstrate the error at posttest but not at pretest, and the other 3 variables had this occur in 10% to 20% of subjects. Because of this small percentage and that our main focus was on evaluating the programs’ effectiveness with improving a variable between pretest and posttest, we chose to not discuss these subjects. We did evaluate whether there were any program, sex, or age group differences between subjects this applied to but failed to see any significant differences.

We used a binomial proportion test to evaluate the null hypothesis that a specific LESS error would not improve after completing the program ($P = .00$). These individual item analyses were only performed on specific LESS errors if at least 10 subjects demonstrated the error at pretest. For all statistical analyses, we used SPSS 15.0 (SPSS Inc, Chicago, IL), an a priori level of significance of .05, and generalized estimating equations to account for the clustered random assignment.

Figure 2. Flowchart of study procedures. MKD, medial knee displacement; TO, toe out; NA, neutral alignment.

RESULTS

Forty percent of the players (90 male subjects: age, 13 ± 2 years; height, 166 ± 13 cm; mass, 54 ± 14 kg; and 83 female subjects: age, 13 ± 2 years; height, 160 ± 8 cm; mass, 50 ± 10 kg) from the 27 recruited teams volunteered for the study and completed both testing sessions (Figure 2). Detailed subject demographics based on sex, program, and training group assignment are provided in Table 1. All teams remained in the analysis regardless of compliance score because we intended to treat all of them. The average compliance score was 3.13, indicating that the teams averaged more than 75% compliance. No statistically significant differences were observed between groups for height, weight, age, or pretest LESS score.

Our findings indicate that the level of baseline movement error affected the subjects’ abilities to improve after completing one of the injury prevention programs. A significant difference in change scores was observed between levels of baseline movement error (Wald = 80.22, $P < .0001$) (Figure 3). By comparing confidence intervals, it is clearly evident that the “poor” landing technique group improved their LESS score greater than any other group. Also, the “good” and “moderate” baseline movement error groups improved more than the “excellent” group.

In addition to baseline level of movement error, age appeared to influence the potential for improvement as we
observed a significant difference in change scores between the 2 age groups (Wald = 7.27, P = .007) (Figure 4). The high school–age group improved their LESS total score to a greater extent than the pre–high school age group. No significant differences in change scores were observed between programs (Wald = 0.65, P = .42) (Table 2) or sexes (Wald = 0.87, P = .35) (Table 3). We did not include testing session as an independent variable so we were not able to perform statistical analysis to evaluate a time main effect. However, we did observe an overall negative LESS total change score (posttest-pretest = −0.66 ± 1.9), suggesting that all subjects, regardless of intervention group, appeared to improve their landing patterns after completion of the injury prevention program.

The individual item analysis yielded significant improvements for all of the variables evaluated (P < .0001): knee flexion at initial contact, trunk flexion at initial contact, foot external rotation, narrow stance width, knee flexion displacement, knee valgus displacement, and trunk flexion displacement. Our objective with this analysis was to determine if there were specific LESS items that were responsible for changes in the total LESS score. Therefore, we performed the same binomial proportion test as before but changed the null hypothesis to evaluate if there were differences in proportions between subjects who improved the item and those who did not (P = .5 instead of P = .0). When we performed this analysis, we observed significant improvements in the following variables: knee flexion at initial contact (P = .009, 65% improvement), trunk flexion at initial contact (P = .005, 70% improvement), and knee flexion displacement (P = .001, 93% improvement) (Table 4). Contrary to these results, the majority of subjects did not improve foot external rotation (P < .0001, 23% improvement), narrow stance width (P < .0001, 29% improvement), or knee valgus displacement (P < .0001, 21% improvement) (Table 5).

**DISCUSSION**

The most important finding is that subjects who possessed the largest number of landing errors at baseline achieved the greatest improvements after completion of the injury

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**TABLE 2**

<table>
<thead>
<tr>
<th>Program</th>
<th>Pretest</th>
<th>Posttest</th>
<th>Change Score</th>
<th>95% CI of Change Score</th>
</tr>
</thead>
<tbody>
<tr>
<td>General</td>
<td>5.13 ± 2.0</td>
<td>4.15 ± 1.77</td>
<td>−1.04 ± 0.24</td>
<td>−1.50 to −0.57</td>
</tr>
<tr>
<td>Stratified</td>
<td>4.99 ± 1.80</td>
<td>4.50 ± 1.84</td>
<td>−0.81 ± 0.18</td>
<td>−1.15 to −0.46</td>
</tr>
</tbody>
</table>

**TABLE 3**

<table>
<thead>
<tr>
<th>Sex</th>
<th>Pretest</th>
<th>Posttest</th>
<th>Change Score</th>
<th>95% CI of Change Score</th>
</tr>
</thead>
<tbody>
<tr>
<td>Male</td>
<td>4.43 ± 1.7</td>
<td>3.92 ± 1.79</td>
<td>−1.08 ± 0.26</td>
<td>−1.58 to −0.57</td>
</tr>
<tr>
<td>Female</td>
<td>5.75 ± 1.9</td>
<td>4.76 ± 1.74</td>
<td>−0.76 ± 0.19</td>
<td>−1.14 to −0.39</td>
</tr>
</tbody>
</table>

*SD, standard deviation; SE, standard error; CI, confidence interval.
TABLE 4
Variables That Improveda

<table>
<thead>
<tr>
<th>Landing Error</th>
<th>No. With Error at Pretest</th>
<th>Improved, no. (%)</th>
<th>Not Improved, no. (%)</th>
<th>Level of Significance</th>
</tr>
</thead>
<tbody>
<tr>
<td>Knee flexion at initial contact</td>
<td>85</td>
<td>55 (65)</td>
<td>30 (35)</td>
<td>(P = .009)</td>
</tr>
<tr>
<td>Trunk flexion at initial contact</td>
<td>53</td>
<td>39 (70)</td>
<td>17 (30)</td>
<td>(P = .005)</td>
</tr>
<tr>
<td>Knee flexion displacement</td>
<td>15</td>
<td>14 (93)</td>
<td>1 (7)</td>
<td>(P = .001)</td>
</tr>
</tbody>
</table>

aTest proportion = 0.50.

TABLE 5
Variables That Did Not Improvea

<table>
<thead>
<tr>
<th>Landing Error</th>
<th>No. With Error at Pretest</th>
<th>Improved, no. (%)</th>
<th>Not Improved, no. (%)</th>
<th>Level of Significance</th>
</tr>
</thead>
<tbody>
<tr>
<td>Foot external rotation</td>
<td>70</td>
<td>15 (23)</td>
<td>55 (77)</td>
<td>(P &lt; .0001)</td>
</tr>
<tr>
<td>Narrow stance width</td>
<td>113</td>
<td>33 (29)</td>
<td>80 (71)</td>
<td>(P &lt; .0001)</td>
</tr>
<tr>
<td>Knee valgus displacement</td>
<td>123</td>
<td>24 (21)</td>
<td>89 (79)</td>
<td>(P &lt; .0001)</td>
</tr>
</tbody>
</table>

aTest proportion = 0.50.

prevention program. Subjects in the “poor” baseline movement error group averaged more than 6 points on the LESS before beginning the injury prevention program. This group demonstrated 3 times as much improvement by improving 2.5 points, which is 2 points higher than the overall mean change of 0.66 points. The “moderate” and “good” groups also experienced significant improvement in their landing technique. In contrast to these groups, the “excellent” group, or subjects with the smallest amount of error, did not appear to improve greatly or actually digressed slightly in their landing ability.

Even though the “excellent” group did not improve their landing technique, the finding that the 3 other baseline movement error groups improved is significant because numerous landing errors theoretically correlate with a greater risk of injury. Consequently, the subjects in these 3 groups appear to be the subjects where improvement may be the most critical to reduce injury risk. Similar to our analysis using baseline movement error, Myer et al47 used pretest knee abduction moments during a drop-vertical jump to divide subjects into “high-risk” or “low-risk” groups and compared the effects of a neuromuscular training program between these groups. In agreement with our current findings, the authors concluded that subjects in the “high-risk” group, or those with greater hip abduction moments, responded more favorably to the training program than subjects in the “low-risk” group.

These findings suggest that neuromuscular training programs are most effective with athletes who display poor movement techniques before beginning the program. To maximize the effectiveness of future injury prevention programs, it may be necessary to use clinical screening tools to identify individuals with high-risk biomechanical profiles and target injury prevention programs toward these individuals. Comparing training effects between individual biomechanical characteristics also allows greater differences to be observed between subjects and reveals that subjects with greater potential risk factors respond more favorably to an intervention program. The improvements observed in both of these studies may have been diminished if the subjects had not been compared according to their degree of movement error or external abduction moment. Authors of future studies aimed at changing movement patterns or risk factors should consider these findings when designing their analysis to ensure their results account for differences in improvement potential based on initial assessment.

On the basis of our previous observation that subjects with higher LESS scores at baseline demonstrated the greatest improvement, we hypothesized the pre–high school age group, who possessed more landing errors than the high school–age group, would either improve equally or better than subjects in the high school–age group.28 Contrary to this hypothesis, the high school–age group sustained greater improvements from the injury prevention program compared with their younger counterparts. This finding is also surprising because the younger players performed the injury prevention program for 4 months longer than the older players. No other study has compared duration length between programs so it is unknown whether this result is due to differences in the amount of training or the age difference between the groups. In hindsight, assessing the younger age group at the end of both the fall and spring seasons would have provided more insight into this finding and should be a consideration for future studies.

Intervening during early adolescence has been suggested to help reduce ACL injuries,30,65 but little is known about the potential for this population to respond to an injury prevention program. Grandstrand et al28 is the only other study, to our knowledge, to incorporate athletes as young as 10 years of age into an injury prevention program and the authors did not observe any improvements in injury risk factors. The authors concluded that the program may have been too difficult for the young players to complete. In contrast, simple verbal cues instructing young children to bend their knees and land softly resulted in reduced landing forces.66 These
conflicting findings suggest extensive ACL injury prevention programs may not be appropriate for young prepubescent athletes or may suggest the need for a specialized injury prevention program that matches these athletes’ stage of motor and growth development. Although our high school–age group improved to a greater extent than the pre–high school age group, improvements were still present in the younger subjects. Their posttest LESS scores became similar to the older subjects’ pretest scores, illustrating that the younger players are improving to some degree, and future research with this age group is encouraged.

Sex differences exist with both ACL injury rates and movement patterns. Female athletes consistently perform common sport maneuvers with reduced trunk, hip, and knee flexion, as well as greater hip and knee transverse and frontal plane motion compared with their male counterparts. We also observed differences between sexes as male subjects began the injury prevention program with fewer landing errors than the female subjects. Similar to the age group analysis, we hypothesized that female subjects would sustain greater improvements compared with the male subjects. However, male and female subjects responded similarly to the injury prevention program. We did observe that after training female athletes’ landing technique is comparable to males’ landing technique before completing the injury prevention program. It is unknown if these improvements equate to reductions in female injury rates. To our knowledge, no other study has compared changes due to a neuromuscular training program between sexes; in fact, no other study has even investigated whether male athletes alter neuromuscular risk factors after a prevention program. While female athletes are at a greater risk of injuring their ACL in sports, such as soccer and basketball, more male athletes actually injure their ACLs each year than do female athletes. Future research needs to evaluate male responses to injury prevention programs to effectively reduce ACL injuries.

The secondary objective of this study was to compare neuromuscular risk factor improvements between a generalized and stratified injury prevention program. Our hypothesis was that a stratified approach would result in greater improvements; however, our results do not support this hypothesis as there was no difference between programs. We cannot conclude that the improvements observed by both programs are not due to maturation alone without having the ability to compare change scores to a control group. However, all of the improvements detected between the baseline movement error groups, age groups, and sexes lead us to believe that these changes are due to the injury prevention program. One hypothesis we have for failing to see differences between the 2 programs is that, in hindsight, there were too many similarities between the programs and the stratified program was not individualized enough. Other studies comparing 2 programs against one another have evaluated interventions with predominantly one type of exercise, such as plyometric or dynamic stability, versus a program with a different principal exercise type. While the 2 programs included in this study consisted of several different exercises, both programs were multifaceted and included similar amounts of balance, plyometric, strengthening, and agility exercises. Although the subjects performed different exercises targeted at the same purpose, it is possible the exercises loaded the body similarly, resulting in comparable results.

We performed the individual item analysis to observe if certain variables were responsible for changes in the total LESS score. On the basis of these results, it appears the variables knee flexion at initial contact, knee flexion displacement, and trunk flexion at initial contact are able to be successfully improved with the use of a neuromuscular training program. These findings may lead to a reduction in ACL injuries as knee flexion has frequently been cited as a risk factor for injury. Unfortunately, only a small percentage of subjects who demonstrated excessive foot external rotation and knee valgus displacement, as well as narrow stance width, were able to improve this error after the training program. These results suggest plane of motion may influence the capability for improvement. Variables that improved the greatest were all motions in the sagittal plane, while the majority of the variables that did not change were motions in the frontal and transverse planes. Future research should evaluate whether the incorporation of certain exercises affects modification of risk factors in specific planes of motion.

In general, injury prevention programs have shown promising results in decreasing overall injury rates, ACL injury rates, and modifying neuromuscular risk factors. A recent systematic review indicated there is moderate evidence to illustrate that injury prevention programs incorporating balance, plyometric, strengthening, and agility exercises can decrease ACL injury rates. It was noted in this systematic review that very few studies used a randomized controlled trial design, thus weakening the level of evidence supporting the effectiveness of current injury prevention programs. Future research incorporating randomized controlled trial designs is needed to strengthen the evidence surrounding ACL injury prevention programs. Another limitation of previous research is the inclusion of programs that require more than 30 minutes to complete. To best ensure maximal public health effect and adoption by the community at large, injury prevention programs should be easy to implement and time efficient. Although a limitation of this study is the lack of a pure control group, both injury prevention programs implemented were randomly assigned to teams, required only 10 to 15 minutes to complete, were effectively supervised by team coaches, were efficiently incorporated into daily practice routines, and successfully altered movement patterns.

**CONCLUSION**

These findings suggest that multifaceted exercise interventions incorporated as part of a normal warm-up routine successfully modified movement technique; however, additional research is needed that incorporates biomechanical
analyses to better understand the influence of exercise interventions on biomechanical factors associated with injury risk. Such research may be particularly important in high school-age soccer athletes who appear to be at greatest risk and most amenable to changes in movement patterns. Players with the greatest amount of movement errors, and potentially greatest amount of injury risk, sustained the greatest improvement after the program. Injury prevention programs may be more efficient if they are specifically targeted for these athletes. In addition, this study demonstrated that no further benefits are observed from an injury prevention program designed for specific movement patterns compared with a traditional “one-size-fits-all” program; however, the 2 programs compared in this study may have been too similar, leading to these similar results. The results of this study indicate great potential for ACL injury prevention programs.

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