A Training Program to Improve Neuromuscular and Performance Indices in Female High School Soccer Players

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Abstract

Noyes, FR, Barber-Westin, SD, Smith, STT, and Campbell, T. A training program to improve neuromuscular and performance indices in female high school soccer players. *J Strength Cond Res* 27(2): 340–351, 2013—The purpose of this study was to determine if a sports-specific anterior cruciate ligament injury prevention training program could improve neuromuscular and performance indices in female high school soccer players. We combined components from a published knee ligament intervention program for jump and strength training with other exercises and drills to improve speed, agility, overall strength, and aerobic fitness. We hypothesized that this program would significantly improve neuromuscular and athletic performance indices in high school female soccer players. The supervised 6-week program was done 3 d·wk^{-1} for 90–120 minutes per session on the soccer fields and weight room facilities in area high schools. In phase 1, 62 athletes underwent a video drop-jump test, *t*-test, 2 vertical jump tests, and a 37-m sprint test before and upon completion of the training program. In phase 2, 62 other athletes underwent a multistage fitness test before and after training. There were significant improvements in the mean absolute knee separation distance ($p < 0.0001$), mean absolute ankle separation distance ($p < 0.0001$), and mean normalized knee separation distance ($p < 0.0001$) on the drop-jump, indicating a more neutral lower limb alignment on landing. Significant improvements were found in the *t*-test ($p < 0.0001$), estimated maximal aerobic power ($p < 0.0001$), 37-m sprint test ($p = 0.02$), and in the 2-step approach vertical jump test ($p = 0.04$). This is the first study we are aware of that demonstrated the effectiveness of a knee ligament injury prevention training program in improving athletic performance indices in high school female soccer players. Future studies will determine if these findings improve athlete compliance and team participation in knee ligament injury intervention training.

Key Words sports-specific training, lower limb alignment

Introduction

Soccer is one of the fastest growing sports in the United States. Over the last 30 years, high school soccer participation has increased nearly 30-fold among girls (53). Unfortunately, the benefits of playing may be offset with injuries, and female athletes are at greater risk than male athletes in sustaining serious knee ligament injuries (26). Darrow et al. (13) and Yard et al. (53) analyzed data from 100 high schools and reported that female soccer players sustained a greater proportion of complete ligament tears than male players (31.4 and 10.9%, respectively, $p = 0.005$), of which 82% were to a knee ligament. Lindenfeld et al. (30) reported a higher rate of serious knee ligament injuries in female soccer players compared with male players (0.87 and 0.29 per 100 player-hours, $p < 0.01$). In collegiate athletes, a 15-year study reported that female soccer players had a significantly greater incidence of anterior cruciate ligament (ACL) ruptures than did male players (0.32 and 0.12 injuries per 1,000 athlete exposures, $p < .05$) (32).

In response to this problem, a number of intervention training programs have been developed to decrease the incidence of knee ligament injuries in female athletes (14,19–21,23,27,31,42,43,48–50,52). However, only 1 program to date had a statistically significant effect in reducing ACL injury rates in soccer players ($p < 0.0001$) (31), whereas another approached statistical significance in reducing the ACL injury rate ($p = 0.07$) (23). A common problem with ACL injury prevention training is poor compliance among athletes because of player boredom and poor attitudes among coaches and school administration regarding the necessity for injury prevention training (35,42). Recently, investigators have speculated that improved compliance with knee injury prevention training programs would most likely occur if the programs focused on improving athletic performance indicators such as speed and agility, as well as providing neuromuscular retraining (2). However, no study

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TABLE 1. Subject characteristics.

	Age (y)*	Height (cm)*	Weight (kg)*	Body mass index*
Phase 1	15 ± 1	162 ± 6	54 ± 6	20.5 ± 2.0
N = 62	(13–18)	(150–178)	(38–63)	(16.5–25.0)
Phase 2	15 ± 1	163 ± 6	55 ± 7	20.4 ± 2.0
N = 62	(12–17)	(145–178)	(38–70)	(17.0–27.2)

*Mean ± *SD*, range.

that we are aware of has demonstrated that knee ligament injury prevention programs are effective in improving athletic performance indices in female soccer players (20,49,52).

Our laboratory previously reported a reduction in ACL injury rates in female soccer players who underwent Sportsmetrics neuromuscular training for 6 weeks (23). The training program at that time consisted of a warm-up, jump training, strength training, and flexibility. Since then, the program has been enhanced to include sport-specific exercises and drills designed to improve speed, agility, overall strength (upper extremity, lower extremity, and core), and aerobic conditioning. These additions were done to satisfy the requests of players and coaches and to increase player compliance and participation (3,37,38). The components considered essential to the reduction of ACL injury rates in female athletes remained the same, including the jump and land training methods and lower extremity and hip strength training, which have been described in detail previously (4,25). These include avoiding a valgus overall lower limb alignment on landing, reducing ground reaction forces, and improving hamstrings and hip strength through the use of a variety of exercises based on equipment that is available.

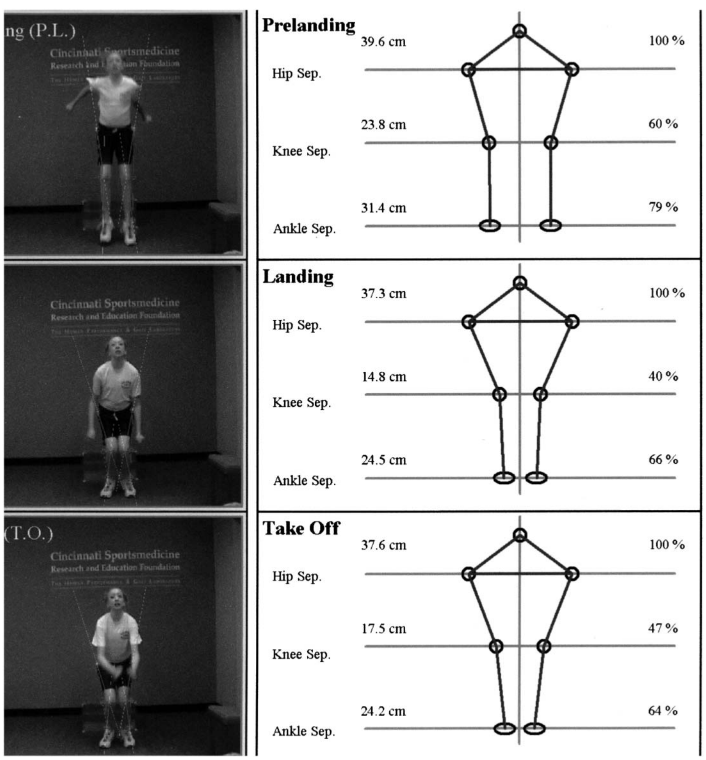

Figure 1. The 3 phases of the drop-jump video test are shown. The absolute centimeters of distance between the hips, knees, and ankles are shown on the left of the stick figures, whereas the normalized knee and ankle separation distances are shown on the right. During the landing phase, this 14-year-old female soccer player had a 40% normalized knee separation distance. The overall valgus lower limb alignment is clearly evident in the photographs. The goal of the neuromuscular training program is to improve the normalized knee separation distance and produce a more neutral lower limb alignment on landing (from Noyes et al. [35]).

The overall goal of this study was to determine if our Sportsmetrics soccer training program was effective in improving neuromuscular and athletic performance indices. This would allow recommendation of this program to athletes, coaches, and parents for not only ACL injury prevention but also for correction of neuromuscular deficiencies and enhancement of athletic performance indices. Future studies could then determine if these findings would improve athlete compliance and team participation in knee ligament injury intervention training. We hypothesized that this program would improve lower limb alignment on a drop-jump test from a valgus to a more neutral alignment, and increase agility, vertical jump height, sprinting speed, and estimated maximal aerobic power ($\dot{V}O_2max$) in high school female soccer players.

METHODS

Experimental Approach to the Problem

This study was undertaken to determine if a sports-specific training program could improve neuromuscular and athletic performance indices in female high school soccer players. A program was created, which used the dynamic warm-up, jump training, strength training, and flexibility components from a previously published ACL injury prevention program (4), along with new exercises and drills designed to improve speed, agility, overall strength, and aerobic conditioning. The effectiveness of this program was assessed in 2 consecutive phases. The first phase determined if the training altered certain neuromuscular and performance indices, and this was accomplished by measuring lower limb alignment on a drop-jump test, agility, vertical jump height, and sprint speed. The encouraging results from phase 1 lead to the next phase, in which the objective was to determine if the training program increased estimated $\dot{V}O_2$max. The assessment of lower limb alignment while landing on a drop-jump test is important as a valgus alignment is believed by others to increase the risk of a noncontact ACL injury (24). Measuring agility, sprint speed, explosive power, and aerobic conditioning was considered vital because these are essential components of competitive soccer player (10,28,33,46).

The athletes who participated in this study were high school female soccer players aged 12–18 years. In phase 1, 62 players underwent a series of tests approximately 1 week before the first training session, completed the 6-week training program, and then completed the same series of tests approximately 1 week after the last training session. The assessment involved a video drop-jump, *t*-test, countermovement vertical jump, 2-step approach vertical jump, and a 37-m sprint test. In phase 2, 62 other players underwent a multistage fitness test (MSFT), completed the 6-week training program, and then underwent the same MSFT approximately 1 week after the final training session.

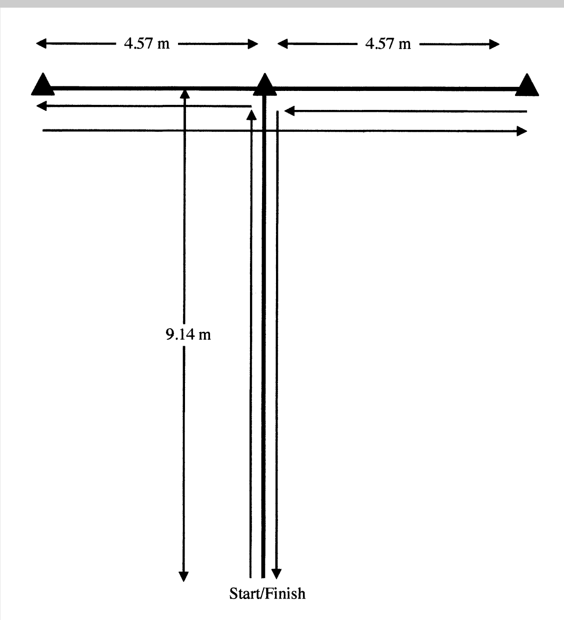

Figure 2. The *t*-test requires the athlete to follow the directions shown with the arrows in consecutive order from start to finish.

All the subjects participated in the same neuromuscular training program 3 sessions per week on Mondays, Wednesday, and Fridays for 6 weeks. The training sessions lasted approximately 90–120 minutes and consisted of a dynamic warm-up, jump training, strength training, speed and agility drills specific for soccer, aerobic conditioning, and flexibility. Certified Sportsmetrics instructors supervised the training sessions, which were conducted on area high schools' soccer field and weight room facilities. Phase 1 was conducted during the summer off-seasons of 2006–2007, and phase 2 was conducted during the summer off-seasons of 2008–2011. Training was done during the off-season so that the effects of the program could be measured without the influence or contamination of possible training effects from concurrent practices or game participation. The athletes did not participate in other sports activities or conditioning programs during the intervention training period.

Subjects

All testing and training procedures were fully explained, and written informed parental consent was obtained for each subject. The study was approved by an Internal Review Board for use of human subjects. All the athletes were from area high schools and voluntarily participated in this study. There were no significant differences between the athletes in phases 1 and 2 in age, height, weight, and body mass index (Table 1). None of the subjects had participated in a formal neuromuscular or resistance training program, but all had at least 1 season of competitive soccer experience. There were no athletes with a history of knee injury, pathology, or surgery, and all had no symptoms of pain, patella instability, or a visible knee joint effusion. All the subjects participated in their fall high school soccer season upon completion of training program.

Procedures

Before the pretrain and posttrain tests, the athletes completed the dynamic warm-up of the Sportsmetrics program previously described in detail (4). They were instructed not to perform any strenuous activity the day before the test and not to engage in any activity the day of the test before arrival at our laboratory other than their normal routine daily activities. Each test was described, and the subjects were allowed practice trials so that they understood the basic elements of each task. In phase 1, the order of tests was the video drop-jump, the vertical jumps, the *t*-test, and the 37-m sprint test.

Video Drop-Jump Test (Phase 1). A drop-jump video screening test was done as previously described in detail (6,36). The subjects performed a drop jump by first jumping off of a box 30.48 cm in height, landing, and immediately performing a maximum countermovement vertical jump. No instructions

Table 2. Sportsmetrics soccer training program.*

Time session #	Jump training	Agility, reaction	Acceleration, aerobic speed, endurance	Ladders-quick feet, dot jump drills
Week 1; #1–3	Wall jump (20 s); tuck jump (20 s); squat jump (10 s); barrier jumps (20 s each); side-to-side; forward-backward; 180° jump (20 s); broad jump (5 repetitions); bounding in place (20 s)	Serpentine run ¼ field, 3 repetitions; wheel drill: listen to instructor, 30 s; 2 repetitions	Partner push offs, hold 5 s, 5 repetitions (sprint to 10-yd line and back); sprint-backpedal, ½ field or 50 yd; 5 repetitions; 4 laps around field (1,280 yd)	Ladder: up-up and back-back; 2 repetitions; dot drill: double leg jumps; 5 repetitions ×3
Week 2; #4–6	Same as sessions 1–3; add 5 s to each jump; add 5 repetitions to broad jump	Modified shuttle ¼ field, 3 repetitions; sprint-stop feet listen, 30 s, 2 repetitions	Acceleration with band (to 10-yd line); sprint with ground touches backpedal, ½ field or 50 yd, 5 repetitions; 100-yd shuttle: 3 × 100 (300 yd); 4 repetitions	Ladders: toe touches, 2 repetitions; dot drills: add split leg jumps; 5 repetitions × 3
Week 3; #7–9	Wall jump (25 s); tuck jump (25 s); triple broad into vertical jump (5 repetitions); squat jump (15 s); barrier hops (25 s each); side-to-side; forward-backward; single-leg hop (5 repetitions); scissors jump (25 s); bounding for distance (1 run)	Square drill, 30′ × 30′ box, 2 repetitions; sprint-quick feet-listen, 45 s, 2 repetitions	Partner push offs, hold 10 s; 5 repetitions (sprint to 10-yd line and back); ¼ Eagle, instructor cued, into sprint, jog back, ½ field or 50 yd, 6 repetitions; 50-yd shuttle: up and back 3 × (300 yd), 4 repetitions	Ladders: outside foot in, 2 repetitions; dot drills: add 180° split leg jump; 5 repetitions × 3
Week 4; #10–12	Same as sessions 7–9; add 5 s to each jump; add 3 repetitions to triple broad into vertical jump	Nebraska drill, 30′ long, 4 repetitions; reaction drill-watch instructor point, 45 s; 2 repetitions	Acceleration with band (to 20-yd line); box drill, sprint-90°-backpedal, ½ field, 3 repetitions; 50-yd cone drill: 10 y-back, 20 y-back, 30 y-back, 40 y-back, 50 y-back; 4 repetitions	Ladders: in-in, out-out, 2 repetitions; dot drills: add single-leg hops; 5 repetitions ×3
Week 5; #13–15	Wall jump (20 s); step, jump up, down, vertical (30 s); squat jump (25 s); mattress jumps (30 s each); side-to-side; forward-backward; triple single-leg hop, stick; (5 repetitions each leg) jump into bounding (3 runs)	Illinois drill, 15′ × 10′, 4 repetitions; reaction mirror drill pressing, 60 s; 2 repetitions	Partner push offs, hold 15 s; 5 repetitions (sprint to 10-yd line and back); sprint-180°-backpedal, jog back, ½ field or 50 yd, 7 repetitions; jingle jangle 20 yd, up and back × 5 (200 yd), 5 repetitions	Ladder: up-up and back-back; 2 repetitions; dot drills: combo all jumps; 5 repetitions × 3
Week 6; #16–18	Same as sessions 13–15; add 5 repetitions to step, jump up, down, vertical; add 1 run to jump into bounding	T-drill: 5–10–5, 4 repetitions; advanced wheel drill: listen to instructor, 60 s, 2 repetitions	Acceleration with band (to 30-yd line); sprint-360°-sprint (jog back), ½ field or 50 yd, 7 repetitions; jingle jangle 10 yd, up and back × 5 (100 yd), 6 repetitions	Ladder: 1 foot forward, 1 foot backward (scissors), 2 repetitions; dot drills: combo all jumps; 5 repetitions × 4

*The program also includes dynamic warm-up, strength, and flexibility exercises not shown, see (4). y = yards.

TABLE 3. Results of sportsmetrics soccer training program.*

Test	Pretrain†	Posttrain†	Difference†	*p* Value	Effect size
Drop-jump test					
Absolute knee separation distance (cm)	14.6 ± 3.6 (8.0–28.6) CI: 13.7–15.5	23.1 ± 6.4 (7.4–36.2) CI: 21.4–24.7	8.5 ± 6.2 (−3.3 to 23.8) CI: 6.9–10.1	<0.0001	0.63
Absolute ankle separation distance (cm)	27.3 ± 6.3 (17.3–43.3) CI: 25.6–28.9	34.6 ± 6.0 (17.6–46.6) CI: 33.1–36.2	7.3 ± 6.3 (−9.1 to 20.3) CI: 5.7–9.0	<0.0001	0.51
Normalized knee separation distance (%)	35.9 ± 7.4 (23.0–62.0) CI: 34.1–37.8	54.2 ± 13.7 (22.0–80.0) CI: 50.7–57.8	18.3 ± 13.8 (−12.0 to 49.0) CI: 14.8–21.9	<0.0001	0.64
T-test (s)	12.05 ± 0.87 (10.22–14.03) CI: 11.83–12.28	11.31 ± 0.69 (9.84–13.81) CI: 11.13–11.48	0.75 ± 0.75 (−3.17 to 1.03) CI: 0.56–0.94	<0.0001	0.43
37-m Sprint (s)	6.11 ± 0.43 (5.27–7.71) CI: 6.00–6.22	5.99 ± 0.38 (5.32–7.08) CI: 5.90–6.09	0.12 ± 0.39 (−0.96 to 0.80) CI: −0.22 to 0.02	0.02	0.14
Vertical jump (cm)					
2-Step approach	40.7 ± 8.9 (18.4–64.8) CI: 38.4–43.0	42.1 ± 8.3 (23.5–64.8) CI: 40.0–44.2	1.3 ± 5.1 (−12.1 to 14.0) CI: 0.03–2.7	0.04	0.08
Countermovement	32.9 ± 6.7 (16.5–52.7) CI: 31.2–34.6	32.6 ± 25.8 (21.0–50.8) CI: 31.2–34.1	−0.3 ± 4.6 (−10.8 to 10.8) CI: −1.4 to 0.9	NS	0.02
Multistage fitness test (estimated $\dot{V}O_2max$, $ml\cdot kg^{-1}\cdot min^{-1}$)	37.9 ± 4.5 (27.6–46.8) CI: 36.8–39.0	40.1 ± 4.7 (27.6–49.3) CI: 38.9–41.2	2.2 ± 4.0 (−7.6 to 10.4) CI: 1.1–3.2	<0.0001	0.23

*NS = not significant; CI = confidence intervals.
†Mean ± *SD*, range, 95% CI.

were provided regarding how to land or jump; the subjects were only instructed to land straight in front of the box. This sequence was repeated 3 times. Three images were captured that represented the preland, land, and take-off phases. The absolute centimeters of separation distance between the right and left hips, knees, and ankles was measured, and the distance between the knees and ankles was normalized according to the hip separation distance using commercially available software (Cincinnati Sportsmedicine Research and Education Foundation, Cincinnati, OH, USA) (Figure 1). The data were also distributed into 3 categories for analysis: ≤60% normalized knee separation distance, 61–80%, and >80%. We reported the reliability of the drop-jump test previously (36). For the test-retest and within-test trials, the interclass correlation coefficients (ICCs) for the hip, knee, and ankles separation distances were all ≥0.90.

Vertical Jump Tests (Phase 1). The subjects' vertical jump was measured using a Vertec Jump Training System (Sports Imports, Columbus, OH, USA), which has been established as a reliable method for measuring vertical jump with ICCs of 0.92 (11) and 0.94 (54). First, the standing reach was measured with the subject standing directly under the Vertec and fully extending an arm to touch the highest vane possible while remaining flat footed. Then, a countermovement maximum jump with arm swing was performed 3 times and the highest jump obtained recorded. Next, the subjects were instructed to stand back from the Vertec, take 2 steps toward the device and then jump using both legs to touch the highest vane possible. This 2-step approach jump was performed 3 times and the highest jump obtained recorded. The differences between the standing reach and the maximum vertical jumps from the 2 tests were calculated.

T-Test (Phase 1). The *t*-test was used to measure agility and speed (Figure 2) (40). The subjects sprinted from a standing point in a straight line to a cone placed 9.14 m away. Then, the subjects shuffled to their left without crossing their feet to another cone placed 4.57 m away. After touching this cone, they shuffled to their right to a third cone placed 9.14 m away, shuffled back to the middle cone, and then ran backwards to the starting position. Two trials were completed, with the best time recorded. The time to complete this test was recorded with a digital stopwatch in one-hundredths of a second. This test has excellent reliability, with ICCs ≥ 0.90 reported by others (40,47).

37-m Sprint Test (Phase 1). Sprint speed was assessed by a 37-m sprint test. A distance of 37 m was measured on the soccer field with the start and finish lines clearly marked with cones. The subjects were instructed to sprint as fast as possible through the finish line, making sure not to slow down before crossing the line. Each athlete completed 1 sprint, and the time was recorded with a digital stopwatch in one-hundredths of a second. The reliability of sprint tests has been reported to be excellent, with ICCs ≥0.90 using a hand-held stopwatch as determined by a previous investigation (22).

Multistage Fitness Test (Phase 2). The $\dot{V}O_2$max was measuring using the MSFT (44). The subjects performed a shuttle run back and forth along 20 m, keeping in time with a series of signals on a compact disk by touching the appropriate end line in time with each audio signal. The frequency of the signals (and hence, running speed) was progressively increased until the subjects reached volitional exhaustion and could no longer maintain pace with the signals. The $\dot{V}O_2$max was estimated using regression equations described by Ramsbottom et al. (44). Test reliability of the MSFT has been shown by others to be excellent, with ICCs ≥ 0.90 (16). The data were also placed into gender- and age-matched percentile groups determined by the American College of Sports Medicine (15). The categories indicated by poor represent <31.0 estimated $\dot{V}O_2$max; fair, 31.0–34.9; good, 35.0–38.9; and excellent/superior, ≥39.0.

Neuromuscular Retraining Program (Phases 1 and 2). All the subjects participated in the Sportsmetrics Soccer (Cincinnati Sportsmedicine Research and Education Foundation, Cincinnati, OH, USA) neuromuscular training program. All the training sessions were conducted by certified Sportsmetrics instructors were held on Monday, Wednesday, and Friday for 6 weeks and were done in the early afternoon each day. Each session lasted approximately 90–120 minutes and was conducted at the schools' soccer fields and weight room facilities. The instructors kept logs of all the exercises completed during each training session.

The training consisted of a dynamic warm-up, jump training, lower extremity strength, and flexibility exercises described previously (4) along with core strength, agility, and speed drills that were added to target the requirements of competitive soccer players (Table 2). The dynamic warm-up consisted of heel-toe walking, straight leg marching, leg cradle walking, dog and bush walking, high knee skipping, high knee and glut kicks, stride-out running, and all-out sprinting.

During the jump training and speed and agility drills, the subjects were instructed and reminded to maintain a neutral overall alignment. Verbal instruction was constantly given by the instructors to the athletes to keep the knees and ankles hip-distance apart and to use exaggerated knee and hip flexion when landing from a jump, decelerating, and cutting (4). Strength training emphasized hamstrings, hip flexion and abduction, core, and abdominal musculatures to aid in proper lower extremity alignment and muscle recruitment patterns. Strength training was done in a weight room using machines, free weights, a cable system, and body weight exercises. Each training session concluded with static flexibility exercises for the hamstrings, quadriceps, iliotibial band, hip flexors, gastrocnemius/soleus, deltoid, triceps, pectoralis major, biceps, and low back.

Statistical Analyses

For data that were normally distributed (Kolmogorov-Smirnov test), a 2-tailed paired *t*-test was used to detect differences between the 2 test periods within each group. Data that failed the normality test were assessed with Wilcoxon matched-pairs signed-ranks tests. Chi-square analyses were used to compare the distribution of the subjects in the percentile rank subcategories before and after training in the MSFT and in the 3 normalized knee separation distance categories (≤60, 61–80, and >80%) in the drop-jump test. Effect sizes were calculated and interpreted according to Cohen's standards (12). For all comparisons, a level of $p \leq 0.05$ was considered to be statistically significant.

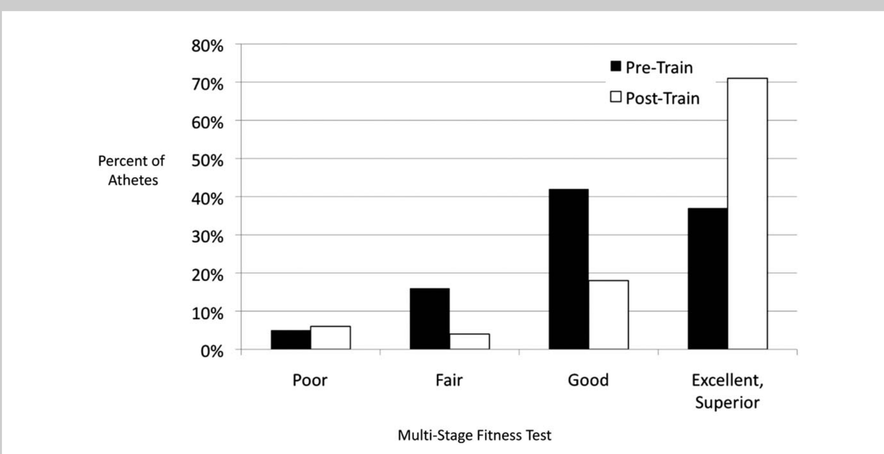

Figure 3. A significant difference was found in the multistaged fitness test in the distribution of athletes in the categories shown before and after training ($p < 0.001$). The poor category indicates <31.0 ($\dot{V}O_2$max: milliliters per kilogram per minute), the fair category ranges from 31 to 34.9, the good category ranges from 35.0 to 38.9, and the excellent/superior category indicates ≥39.0.

Table 4. Published ACL injury prevention training programs for female soccer players.*

Program, citations	Program components, duration	ACL injury rate studies: Athlete exposures (#)	ACL injury rate studies: ACL injuries trained†	ACL injury rate studies: ACL injuries control†	Neuromuscular, athletic performance indice studies	Limitations of studies, comments
Sportsmetrics Hewett (23)	Plyometrics, strength, agility, flexibility; 60–90 min, 3 d·wk^{-1} for 6 wks during preseason	4,517 trained women; 9,017 control women; 8,513 control men	0	6 (0.66) women; 1 (0.12) men; $p = 0.07$	None	Not randomized or double-blinded, low number noncontact ACL injuries.
Frappier acceleration training; Heidt (21)	Plyometrics, strength, agility, conditioning, flexibility; 3 d·wk^{-1} for 7 wks	Not given	1	8	None	42 Trained athletes, 258 controls, trained for 1 season. Not randomized, no exposure data, no reduction ACL injury rate.
PEP Mandelbaum; (31); Gilchrist (19); Pollard et al. (43); Vescovi et al. (52); Sigward et al. (48)	Plyometrics, lower extremity strength, agility, flexibility; 20 min, warm-up for 1 season	High school; 67,860 trained; 137,447 control; collegiate; 35,220 trained; 52,919 control	6 (0.09)	67 (0.49); $p < 0.0001$	Pollard (43): 18 trained, 1 season. Drop-jump test: decreased hip internal rotation, increased hip abduction. No improvement knee flexion angle, knee valgus position.; Vescovi et al. (52): 15 trained, 16 control, trained 12 wks. No improvement vertical jump, speed, agility; Sigward et al. (48): 48 trained, 10 wks. Reactive side-step cut: reduced peak knee valgus moment.	High school: not randomized, voluntary enrollment training, unknown number of training sessions completed; collegiate: low number ACL injuries.
Pfeiffer et al. (42); KLIP	Plyometrics, agility; 20 min, 2 d·wk^{-1} for 1 season	5,913 trained; 9,357 control	0	1 (0.107)	None	Not randomized, low number ACL injuries, no reduction ACL injury rate.

WIPP Grandstrand (20)	Plyometrics, strength, flexibility; 20 min, 2 d·wk^{-1} for 1 season	Not done	Not done	Not done	No improvement vertical jump; no improvement overall lower limb alignment drop-jump	12 Trained athletes, 9 controls, trained 1 season. Prepubescent athletes, could not complete all exercises.
The "11"; Steffen et al. (49,50)	Core stability, balance, plyometrics, strength; 15 min, 3 d·wk^{-1} for 1 season	66,423 trained; 65,725 control	4 (0.06)	5 (0.08); $p = 0.73$	Steffen et al. (49): 17 trained, 14 control; trained 10 wks. No improvement lower extremity or hip strength, jump height, sprint speed, shooting distance.	No reduction ACL injury rate. Poor compliance with training.
DiStefano et al. (14)	Generalized intervention: Plyometrics, balance, flexibility, strength; stratified intervention: strength and flexibility targeting deficient movement patterns, plyometrics, balance; 10–15 min, 3–4 d·wk^{-1} during practice for 1 season	Not done	Not done	Not done	155 Trained men and women each group. Landing error scoring system during drop jump and double-legged squat: subjects with highest baseline score improved the most. High school subjects improved technique more than prehigh school subjects.	No control group or data on effect of training programs on ACL injury rates. No improvement in knee valgus displacement. No difference between programs in results.
HarmoKnee Kiani et al. (27)	Isometrics, plyometrics, strength, core stability, balance; during team practice; preseason: 20–25 min, 2 d·wk^{-1}; In-season: 20–25 min, 1 d·wk^{-1}	Not given	0	5	None	777 Trained athletes, 729 controls. Not randomized, voluntary enrollment participation, player exposures not provided, low number ACL injuries.

*ACL = anterior cruciate ligament; PEP = prevent injury and enhance performance; KLIP = knee ligament injury prevention.
†No. (incidence rate per 1,000 athlete exposures).

Results

Phase 1

Statistically significant increases were found in the video drop-jump test between pretrained and posttrained test sessions in the mean absolute knee separation distance ($p < 0.0001$) and in the mean ankle separation distance ($p < 0.0001$) on landing (Table 3). Significant increases were detected in the mean normalized knee separation distance between the pretrained and posttrained test sessions ($p < 0.0001$), indicating a more neutral lower limb alignment on landing. Before training, the normalized knee separation distance was <60% in 62% of the subjects and 61–80% in 38% of the subjects. After training, a significant improvement was noted as the normalized distance was <60% in just 4% of the subjects and 61–80% in 96% of the subjects ($p < 0.0001$). Improvements were detected in the absolute knee separation distance in 87% of the subjects; in the ankle separation distance, in 84%; and in the normalized knee separation distance, in 90%.

A statistically significant improvement was observed in the mean t-test score ($p < 0.0001$), with 87% of the athletes demonstrating better scores after training. Although the 37-m test score improved from 6.11 ± 0.43 to 5.99 ± 0.38 seconds ($p = 0.02$), the effect size was small (0.14). A significant improvement was found in the 2-step approach vertical jump test ($p = 0.04$), but the effect size was also small (0.08). No improvement was found in the countermovement vertical jump. No subject in this phase sustained an injury that resulted in loss of time training or that required formal medical attention. The mean number of training sessions attended was 13 ± 2 (range 9–18).

Phase 2

Statistically significant improvements were observed in the MSFT in mean estimated $\dot{V}O_2max$ ($p < 0.0001$) and in the difference in the distribution of athletes in the categories between pretrain and posttrain test sessions ($p < 0.001$, Figure 3). Sixty-nine percent of the subjects improved in this test. No subject in this phase sustained an injury that resulted in loss of time training or that required formal medical attention. The mean number of training sessions attended was 15 ± 2 (range 11–18).

Discussion

This study assessed the effects of an ACL soccer-specific neuromuscular and performance enhancement training program on lower limb alignment on a video drop-jump test, agility, vertical jump height, speed, and estimated $\dot{V}O_2max$ in high school female players. The training program combined components from an ACL injury prevention program for jump and strength training with other exercises and drills to improve speed, agility, overall strength, and aerobic conditioning. The main findings of this investigation were a significant improvement in lower limb alignment on landing from a drop-jump, increases in speed and agility, and improved estimated $\dot{V}O_2max$. The overall findings allow recommendation of this program to athletes, coaches, and parents for not only ACL injury prevention but also for correction of neuromuscular deficiencies and enhancement of athletic performance indices. This is the first study that we are aware of that demonstrated that a knee ligament injury prevention program was effective in improving athletic performance indices in high school female soccer players.

Different models for knee ligament injury prevention training programs have been described, with varying results in regard to athlete compliance and reduction of ACL injury rates (5). Training may be done in 15–20 minutes in replacement of a portion of regular soccer practice (7) or accomplished as a rigorous 60- to 120-minute program before the beginning of a soccer season (23). One common problem with knee injury prevention training programs is athlete compliance with training (35,42). Although some authors advocate programs that are used as a warm-up during soccer practice, these interventions have not always proven successful in reducing ACL injury incidence rates (27,42,50). Recently, investigators have stated that improved compliance with knee injury prevention training programs would most likely occur if the programs focused on performance enhancement as well as neuromuscular retraining (2). Our study demonstrated adequate compliance with training even though the sessions lasted between 90 and 120 minutes because 47% of the players attended 14–18 sessions, 37% attended 11–13 sessions, and 16% attended 9–10 sessions.

Several investigations regarding ACL injury prevention programs designed for female soccer players have been published (Table 3) (14,19–21,23,27,31,42,43,48–50,52). The outcome of these programs vary widely in reducing noncontact ACL injuries and changing athletic performance indicators and neuromuscular indices. Study limitations exist such as lack of randomization, failure to document athlete exposures, or limited statistical power, which make direct comparisons between programs not feasible. In regard to reducing ACL injury rates, only 1 program to date had a statistically significant effect in female soccer players ($p < 0.0001$) (31), whereas another program approached statistical significance in this population ($p = 0.07$) (23). Other programs failed to achieve a significant reduction in ACL injury incidence rates (21,27,42,50).

The effect of ACL intervention training on improving neuromuscular indices in female soccer players have only been assessed in 3 studies to date (20,43,48). Participation in the PEP warm-up program in 1 study resulted in a significant reduction in mean hip internal rotation (7.1 vs. 1.9°, $p = 0.01$) and a significant increase in mean hip abduction (−4.9 vs. −7.7°, $p = 0.020$) on a drop-jump test (43). However, there was no effect in knee valgus or knee flexion angles during this task. Another study in athletes who completed the PEP program showed a significant reduction in peak knee valgus moments on a reactive side-step cut (48). Prepubescent athletes aged 9–11 years who underwent another ACL intervention warm-up training program did not improve overall lower limb alignment on landing on a drop-jump test (20). In contrast, our study demonstrated statistically significant improvements in overall lower limb alignment on the drop-jump test. A distinct valgus lower limb alignment on landing was measured in 62% of the athletes before training and in just 4% after completion of the intervention program. A valgus lower limb alignment on landing from a jump is believed to be a potential risk factor for a future noncontact ACL injury (1) and the International Olympic Committee recommended that the drop-jump screening test be used to identify athletes at-risk for a noncontact ACL injury (45). A valgus knee position has been frequently documented using video analysis milliseconds before or after, or at the time of ACL tears (8,29). Therefore, changing this landing position to one of a more neutral lower limb alignment is a goal of neuromuscular training in terms of knee ligament injury prevention. Future studies are required in soccer players to determine if the improvements observed in our study are retained over time.

Improvements in athletic performance tests have not been demonstrated in ACL intervention studies involving female soccer players to date. Soccer players who participated in the PEP program failed to improve vertical jump height, speed, or agility (52). The "11" program did not result in enhanced lower extremity or hip strength, vertical jump height, sprint speed, or soccer skill tasks (49). Our study showed significant improvements in agility as measured with the *t*-test. This test has been found to be useful by other investigators because it measures a combination of leg speed, leg power, and agility and can discern between athletes of various levels (40). In our study, 87% of the subjects improved on this test after completion of the training program. The mean scores of our subjects (12.05 ± 0.87 seconds before training and 11.31 ± 0.69 seconds after training, $p < 0.0001$) are comparable with those published in older collegiate athletes (40,41) and are useful in that they provide baseline data on adolescent female soccer players for future research investigations. Our study demonstrated improvements in speed as measured on the 37-m sprint test; however, the effect size was small and the impact on athletic performance remains unclear.

Our study demonstrated significant improvements in the MSFT, with 69% of the players showing increased estimated $\dot{V}O_2$max levels. This represents the first data reported that we are aware of on the effectiveness of an ACL intervention program on the MSFT in female adolescent soccer players. The MSFT is a common field measure of aerobic fitness that has been used in athletes of varying sports and performance levels (10,17,18,39,51). Maximal aerobic power and intermittent high-intensity endurance levels affect performance during soccer matches and are considered important in talent detection and development in women soccer players (9). It is important to note that Castagna et al. (9) cautioned that, in young female players, the estimated $\dot{V}O_2$max derived from the MSFT may underestimate actual $\dot{V}O_2$max as measured from the player's expired gas with a portable breath gas analyzer. These authors suggested that the distance covered, and not the estimated $\dot{V}O_2$max values, should be used when assessing young female soccer players. Further work is required in adolescent female soccer players in determining the accuracy of the MSFT in predicting $\dot{V}O_2$max and its association with match performance and talent identification.

In our study, only a slight improvement was detected in the 2-step approach vertical jump (mean increase, 1.3 ± 5.3 cm), and no improvement was found in the countermovement vertical jump. Whether continued training with this same program or with different plyometric exercises is required to improve vertical jump height is unknown in this population. Although many studies have advocated high-intensity plyometric training in adult or elite athletes, few have assessed a low-intensity program that may be more reasonable and safer to perform in adolescent female soccer players. In taking this into account, Rubley et al. (46) measured the effects of a low-frequency, low-impact plyometric training program on vertical jump and kicking distance in 10 female soccer players aged 13.4 ± 0.5 years. A significant 18.6% increase was noted in the vertical jump height between pretrain and posttrain test sessions (39.6 ± 8.2 and 47.0 ± 8.1 cm, respectively, $p = 0.001$). Myer et al. (34) reported increases in vertical jump height in high school female athletes aged 15.3 ± 0.9 years following a training program, which was similar to that described in this investigation. However, these authors combined data from basketball, volleyball, and soccer players; therefore, the effect of the training program on soccer players alone could not be determined for comparison with the current investigation.

One limitation to our study was no control or comparison group, which will be included in future studies. We did not control for activities athletes may have done before the training program was initiated or for nutrition during the intervention period; however, no athlete had participated in a neuromuscular training program, and none were playing organized soccer during the study time period. Additional studies are required to determine if these findings will improve athlete compliance and team participation in knee ligament injury intervention training. In addition, it remains to be determined if this program results in improved player performance during competition. The program was conducted in female high school players of varying experience levels and the results may not be applicable to elite or collegiate players.

Practical Applications

This study's findings allow the recommendation of this new soccer training program for ACL injury prevention, correction of neuromuscular deficiencies, and improvement of athletic performance indices. The program combines components from a previously published ACL injury prevention program with other exercises and drills to improve speed, agility, overall strength, and aerobic fitness (Table 2). Training may be conducted in the off-season or just before the beginning of the soccer season. The entire program may be done on a high school soccer field and weight room. This program significantly improves lower limb alignment on a drop-jump test, which is believed to be helpful in preventing ACL injuries. The training also increases speed, agility, aerobic fitness, and vertical jump height in female high school soccer players. We recommend that coaches and trainers who wish to implement this program conduct the tests that were done in this study to determine the program's overall effectiveness. Athletes who fail to improve should be encouraged to continue neuromuscular training.

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