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Balance Improvements in Female High School Basketball Players After a 6-Week Neuromuscular-Training Program

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Context: Poor balance has been associated with increased injury risk among athletes. Neuromuscular-training programs have been advocated as a means of injury prevention, but little is known about the benefits of these programs on balance in high school athletes. ***Objective:*** To determine whether there are balance gains after participation in a neuromuscular-training program in high school athletes. ***Design:*** Nonrandomized controlled trial. ***Setting:*** All data were collected at each participating high school before and after a 6-wk intervention or control period. ***Participants:*** 62 female high school basketball players recruited from the local high school community and assigned to a training (n = 37) or control (n = 25) group. ***Intervention:*** Training-group subjects participated in a 6-wk neuromuscular-training program that included plyometric, functional-strengthening, balance, and stability-ball exercises. ***Main Outcome Measures:*** Data were collected for the Balance Error Scoring System (BESS) and Star Excursion Balance Test (SEBT) before and after the 6-wk intervention or control period. ***Results:*** The authors found a significant decrease in total BESS errors in the trained group at the posttest compared with their pretest and the control group ($P = .003$). Trained subjects also scored significantly fewer BESS errors on the single-foam and tandem-foam conditions at the posttest than the control group and demonstrated improvements on the single-foam compared with their pretest ($P = .033$). The authors found improvements in reach in the lateral, anteromedial, medial, and posterior directions in the trained group at the posttest compared with the control group ($P < .05$) using the SEBT. ***Conclusion:*** The study demonstrates that a neuromuscular-training program can increase the balance and proprioceptive capabilities of female high school basketball players and that clinical balance measures are sensitive to detect these differences.

Keywords: proprioception, motor control, Balance Error Scoring System, Star Excursion Balance Test

Participation in athletics by adolescents is ever increasing, with over 7 million high school students participating in interscholastic athletics.[1] It has been

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estimated that over 700,000 sport- and recreation-related injuries occur in the secondary-school setting annually.[2] At the high school level, it has been found that over 6000 athletes sustain a sport-related injury at least once per year, and over 25% of these injuries result in a loss of more than 7 days of participation.[3] Therefore, there has been an push toward identifying mechanisms of preventing many of these injuries, with one focus being the incorporation of neuromuscular-training programs.

Neuromuscular training aims to improve neuromuscular control, thus increasing functional joint stability,[4] which may have a protective effect against injury. These training programs typically incorporate strengthening, stretching, plyometric, and balance components.[5] The inclusion of balance training in these programs is thought to improve the coactivation of the muscles surrounding joints, increasing joint stiffness and active joint stability,[6] and may also alter biomechanical injury risk factors such as increased knee valgus during landing activities.[5,7,8] Poor balance has also been associated with an increased risk of ankle injuries among both male adult[9–11] and male and female adolescent athletes.[12] Moreover, the Star Excursion Balance Test (SEBT) has been found to be predictive of lower extremity injury in high school basketball athletes.[13] However, studies of other adult and adolescent populations have reported no association between balance ability and ankle injury risk.[14–16] Research investigating multicomponent neuromuscular-training programs and injury rates found that athletes participating in these programs have demonstrated decreased injury rates for anterior cruciate ligament (ACL) sprains,[17–20] ankle sprains,[21–23] and combined lower extremity injuries.[24,25]

Balance is generally considered an important component of athletic activity. Therefore, in addition to the possible reduction in injuries, participation in neuromuscular-training programs may also improve motor control, which could, in turn, improve athletic performance. This aspect can be beneficial because obtaining support from coaches and maintaining athlete compliance in these injury-prevention programs can be challenging if the focus is solely on injury prevention. Having programs that improve athletic performance such as balance, vertical jump, and strength may be an additional incentive for athletes to comply and participate. Holm et al[26] found that after participation in a neuromuscular-training program, team handball players showed significant improvements in their dynamic-balance capabilities. Likewise, Paterno et al[27] found improvements in single-limb total stability and anteroposterior stability in female high school athletes after a 6-week neuromuscular-training program. In addition, improvements in strength, vertical-jump height, mediolateral stability, and maximal bench press, hang clean, and parallel squats were found in female athletes who participated in either a balance-based or plyometrics-based training program.[28]

There is some indication that it is most advantageous to begin neuromuscular training during adolescence to train the body during a time of rapid musculoskeletal growth and decreased balance and coordination that occurs as a result of that growth.[29,30] It has been hypothesized that musculoskeletal growth during adolescence without equal neuromuscular development may result in neuromuscular imbalances that make the individual more susceptible to injury.[31] Therefore, the initiation of these programs in interscholastic athletic programs would be warranted.

Although these results are promising, there is a need for further research in this area studying the effects of different types of neuromuscular programs on balance ability, especially in adolescents. Furthermore, the aforementioned studies used instrumented balance-testing devices that are not readily available in most high school and club sports settings. Therefore, the purpose of our study was to determine whether static and dynamic balance, as measured through clinical balance tests, would improve after participation in a neuromuscular-training program.

Methods

Design Overview

A single-blinded, nonrandomized, controlled trial was developed to determine whether balance ability improves after participation in a neuromuscular-training program. To assess possible balance gains from participating in the training program all participants were tested before starting the program using both the Balance Error Scoring System (BESS) and the SEBT. Two groups were formed, based on school affiliation, to determine the true balance gains achieved by the experimental group. Both the control group and the experimental group participated in 1 pretest and 1 posttest at the beginning and end, respectively, of the 6 weeks.

Because the groups were formed based on school affiliation, subjects in the control group were not aware of the training program in which the other group participated. The assessors scoring the BESS and taking the SEBT measures were blinded to group assignment, and the primary supervisor for the training program did not assist in taking any of the pretraining or posttraining measures.

Subjects

We recruited 37 female high school basketball players to participate in the training program and 25 to participate as control subjects. Subjects were grouped in either the training group or the control group based on their respective schools. We analyzed the data from only 50 (27 trained and 23 controls) participants because of noncompliance or incomplete data sets. The demographic information for each group is listed in Table 1. Participants were selected on the following criteria: currently participating in competitive high school basketball, no lower extremity musculoskeletal injuries in the past 6 months, and no history of head injury in the last 6 months. Before participation, the parent or guardian of each participant and the participant read and signed an informed-consent or -assent form approved by the university's Institutional Review Board for the Protection of Human Subjects.

Table 1 Descriptive Statistics for the Participants (Mean ± SD)

	Trained, n = 27	Control, n = 23
Age (y)	15.6 ± 1.1	16.0 ± 1.3
Height (cm)	170.7 ± 6.8	171.5 ± 8.1
Mass (kg)	58.9 ± 5.9	62.3 ± 7.6

Setting

All testing and training took place in the gymnasiums of the participating high schools during the basketball preseason. To our knowledge, at the time of testing both groups were solely participating in open gym practices before the official start of their basketball preseason practices. Testing for the control group consisted of a pretest and posttest 6 weeks apart with no formalized training program between testing periods. Athletes in the control group were instructed to continue with their normal activities of daily living and participation in sport activities but were not restricted from doing any individual workouts. The experimental group was tested before and after participation in the 6-week training program.

Instrumentation and Procedures

BESS. The BESS consisted of 6 separate 20-second balance tests that the subject performed in different stances and on different surfaces. The test consisted of 3 stance conditions (double-leg, single-leg, and tandem stance) and 2 surfaces (firm and foam). A 16 × 16-in piece of medium-density foam was used to create an unstable surface for 3 of the balance conditions. Errors were recorded as the quantitative measurement of postural stability under different testing conditions. The errors included lifting hands off the hips; opening the eyes; stepping, stumbling, or falling from the testing positions; lifting the forefoot or heel; moving the hip into 30° or more of flexion or abduction; and remaining out of the testing position longer than 5 seconds. The number of errors scored for each of the 6 conditions was recorded. The BESS has demonstrated good reliability compared with force-platform measures[32] and can be scored with excellent intratester reliability.[33] Pilot studies on BESS scoring by our research team demonstrated excellent intratester (ICC = .90) and intertester (ICC = .85) reliability.

BESS testing took approximately 6 minutes per subject, and all scores were recorded on a form by the investigator assessing BESS performance. The order of the 6 conditions was randomized for each trial between subjects and sessions. Subjects were instructed to stay in the required stance with their hands on their iliac crests and eyes closed. Once an athlete closed her eyes, the test was started. During the single-leg stances, the subjects stood on their nondominant limb, as defined as their stance leg during kicking, and were asked to maintain the contralateral limb in 20° of hip flexion and 40° of knee flexion. The nondominant limb was chosen as the standardized test limb across subjects. We told subjects that on losing their balance, they should open their eyes and return to the starting position as quickly as possible. We calculated individual condition scores and by adding the error points in each of the 6 conditions. Trials were considered incomplete if the subject could not remain in the stance position for longer than 5 seconds, in which case she was assigned a standard maximum score of 10 for that stance.[32]

SEBT. A functional testing grid (EFI Sports Medicine, San Diego, CA) was used along with regular athletic tape (Johnson & Johnson, New Brunswick, NJ) to map a star on a tile floor at each site. The SEBT setup consisted of 5 lines at 45° and 90° intervals extending from a center point. The angles used extended out from the center at 45°, 90°, 180°, 270°, and 315° to provide targeting for the participants. Reliability of the SEBT is good to excellent for both intertester and intratester reliability.[34]

Subjects were instructed on where to stand and proper technique for performing the tests. They stood with the distal end of the first metatarsal directly in the center of the mat. They then used the opposite foot to reach out as far as possible in the 4 directions. The distance that the farthest portion of their foot reached was recorded. The participants placed their hands on their iliac crests before starting the test and were instructed to maintain the hand position as they performed the reach. The entire stance foot remained on the ground throughout the entire test. Lifting part of the foot resulted in that portion of the test being redone. SEBT testing was conducted with both the dominant and the nondominant leg as the stance leg.

The SEBT testing took approximately 10 minutes per subject, and all scores were recorded on a form by the investigator assessing BESS performance. Based on previous research that has shown redundancy in the different reach directions,[35] we chose to only take measurements in 4 directions: anteromedial, medial, posterior, and lateral. The direction was determined in relationship to the stance leg. The participants were given 3 practice trials to become comfortable with the testing before recording. Each participant performed 2 trials in each direction standing on each leg. The average reach distances for each direction were recorded and used in the analysis (Table 3).

Training Program

The training program was developed by one of the investigators supervising the training sessions, who modified the exercises from previously published programs.[17–20] The program consisted of 2 sessions per week for 6 weeks before the start of the basketball season. Each training session lasted 1 1/2 hours. During each session participants began with a 5-minute warm-up consisting of jogging, side shuffles, cariocas, and stretches. Subjects then rotated through 4 different stations including functional strengthening (30 minutes), plyometrics (20 minutes), agility training (10 minutes), and balance training (10 minutes). Functional strengthening included stability-ball exercises, lunges, and band walks.

Table 3 Star Excursion Balance Test Composite Reach Distances (cm) Across the 2 Time Points and Between the 2 Groups for the 4 Directions (Mean ± SD)

	Pretest		Posttest	
Direction	**Control**	**Trained**	**Control**	**Trained**
Lateral	78.6 ± 6.6	76.2 ± 9.2	80.3 ± 6.9	86.2 ± 6.7[a,b]
Anteromedial	86.7 ± 5.8	83.1 ± 6.3	86.8 ± 4.2	90.6 ± 6.6[b]
Medial	91.2 ± 6.7	85.9 ± 7.6	89.9 ± 4.5	95.1 ± 6.2[a,b]
Posterior	97.9 ± 7.6	97.3 ± 8.8	93.9 ± 4.9	104.6 ± 6.4[a,b]

[a] Significantly farther reach for the trained group during the posttest than the control group.
[b] Significantly farther reach in posttest than pretest.

Single- and double-leg jumping and bounding in the anteroposterior and mediolateral directions were performed at the plyometrics station. The agility station focused on jumping rope, cone runs, and shuttle runs with emphasis on proper cutting technique. The balance-training station included single- and double-leg balance exercises on a half foam roll and variations such as squatting and dribbling a basketball while balancing. Exercises at each station were progressed weekly by increasing the number of repetitions, time spent doing a particular exercise, or the difficulty of the exercise. The exercises for weeks 1, 3, and 5 of the training program can be found in the Appendix.

Statistical Analysis

All analyses were performed using SPSS version 13.0 (SPSS Inc, Chicago, IL), and significance was set at .05 a priori. To determine whether the athletes who were not compliant with the training program differed from those who were, independent *t* tests were run on the demographic data and the pretest balance measures for the 37 athletes who made up the trained group.

For the BESS analysis, a 2 × 2 × 6 repeated-measures analysis of variance (ANOVA) was used. The between-subjects variable was group (2 levels: control, experimental) and the within-subject variables were time (2 levels: pre, post) and condition (6 levels: double-firm, single-firm, tandem-firm, double-foam, single-foam, tandem-foam). In cases where the assumption of sphericity was violated, Greenhouse–Geisser corrections were applied. Significant differences were analyzed further with Tukey honestly significant difference post hoc analysis.

A preliminary analysis of the SEBT data revealed no difference between the dominant and nondominant sides, so these values were collapsed for subsequent analyses. The reach distance for each of the 4 directions of the SEBT was analyzed with separate 2 × 2 repeated-measures multivariate analysis of variance (MANOVA). The between-subjects variable was group (2 levels: control, experimental) and the within-subject variable was time (2 levels: pre, post). In cases where the assumption of sphericity was violated, we applied Greenhouse–Geisser corrections. We corrected for multiple analyses using a Bonferroni correction with $P < .013$. Significant differences were analyzed further with Tukey honestly significant difference post hoc analysis.

Results

Subject Compliance

We had 27 training-group subjects complete at least 50% of the training sessions (mean attendance 9.88 ± 1.67 sessions, range 7–12). Ten trained subjects were excluded from the posttest because they did not attend at least 50% of the training sessions (mean attendance 1.75 ± 2.30 sessions, range 0–5). Our compliance rate for program participation was 73%. Complete BESS data were only available for 19 subjects, because 5 did not attend the BESS posttest session and we did not have pretraining or posttraining data for 3.

Analysis of the trained-group participants who were compliant with the program versus those who were not revealed that the noncompliant athletes were younger (14.89 ± 0.7 vs 16.0 ± 1.2 years, $t = -2.92$, $P = .006$), in a lower grade (grade 9.6 ± 0.7 vs 10.6 ± 1.0, $t = -3.08$, $P = .004$), and shorter (163.9 ± 5.3 vs 170.9 ± 7.1 cm, $t = -3.05$, $P = .004$) and had fewer years of high school basketball experience (0.8 ± 1.0 vs 1.7 ± 1.3 years, $t = -2.33$, $P = .026$). There were no differences between compliant and noncompliant trained-group subjects on any of the pretest BESS conditions or SEBT reach directions.

BESS

Complete BESS scores were available for 19 trained subjects and 23 control subjects. Five subjects did not return for BESS posttesting. We had a significant time × condition × group interaction ($F_{3.02,120.79} = 2.997$, $P = .033$). Post hoc analyses of this 3-way interaction found that the trained group scored significantly fewer errors than the control group at the posttraining assessment on the single-foam and tandem-foam conditions (Table 2). In addition, the trained group demonstrated significantly fewer errors at the posttest assessment than at their pretest assessment on the single-foam condition. The trained group scored significantly fewer BESS errors at the posttest assessment (7.1 ± 0.7) than the control group (14.2 ± 1.2).

Because of the number of noncompliant subjects, our analyses were replicated using an intention-to-treat analysis carrying the pretest values forward to serve as their posttest measures. This analysis of available data from 25 control subjects and 23 trained subjects revealed a significant time × condition × group interaction ($F_{3.03,139.51} = 2.845$, $P = .039$). Post hoc analyses found that the trained group scored significantly fewer errors on the single-foam and tandem-foam conditions and total errors (7.9 ± 3.6 vs 14.2 ± 4.6) at the posttest than the control group.

Table 2 Balance Error Scoring System Errors (Mean ± SD) Across the 2 Time Points and Between the 2 Groups for the 6 Conditions

	Pretest		Posttest	
Condition	**Control**	**Trained**	**Control**	**Trained**
Double firm	0 ± 0.0	0 ± 0.0	0 ± 0.0	0 ± 0.0
Single firm	2.6 ± 1.6	2.42 ± 2.5	2.5 ± 2.1	1.5 ± 1.0
Tandem firm	1.1 ± 1.5	0.47 ± 0.8	1.3 ± 1.3	0.4 ± 0.8
Double foam	0.3 ± 0.6	0.1 ± 0.3	0.4 ± 0.7	0 ± 0.0
Single foam	5.3 ± 1.1	5.1 ± 2.0	6.0 ± 1.6	3.6 ± 1.07[a,b]
Tandem foam	4.4 ± 1.4	2.6 ± 1.0	4.0 ± 1.5	1.6 ± 1.3 [a,b]
Total	13.7 ± 1.0	10.62 ± 1.1	14.2 ± 1.2	7.1 ± 0.7 [a]

[a] Significantly fewer total errors for the trained group than the control group during the posttest.
[b] Significantly fewer errors for the trained group during the posttest than in their pretest.

SEBT

The SEBT analysis included 27 trained subjects and 23 control subjects. The ANOVA for the lateral reach direction demonstrated a significant time × group interaction ($F_{1,48} = 18.612$, $P < .001$). Post hoc analyses of these findings showed that the trained group's posttest lateral reach was significantly farther than their own pretest, as well as both the pretest and posttest distances for the untrained group. Analysis of the anteromedial reach direction revealed a significant time × group interaction ($F_{1,48} = 19.568$, $P < .001$) that showed that the trained group's posttest reach distance was significantly greater than at their pretest. Similarly, our findings for the medial reach direction demonstrated a significant time × group interaction ($F_{1,48} = 36.202$, $P < .001$), with the post hoc analysis showing that the trained group's posttest was significantly farther than their own pretest and the untrained group's posttest. Analysis of the posterior reach direction revealed a significant time × group interaction ($F_{1,48} = 32.003$, $P < .001$) in which the post hoc analysis showed that the trained group's posttest was significantly farther than their own pretest and both the pretest and posttest distances for the untrained group.

Discussion

Our main findings demonstrate improvements in both the static- and dynamic-balance ability of high school female athletes after participation in the training program and the ability of 2 clinical balance measures to be sensitive to detect these differences. With respect to static balance, as measured by the BESS, we found a decrease in total BESS errors, errors on the single-foam, and errors on the tandem-foam conditions in the athletes who participated in the training program. We also found increases in dynamic-balance reach distance in the 4 SEBT directions in the subjects who participated in the program compared with the controls. Together these findings demonstrate improvements in both static and dynamic balance after participation in the training program and the sensitivity of these 2 clinical balance measures to detect these differences.

The BESS and the SEBT are valid and reliable clinical measures of static and dynamic balance.[32–34] They are both tools that can be used in the clinical setting, especially for those with limited budgets and space, often encountered at the secondary-school level. These balance tests require little equipment and are relatively easy to administer. In addition to being able to detect improvements in balance, as found in our study, the BESS has been shown to be sensitive for detecting balance deficits after concussion[36] and in patients with functional ankle instability,[37] and the SEBT has been shown to be sensitive for detecting balance deficits caused by functional ankle instability.[38]

We did find that the balance improvements on the single-foam and tandem-foam conditions in our trained group led to the decrease in total BESS errors. It is important to note that there were group differences during the pretest on the tandem-foam condition, with the training group demonstrating better balance. Although there were more errors scored in the single-foam and tandem-foam conditions, they were the 2 conditions that showed improvements after our training program. This is consistent with findings of other researchers using the BESS.[32,33,36,39] These 2 conditions are considered harder because of a decrease in the subject's base of support and the use of an unstable surface. They have also been shown to be most susceptible to learning effects.[33,39] Unlike previous research looking at balance after a training program that found no improvements in static balance,[26] we included a control group to help eliminate the possibility that the learning effects caused the improvements. Moreover, we were still able to find significant improvements in static balance compared with the control group. Therefore, we feel that the balance improvements found can be attributed to the training program.

We expected minimal improvement in the other 4 conditions because they are easier and similar to daily activities. The improvement in the single-foam and tandem-foam conditions can be attributed to the activities and progressions in the training program. Part of the training program consisted of balance-related activities that constantly increased in difficulty. The exercises progressed from balancing on the ground to balancing on a half foam roller and added activities such as squats, lunges, dribbling, and passing. This progression of exercises, intended to increasingly stress the motor-control system and provide greater neuromuscular-control challenges, may have resulted in improved balance. In addition, the functional-strengthening component of our program used stability-ball exercises, which have been found to improve static balance. A study comparing a 5-week core-stability program of sit-ups and back-extension exercises done on a stability ball found significantly greater improvements in single-limb static balance with eyes closed and the stance limb in full extension and at 60° of knee flexion than in a group who did the same exercises on the floor.[40] It was hypothesized that the neural adaptations of the stability-ball training resulted in more efficient neural recruitment patterns and improved synchronization of motor units that led to increased limb stability and balance.[40] Similar mechanisms are likely responsible for the static-balance gains found in this investigation.

We did find significant improvements in the reach distances of the trained group after the training program. The improvements that were found for the SEBT can also be attributed to the exercises in the training program. The balance training, as well as the functional strengthening, likely increased both lower extremity strength and neuromuscular control during the SEBT. Research has shown that an increase in reach distance creates an increase in the demands placed on balance and the neuromuscular system.[41] The ability to improve reach distances results from increased range of motion in the hip, knee, and ankle, as well as increased neuromuscular control of the lower extremity. It has also been found that muscle activity depends on the direction of the excursion.[41]

The weekly progressions in the difficulty of the exercises and the increased number of repetitions may have also aided in improving neuromuscular control and SEBT performance. Exercise progression may have contributed to improvements in maintaining stability while performing a functional-reach test. The addition of activities such as squats and lunges likely improved strength and neuromuscular control about the hip, knee, and ankle while balancing, allowing for increased reach distances in the posttest SEBT. The core-strengthening components of the functional strengthening may have also played a role in creating a strong, stable base of support for peripheral movement. Collectively, these exercises may have led to increased neuromuscular control in the stance leg that was evident in the trained group's ability to reach farther during their posttest.

Research has shown that proprioceptive training and functional core strengthening improve dynamic balance.[26–28] Holm et al[26] studied 35 female handball players and used the KAT 2000 to assess balance performance before and after a 7-week ACL-injury-prevention program. They found that after the program there was significant improvement in the dynamic-balance scores; however, no improvements in static balance were noted. Paterno et al[27] assessed improvements in single-leg stance after a 6-week neuromuscular-training program. They used a Biodex Stability System to assess the single-limb postural stability for each limb before and after the ACL-injury-prevention program. They found significant improvements in single-limb total stability, as well as anteroposterior stability, but found no differences in mediolateral stability.[27] The findings of our study support the previous research and add improvements in static balance, as well as the usefulness of clinical balance measures, to the body of literature on neuromuscular training.

Although the intent of this study was solely to measure changes in clinical measures of static and dynamic balance after a 6-week neuromuscular-training program, it is important to recognize that there are a number of published studies investigating the relationship between balance ability and injury risk, as well as the effectiveness of training programs on reducing lower extremity injury risk. Although there is no consensus on whether balance ability can predict injury risk,[9–12,14–16] several studies have found that either balance training or multicomponent training programs can reduce injury rates.[17–25] These studies varied with respect to the timing of their programs (preseason vs in-season vs both), types of exercises used (balance training only vs multicomponent programs), and injuries recorded (ankle sprains vs recurrent ankle sprains vs ACL sprains vs all lower extremity injuries). It is also unknown whether balance improvements achieved during the course of a training program are maintained once the program ended. However, it does seem that studies that continued with an in-season maintenance training program were more successful in injury-risk reduction.[19,21,25,42–44] We did not investigate how long our balance improvements were maintained after our posttraining data-collection session.

Anecdotally, it has been thought that improvements in balance may lead to improvements in stability that could ultimately improve functional and athletic performance. Improved dynamic balance may be associated with increased core stability, which allows for improved ability to respond to perturbations and outside forces during athletic activity.[30] Balance training has also been found to be effective for gains in muscle strength and reducing muscle imbalances.[45] One study compared the effects of balance training versus strength training on 2 balance measures and isokinetic strength measures. The balance-trained group demonstrated a 146% increase in a single-leg balance test, compared with only a 34% increase in the strength-trained group. The gain in flexion and extension strength in the balance-trained group was similar to that of the strength-trained group. It was hypothesized that the gain in strength was the result of increased muscle coordination and better coactivation of the muscles to stabilize the limb. A reduction in muscle imbalances may be especially important in female athletes because agonist–antagonist and side-to-side muscle imbalances have been thought to be contributing risk factors for ACL injury in females.[46] Myer et al[28] compared the effects of a plyometrics-based training program with a dynamic-stabilization and balance-training program on several athletic performance markers including vertical jump, strength, and balance. After training, both groups demonstrated improvements in mediolateral stability, vertical-jump height, isokinetic hamstring peak torque, hamstring-to-quadriceps strength ratios, and predicted measures of 1-repetition-maximum bench press, hang clean, and parallel squat. In addition, participation in the balance-training group led to a decrease in impact forces during a single-leg hop, which may be protective for the knee.[28] We acknowledge that we only measured static and dynamic balance ability and cannot infer improved athletic performance in our sample. However, the findings of others that balance training can increase strength and other performance measures may be a motivator to increase compliance in prevention training programs.

Compliance with training programs is a continued area of concern. Taking only an injury-prevention approach may not keep athletes compliant in participating, thus reducing the effectiveness of these programs as a means of injury prevention. Myklebust et al[19] found that with their ACL-injury-prevention program, female handball athletes had a compliance rate of only 29% in their general athlete population and 50% in their elite athlete population. We saw a 73% compliance rate in our trained subjects. It has been noted that improvements in compliance have increased to 80–90% when programs are targeted toward performance enhancement.[30] This may be an even more important issue in high school athletes, for whom these programs seem to have the most beneficial effects and the athletes may be less compliant.[5,30]

In addition, the timing and supervision of athletes participating in these types of training programs may also improve compliance. A compliance rate >90% has been reported in 2 separate studies investigating the effectiveness of balance-training programs on ankle-sprain incidence in adolescent athletes.[47,48] These 2 studies used programs that were supervised by the team's coach or athletic trainer and were performed as part of a team practice or training session. In contrast, an unsupervised home-based balance-training program in adolescent athletes demonstrated a 60.3% compliance rate. Therefore, clinicians hoping to implement these types of programs should consider including performance measures, implementing the program in a team setting, and providing adequate supervision.

We acknowledge that this research used a convenience sample and that subjects were not randomly assigned to the training or control group but, rather, grouped according to their school affiliation. The use of a blinded randomized controlled study design would improve the generalizability of our results. In addition, we had 10 subjects from our trained group not present at 50% of the training sessions or the posttest, and 2 control subjects were not present for their posttest. As mentioned previously, athlete compliance is an issue with these types of training programs, and this was no different with our sample. The reasons that subjects did not complete the training program or return for posttesting are unknown. It is possible that subjects who had difficulty performing the more advanced exercises chose to stop participating in the program; however, we did not contact subjects after the program to ask why they did not continue to participate.

Through our program that incorporated agility training, balance and proprioception, plyometrics, and functional strengthening we were able to detect improvements in static and dynamic balance, as measured with 2 clinical balance tests. Demonstrating balance improvements and possible performance enhancement through participation in a neuromuscular-training program may increase athlete compliance, which may afford them the benefits of these programs as a means of injury prevention. Future research should be directed at studying balance and other performance-enhancement tasks with athletes from different sports, using a randomized controlled design to improve the generalizability of the findings. Studies should also investigate the role of an in-season maintenance program, as well as looking at the retention of balance gains after training and throughout the course of a season.

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Appendix: Examples of the Exercises and Goals of the Training Program

Agility exercise	Week 1	Week 3	Week 5
Cone figure 8s forward running			
wide width	Up and back twice		
medium width	Up and back twice	Up and back twice	
narrow width	Up and back twice	Up and back twice	
single-line cones		Up and back twice	
45° cuts with 2 rows of cones (forward and backward)			
medium width			Up and back twice
narrow width			Up and back twice
Shuttle run using basketball court key			
forward/backward	2×10 s		
lateral slide	2×10 s		
box pattern		2 times each direction	
M pattern		2 times each direction	2 times each direction
W pattern			2 times each direction
Line jumps (quick feet)			
side/side, double leg	2×10 s	2×15 s	
forward/backward, double leg	2×10 s	2×15 s	
Jump rope (no double jumping)			
double-leg jumping			3×30 s
single-leg jumping			3×15 s each

Balance/Proprioception exercise	Week 1	Week 3	Week 5
Double-leg balance (A/P tilt)			
ready position	3 × 30 s		
ready position with passing		3 × 30 s	
with ball handling drills on half foam roll			3 × 30 s
Single-leg balance (M/L tilt)			
ready position	3 × 15 s		
ready position with passing		3 × 20 s	
with ball handling drills on half foam roll			3 × 20 s
Lateral step-downs on half foam roll (M/L tilt)	15 reps each leg		
Forward step-downs on half foam roll (A/P tilt)		15–20 reps each leg	
Double-leg squats on half foam roll (A/P tilt)			10 reps
Single-leg squats on half foam roll (M/L tilt)			5 reps each leg

A/P tilt, anteroposterior tilt on foam roll; M/L tilt, mediolateral tilt on foam roll.

Plyometric exercise	Week 1	Week 3	Week 5
Ankle jumps	10 s	20 s	30 s
Tuck jumps	10 s	20 s	30 s
Double-leg broad jumps	5 reps		
Squat jumps	10 s	20 s	20 s
Cone jumps			
lateral	10 s	20 s	30 s
forward/retro	10 s	20 s	30 s
Scissors jumps		20 s	30 s
180 jumps	10 s		
bounding in place	10 s		
bounding with movement		2 runs	
Single-leg hop for distance			1 run
Jump, jump, jump, vertical jump		5–8 reps	8–10 reps
Hop, hop, stick second landing		5 reps each leg	2 runs

Run, continuous reps moving down the court (approximately 5–7 reps).

Functional-strengthening exercise	Week 1	Week 3	Week 5
Push-ups (knees on floor okay)	10–20 reps	20–30 reps	30–40 reps
Stability-ball crunches (straight, diagonals)	10 reps	15 reps	20–25 reps
Stability-ball alternating hip flexion			
reclined position	10 reps each leg		
full bridged position		10 reps each leg	15–20 reps each leg
Stability-ball bridging with knees over ball			
double-leg	10 reps	15 reps	
single-leg			20 reps
Swiss-ball hamstring curls in bridge position			
double-leg	10 reps	15 reps	
single-leg			10 reps
Stability-ball prone roll-outs to the feet with push-up (hold 5 s)	5 reps	5 reps	5 reps
Stability-ball prone swimmers (alternate opposite UE/LE)	10 reps each side	15 reps each side	20 reps each side
Lunges: forward, lateral, retro (diagonal plane)	10 reps each direction	15 reps each direction	2 × 10 reps each direction
Stability-ball wall squats (hold 5 s)	10 reps	20 reps	25 reps
Ankle-band-resisted walks with passing drills (forward, retro, lateral)	20 ft × 2 each	20 ft × 4 each	20 ft × 4 each

A/P tilt, anteroposterior tilt on foam roll; M/L tilt, mediolateral tilt on foam roll; UE, upper extremity; LE, lower extremity.