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original research

Elite Female Basketball Players' Body-Weight Neuromuscular Training and Performance on the Y-Balance Test

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Context: Neuromuscular training enhances unconscious motor responses by stimulating both the afferent signals and central mechanisms responsible for dynamic joint control. Dynamic joint-control training is a vital component of injury-prevention programs.

Objective: To investigate the effects of body-weight neuromuscular training on Y-Balance Test (YBT) performance and postural control in female basketball players.

Design: Randomized controlled clinical trial.

Setting: Basketball practice sessions.

Patients or Other Participants: A total of 28 healthy elite female basketball players were randomly assigned to an experimental (n = 14) or a control group (n = 14).

Intervention(s): Before their regular practice sessions, the experimental group warmed up with body-weight neuromuscular exercises and the control group with standard tactical-technical exercises twice weekly for 8 weeks.

Main Outcome Measure(s): Anterior-, posteromedial-, and posterolateral-reach and composite YBT scores were measured before and after 8 weeks of training.

Results: Improvement over baseline scores was noted in the posteromedial (right = 86.5 ± 4.5 cm versus 89.6 ± 2.2 cm, +3.5%, P = .049; left = 85.5 ± 4.3 cm versus 90.2 ± 2.7 cm, +5.5%, P = .038)- and posterolateral (right = 90.7 ± 3.6 cm versus 94.0 ± 2.7 cm, +3.6%, P = .016; left = 90.9 ± 3.5 cm versus 94.2 ± 2.6 cm, +3.6%, P = .011)-reach directions and in the composite YBT scores (right = 88.6% ± 3.2% versus 94.0% ± 1.8%, +5.4%, P = .0004; left = 89.2% ± 3.2% versus 94.5% ± 3.0%, +5.8%, P = .001) of the experimental group. No differences in anterior reach were detected in either group. Differences were noted in postintervention scores for posteromedial reach (right = 89.6 ± 2.2 cm versus 84.3 ± 4.4 cm, +4.1%, P = .005; left = 94.2 ± 2.6 cm versus 84.8 ± 4.4 cm, +10%, P = .003) and composite scores (right = 94.0% ± 1.8% versus 87.3% ± 2.0%, +7.1%, P = .003; left = 94.8% ± 3.0% versus 87.9% ± 3.4%, +7.3%, $P < .0001$) between the experimental and control groups.

Conclusions: Body-weight neuromuscular training improved postural control and lower limb stability in female basketball players as assessed with the YBT. Incorporating neuromuscular training into the workout routines for basketball players may enhance joint awareness and reduce the risk of lower extremity injury.

Key Words: core stability, lower limb stability, plyometric exercises

Key Points

- In female basketball players, a body-weight neuromuscular-training program improved postural control and lower limb stability as assessed on the Y-Balance Test.
- Warm-up programs that emphasize neuromuscular control of the lower extremities may help to enhance postural control, increase joint awareness, and reduce the risk of lower extremity injury.

Basketball is one of the world's most popular physical activities. According to the International Basketball Federation, at least 450 million people, ranging from licensed players to amateurs, play basketball worldwide.[1] Although basketball is not strictly considered a contact sport, the lower limb joints are constantly subjected to physical stress from the technical movements and intense physical interactions during play.[2] McInnes et al[3] identified different types and intensities of activities and movement patterns, including quick and frequent running movements, shooting, direction alterations, and jumps, that changed every 2 seconds during play. They estimated that a mean total of 105 ± 52 high-intensity runs (mean duration = 1.7 seconds) recorded in a game translated into 1 high-intensity run every 21 seconds during play.

Despite the development and implementation of injury-prevention activities, lower limb and ankle injury rates in basketball players remain high in sports injury-surveillance systems.[4,5] Drakos et al,[6] in their descriptive epidemiologic study of National Basketball Association athletes, highlighted that injuries sustained in 17 championship seasons involved the lower limbs in 62.4% of cases, with the ankle being the most commonly injured site (14.7%), followed by the spine and the knee. Authors of prospective studies have reported that previous injury,[5] biomechanical alignment,[6] anatomical factors,[7] decreased muscle flexibility,[8] and poor balance[9] are common risk factors for lower limb injuries in basketball players. Moreover, injury rates are higher among female players than their male counterparts due to sex-related neuromuscular imbalances, including ligament, quadriceps, and leg dominance.[10] Specifically, women have a 2 to 8 times higher rate of anterior cruciate ligament (ACL) injury than men.[11] Zelisko et al[10] compared the injury rates of male and female professional basketball players and found that women sustained 60% more injuries to the knee and the ankle than did men.

Among other risk factors, lack of neuromuscular control of the lower limbs has been associated with knee and ankle injuries. Considered a critical component of motor skills,[9] *neuromuscular control* is defined as the ability to maintain the body's center of gravity within its base of support. It can be categorized as either static or dynamic balance[12] and may be the most modifiable risk factor in the prevention of knee injuries.[7] Neuromuscular-training programs have proven effective to reduce the risk of lower extremity injuries in a variety of sports.[8,13,14] Interventions that target neuromuscular control have demonstrated improvements in dynamic lower extremity alignment on landing from a jump; shock attenuation of peak landing forces; muscle-recruitment patterns; and postural stability or balance gained through plyometric, strengthening, balancing, endurance, and stability exercises.[7,15–17] Such programs often entail the use of Swiss balls, medicine balls, and unstable bases; however, their practicality for many individuals, teams, and clubs may be limited by the need for equipment purchases and extra training sessions in addition to the usual practices and competitions. A more practical, cost-effective solution would be to implement a neuromuscular-training program that requires no additional equipment and can be easily integrated into warm-up routines.

Body-weight neuromuscular training with resistance-training exercises makes use of body-weight overload: the neuromuscular component is body control during the performance of static and dynamic exercises. Combining core stability and plyometric exercises may provide a useful strategy to develop these body-control skills and improve neuromuscular control. *Core stability* refers to the body's ability to maintain or recover trunk position in response to internal or external forces. According to Zazulak et al,[17] deficits in neuromuscular control of the body's core may lead to uncontrolled trunk displacement during movement which, in turn, may place the lower extremity in a valgus position and increase knee-abduction motion and torque, resulting in knee ligament strain and ACL injury.[17] To reduce the risk of injury and improve joint awareness, balance, and neuromuscular control, strength and conditioning coaches direct their athletes in plyometric exercises during preseason and in-season training.[18] *Plyometrics* is a high-intensity, high-impact training technique that enables a muscle to reach maximal force in the shortest amount of time.[19] According to Wilk et al,[19] plyometrics makes use of the stretch-shortening cycle, in which the energy stored during the eccentric-loading phase and stimulation of the muscle spindles are used to facilitate maximum power production during the concentric phase of movement.[19] Though essentially a sport-specific training to enhance power and performance, plyometric exercises can be usefully integrated as warm-up routines in neuromuscular injury-prevention programs.

The Y-Balance Test (YBT), a validated derivation of the Star Excursion Balance Test (SEBT), is a functional screening tool that can be reliably administered for a variety of purposes: to assess lower extremity stability, monitor rehabilitation progress, understand deficits after injury, and identify athletes at high risk for lower extremity injury.[20] The YBT uses the anterior (A), posteromedial (PM), and posterolateral (PL) components of the SEBT to evaluate neuromuscular characteristics such as lower extremity coordination, balance, flexibility, and strength. Plisky et al[21] found that poor performance on the YBT was associated with an elevated risk of noncontact lower extremity injury. We reasoned that the YBT could be a useful tool to assess the effectiveness of an injury-prevention program for reducing the risk of such injuries. Therefore, the aim of our study was to determine whether an 8-week neuromuscular-training program focused on core stability, plyometric, and body-weight strengthening exercises could improve postural control, as assessed with the YBT, in female basketball players. Our rationale for selecting the YBT was that it would screen for deficits in postural control of the trunk (core) muscles, which could then be corrected through neuromuscular training using sport-specific and short warm-up routines to optimize subsequent athletic performance, enhance compliance, and prevent injuries.

METHODS

Participants

Participants were recruited from 2 female basketball teams of the Italian national league. Before entering the study, the participants were fully informed about the study aims and procedures, and they provided written informed consent before testing. The study protocol was approved by the Institutional Ethics Review Committee of the Università degli Studi di Milano in accordance with current national and international laws and regulations governing the use of human subjects (Declaration of Helsinki II). Inclusion criteria were age $\geq$18 years, playing at the national level, and practicing 4 times a week for $\geq$2 hours. The exclusion criterion was a history of lower extremity injury or surgery in the 6 months before testing. Participants' data were excluded from analysis if they did not attend 90% of the training sessions. A sports physician and a certified strength and conditioning coach screened the participants for eligibility. None were known to have had prior exposure to the YBT or specific dynamic balance training, which might have interfered with the validity of the testing protocol. Of the 32 players screened, 29 were deemed eligible and randomly assigned in a 1 : 1 ratio by one of the authors (R.B.) to either an experimental group (n = 14; age = 20 $\pm$ 2 years; height = 1.72 $\pm$ 0.07 cm; body mass = 62 $\pm$ 8 kg; weekly training volume = 7 $\pm$ 1 hours) that performed neuromuscular warm-up exercises or a control group (n = 15; age = 20 $\pm$ 1 years; height = 1.70 $\pm$ 0.07 cm; body mass = 63 $\pm$ 7 kg; weekly training volume = 7 $\pm$ 1 hours) that performed a standard tactical-technical warm-up. The groups were matched for their pretraining composite scores, with no significant differences (right limb = 88.6 $\pm$ 3.2 versus 87.9 $\pm$ 3.5, P = .609; left limb = 89.1 $\pm$ 3.2 versus 87.2 $\pm$ 2.9, P = .201 for the experimental and the control group, respectively). Both groups were present during training and testing but were blinded to the aim of the warm-up. One participant in the control group did not attend 90% of the training sessions, and her data were not included in the final analysis (Figure 1). Data on

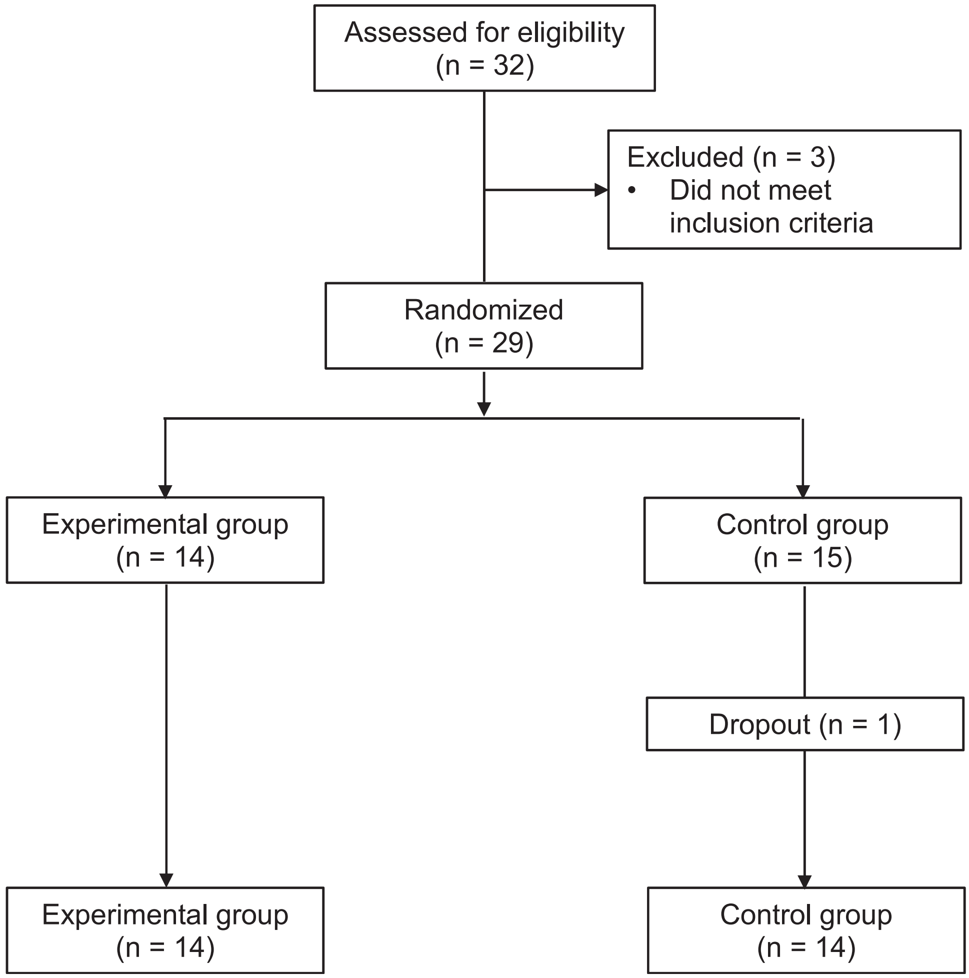

Figure 1. Study flow diagram.

medical history, age, height, body mass, training characteristics, injury history, team basketball experience, and performance level were collected at baseline. Height was measured to the nearest 0.1 cm; body mass was measured to the nearest 0.1 kg; and limb length was measured from the anterior-superior iliac spine to the medial malleolus of each limb to the nearest 0.1 cm in the supine position. Comparisons of the demographic characteristics of the 2 groups showed no differences in age, body height, or mass. The participants were asked not to engage in forms of physical activity other than their normal routines and to maintain their usual diets for the duration of the study.

Warm-Up Exercises

We developed the neuromuscular-training protocol from theory and findings from injury-prevention research on core stability and plyometrics.[7,15,16,22,23] Training took place twice a week (Tuesdays and Wednesdays) for 8 weeks (16 sessions) during the warm-up session immediately before regular basketball training. A certified strength and conditioning coach conducted the sessions and gave verbal and visual feedback on exercise technique. Each 30-minute session consisted of circuit training with 10 exercises and 3-minute rests between circuits. The exercises were progressed through 3 phases (Table) using periodization methods. Initially, low-volume, high-intensity exercises were performed until the technique was mastered. The volume was increased when the exercise was executed correctly according to the coach's judgment. The exercises were progressed from a stable to an unstable position to increase demands on lower extremity strength and core stability. However, the training program did not include exercises that emulated the YBT. No acute injuries occurred during the training sessions. The conventional warm-up consisted of light aerobic exercises, basketball and team drills, and dynamic stretching of the major muscle groups before the regular practice sessions.

Testing Procedures

Postural-control assessment using the YBT was performed at baseline (T0) and at the end (T8) of the 8-week study period. Test-retest reliability and measurement error of the YBT were analyzed by repeating the test at 2 sessions 1 week apart and then comparing the scores using interclass correlation coefficients (ICCs). The YBT was conducted using a reliable standardized testing protocol.[21,24] Because variations in footwear can make it difficult to standardize test results, the recommendation is that the test should be performed barefoot[21]; however, we allowed participants to wear sport-specific shoes during testing to more accurately replicate the technical

Table. Phases of the Body-Weight Neuromuscular-Training Program

Phase (wk)		
1 (1–3)	2 (4–6)	3 (7–8)
1. Plank on elbows (30 s)	1. Plank on elbows, alternate 1 leg up (30 s)	1. Plank on hand, alternate 1 leg up (30 s)
2. Side bridge (30 s)	2. Side bridge, with leg open (30 s)	2. Side bridge with hip and arm abduction (30 s)
3. 1-Leg hip lift (10 reps)	3. 1-Legged hip lift over basketball (10 reps)	3. 1-Legged hip lift on step (10 reps)
4. Split squat (10 reps)	4. Bulgarian split squat (10 reps)	4. Bulgarian split squat and jump (10 reps)
5. Front lunges (10 reps)	5. Walking lunges (10 reps)	5. Walking lunges and crossover (10 reps)
6. 2-Legged calf raise on step (10 reps)	6. 1-Legged calf raise on step (10 reps)	6. 1-Legged calf raise, repeated, on step (10 reps)
7. Abdominal crunches (20 reps)	7. Abdominal sit-up and twist (20 reps)	7. Bicycle abdominals (20 reps)
8. Lateral jump and hold (10 reps)	8. Lateral jump, continuous movements (10 reps)	8. Lateral hop and hold (10 reps)
9. Back hyperextension on ground (10 reps)	9. Superman, static (30 s)	9. Hyperextension, on bench (10 reps)
10. Tuck jump and soft landing (10 reps)	10. Tuck jump, repeated (10 reps)	10. Jump over the cone (10 reps)

Abbreviation: reps, repetitions.

movements of basketball.[24] The participants were fully familiarized with the testing procedures during their first visit to the laboratory. After watching a standard video demonstration, they were provided initial YBT instruction and allowed 6 practice trials with 6 reaches in each direction. This was done to minimize the potential for learning effects.[21] Before testing, the participants performed 10 minutes of standardized warm-up, with 5 minutes of submaximal running followed by a dynamic stretch routine consisting of functional exercises: front-to-back leg swing, side-to-side leg swing, lateral lunge (squat to flow), and sumo squat to stand. Stretching was not permitted, as it might have introduced a confounding factor if 1 side was stretched more vigorously than the other. For assessment of the YBT, we used a YBT kit comprising a stance platform to which 3 pieces of polyvinyl chloride pipe were attached in the A, PM, and PL reach directions. The posterior pipes were positioned 135° from the A pipe with 45° between them. Each pipe was marked in 5-mm increments. The YBT was performed with the distal aspect of the great toe centered at the junction of the Y. The participant had to reach with the opposite leg in the A, PM, and PL directions (Figure 2) and push a target (reach indicator) along the pipe that standardized the reach distance; the target remained over the tape measure after completion of the test. The testing order was 3 trials standing on the right foot while reaching with the left foot in the A direction, followed by 3 trials standing on the left foot and reaching with the right foot in the A direction. The procedure was repeated for the PM- and then the PL-reach directions. During the trials, the reach foot was not allowed to touch the floor or balance using the reach indicator or support pipe. If the participant was unable to perform the test according to these criteria in 6 attempts, she failed that direction, no data were collected, and another trial was attempted. Reach distance was measured from the most distal aspect of the toes of the stance foot to the most distal aspect of the reach foot in the A, PM, and PL directions. The YBT scores were analyzed using the average of the last 3 trials for each reach direction for each lower extremity, as well as the average of the total of the reach directions (composite score). The YBT composite score was calculated according to Plisky et al[24] by dividing the sum of the maximum reach distance in the A, PM, and PL directions by 3 times the limb length of the participant and then multiplying by 100: ([A + PM + PL]/[leg length*3])*100. The maximum value measured for each direction and the summed composite score of the maximums for each lower extremity were also analyzed. To control for the effect of limb length among participants, the YBT values were normalized to the percentage of average anatomical limb length (average of the right and left sides).

Figure 2. Participant performing the Y-Balance Test in the A, anterior, B, posteromedial, and C, posterolateral directions.

Data Analysis

Descriptive statistics (mean ± standard deviation) for the outcome measure were calculated. Data normality was checked using the D'Agostino-Pearson test. The ICC was used to establish intersession repeatability of all measures, where α or $r < 0.50$ was classified as *weak*, from 0.50 to 0.79 as *moderate*, and $\geq$0.80 as *strong*. To determine the effect of neuromuscular training, we calculated a 2-way analysis of variance and applied the Tukey multiple-comparisons test. The level of significance was set at $P <$ .05. Statistical analysis was performed using Prism (version 6.00 for Mac OSX; GraphPad Software, San Diego, CA). As a measure of effect size, the Cohen d was calculated, and values of 0.2, 0.6, and 0.8 or greater were considered *small*, *medium*, and *large*, respectively.[25]

RESULTS

The ICC (1,1) of the A, PM, PL, and composite YBT scores were 0.91, 0.88, 0.83, and 0.90, respectively, for the right limb and 0.88, 0.90, 0.82, and 0.89, respectively, for the left limb. At the end of the training program, for the experimental group, the composite YBT score for the reaching right limb improved from 88.6% to 94.0% (88.6% ± 3.2% versus 94.0% ± 1.8%, +5.4%, $P =$ .0004, d = 2.1) and from 89.2% to 95.5% (89.2% ± 3.2% versus 94.5% ± 3.0%, +5.8%, $P =$ .001, d = 2.0) for the

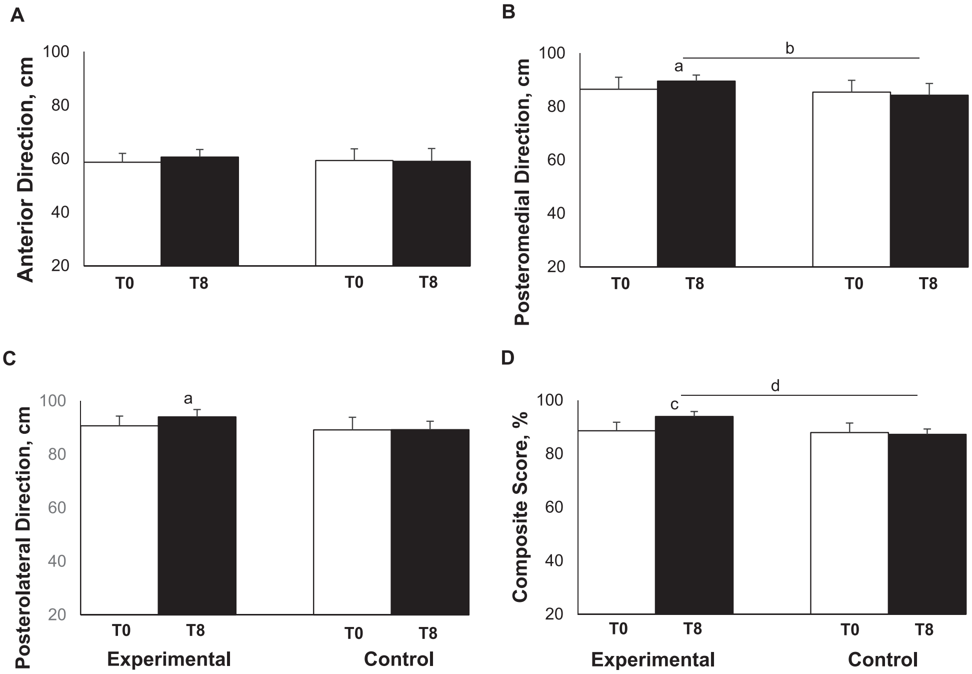

Figure 3. Changes in the A, anterior-, B, posteromedial-, and C, posterolateral-reach and D, composite Y-Balance Test scores for the right limb in the experimental group before (T0) and after (T8) body-weight neuromuscular training and in the control group ([a] $P < .05$; [b] $P < .01$; [c] $P < .001$; [d] $P < .0001$).

reaching left limb. Figures 3 and 4 show that, as compared with the control group, the experimental group improved on all measures at T8 versus T0 for the right lower limb (86.5 ± 4.5 cm versus 89.6 ± 2.2 cm, +3.5%, $P = .049$, d = 0.9 for the PM direction [Figure 3B]; 90.7 ± 3.6 cm versus 94.0 ± 2.7 cm, +3.6%, $P = .016$, d = 1.0 for the PL direction [Figure 3C]) and on the composite YBT score (88.6% ± 3.2% versus 94.0% ± 1.8%, +5.4%, $P = .0004$, d = 2.1 [Figure 3D]) and for the left lower limb (85.5 ± 4.3 cm versus 90.2 ± 2.7 cm, +5.5%, $P = .038$, d = 1.0 for the PM direction [Figure 4B]; 90.9 ± 3.5 cm versus 94.2 ± 2.6 cm, +3.6%, $P = .011$, d = 1.1 for the PL direction [Figure 4C]) and on the composite YBT score (89.2% ± 3.2% versus 94.5% ± 3.0%, +5.8%, $P = .001$, d = 2.0 [Figure 4D]). Differences between the groups at T8 in the PM direction (89.6 ± 2.2 cm versus 84.3 ± 4.4 cm,

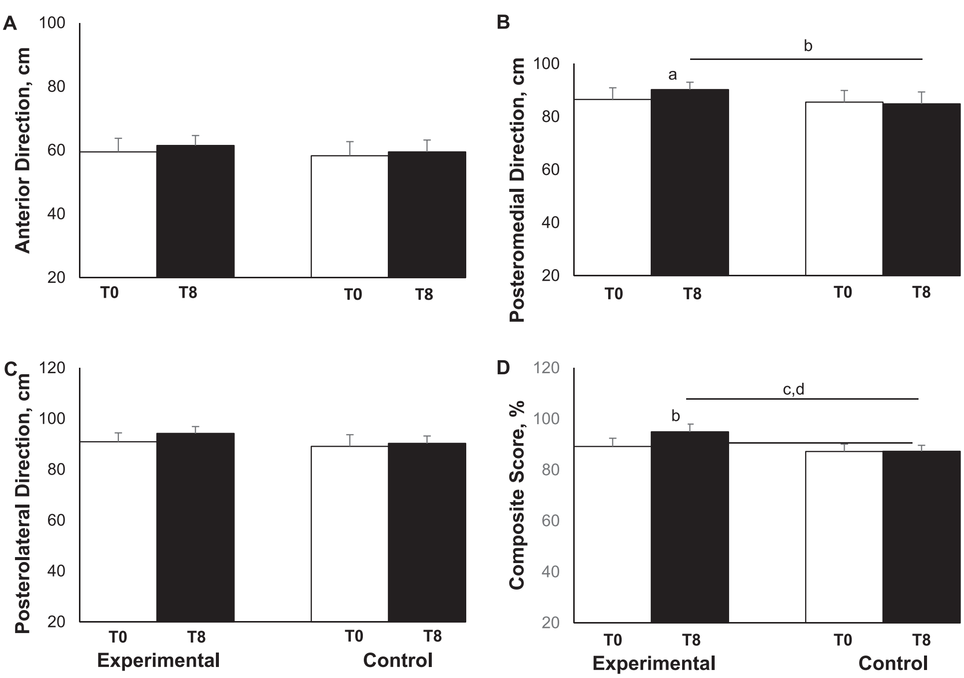

Figure 4. Changes in the A, anterior-, B, posteromedial-, and C, posterolateral-reach and D, composite Y-Balance Test scores for the left limb in the experimental group before (T0) and after (T8) body-weight neuromuscular training and in the control group ([a] $P < .05$; [b] $P < .01$; [c] $P < .001$; [d] $P < .0001$).

+4.1%, $P = .005$, d = 2.3) and composite YTB score (94.0% ± 1.8% versus 87.3 ± 2.0%, +7.1%, $P < .0001$, d = 2.6) for the right lower limb (Figure 3) and in the PM direction (94.2 ± 2.6 cm versus 84.8 ± 4.4 cm, +10%, $P = .003$, d = 1.9) and composite YTB score (87.9% ± 3.4%, +7.3%, $P < .0001$, d = 2.5) for the left lower limb (Figure 4). No differences were found in the A direction.

DISCUSSION

The experimental and control groups demonstrated similar baseline YBT performances for all variables measured. Comparison of the preintervention and postintervention PM reach and composite YBT scores for both lower limbs showed improvement in the experimental group as compared with the control group. Improvement in the YBT composite score in the experimental group reflected increases in PL and PM reach at T8 versus T0. No differences in the A direction were observed.

We selected the exercises for this neuromuscular-training program based on findings from injury-prevention research on core stability and plyometrics.[7,15,16,22,23] *Core stability* is defined as the dynamic trunk control that allows for the production, transfer, and control of force and motion to distal segments of the kinetic chain.[26] Inadequate neuromuscular control of the trunk muscles can adversely affect the dynamic stability of the lower extremities during high-speed athletic maneuvers.[16] Moreover, core muscle function can influence structures from the low back to the ankle,[27] and deficiencies in core muscle capacity may increase the risk of lower extremity injury.[28] In their study of core-stability training, Kahle and Gribble[29] reported that, as compared with a control group, maximal reach distances on the SEBT improved in healthy participants after a 6-week core-stability–training program. The improvements were related to contraction of the transverse abdominal, internal and external obliques, and rectus abdominis muscles to stabilize the spine and provide a stronger base of support for lower extremity movement. Furthermore, the strength and recruitment of the trunk musculature had improved to such an extent that standing on 1 limb during the SEBT while using the opposite limb to reach may have activated the core muscles and perhaps led to greater reach distances posttest. Because greater control rather than strength was the focus of our intervention, the improvements in PM and PL reach may have been due to enhanced neuromuscular control and dynamic balance.[30]

We included body-weight plyometric exercises in our neuromuscular-training program because they train the muscles, connective tissue, and nervous system to effectively carry out the stretch-shortening cycle. It has been suggested that plyometric exercises can improve neuromuscular control in female athletes.[31] In their studies on preventing ACL injury in female athletes, Hewett et al,[14] Huston et al,[32] Myklebust et al,[33] and Mandelbaum et al[16] incorporated into their intervention a neuromuscular-training program consisting of stretching, plyometrics, and weight training with an emphasis on proper alignment and technique. All 4 groups reported a reduction in the risk of ACL injury. In contrast, no reduction in ACL injury risk was reported by Heidt et al[34] or Soderman et al,[35] who did not include plyometric exercises in their injury-prevention programs.

We directed participants' attention to correct execution of technique and biomechanical movements to better prepare them for multidirectional activities, to address neuromuscular imbalances, and to reduce the risk of serious ligament injuries common in female basketball athletes.[31] During the training sessions, a certified strength and conditioning coach gave verbal and visual feedback on the accuracy and precision of technique. Professional supervision is essential for the success of injury-prevention programs.[14,33] Because athletic trainers and physical therapists are trained to recognize lower extremity impairments and faulty movement patterns, they may be better equipped to assess movement patterns and provide the precise corrective feedback required to implement such programs effectively.[31]

Our body-weight neuromuscular-training program was integrated into the warm-up routine to ensure high compliance. In their systematic review, Ter Stege et al[31] reported compliance rates of more than 75% with short-duration programs involving sessions of up to 25 minutes. As an added incentive to compliance, the warm-ups included lower limb strength exercises. Hewett et al[15] noted that female athletes might not be sufficiently motivated to participate in a neuromuscular-training program without performance-enhancing effects, whereas compliance with programs that combine performance enhancement and injury prevention may range from 80% to 90%. Finally, recognizing that training time is limited for nonprofessional athletes and that purchasing special equipment (eg, Swiss balls, medicine balls, unstable bases) may be necessary, we devised this training program based on body-weight exercises that can be easily integrated into warm-up routines.

Moreover, we assessed our athletes with the YBT because it is a validated, reliable derivation of the SEBT, a widely used tool to screen individuals for limitations in dynamic balance.[21] Poor performance on the YBT has been associated with an elevated risk of noncontact lower extremity injury.[24] Plisky et al[24] found that girls with a composite reach distance of less than 94.0% of their limb length were more than 6 times more likely to sustain a lower extremity injury. Although we did not investigate the effects of neuromuscular training on lower limb injury, the postintervention improvements in postural stability suggest that performance on the YBT may serve as a corollary outcome measure for assessing athletes at risk for lower limb injury. One limitation of our study is that we did not evaluate lower limb strength. However, Lee et al[36] noted a positive correlation between lower limb strength and reach distance in all 3 directions of the YBT in women. A strong relationship was also seen between knee-flexor strength and performance in all 3 directions due to dynamic postural control during the YBT. Because a greater range of hip flexion is required to reach a greater distance, this may have increased the demand on hip-extensor strength to maintain postural control. Furthermore, because reaching in the PM direction requires lateral stabilization of the pelvis, hip-abductor strength correlated positively with the PM-reach distance.

CONCLUSIONS

Posteromedial- and PL-reach and composite YBT scores for both lower limbs improved in the experimental group after neuromuscular training using body-weight core stability and plyometric exercises. Neuromuscular warm-up programs that focus on developing neuromuscular control of the lower extremities may be an effective way to increase joint awareness and improve postural control. Because of their training and expertise, athletic trainers and other sports medicine clinicians are uniquely placed to develop injury-prevention and sport-specific agility-skills programs that address the proprioceptive and biomechanical deficits seen in high-risk female athletes.

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