Neuromuscular Training Improves Performance on the Star Excursion Balance Test in Young Female Athletes

In the United States more than 3.1 million females participate in high school sports annually.22 Soccer is ranked fifth in popularity, with over 346,000 female athletes having participated in the sport during the 2007-2008 school year.22 As the popularity of women’s soccer grows, the incidence of injury in high school sports has become more apparent.

From 1995 to 1997, an estimated one quarter of female soccer athletes reported experiencing multiple injuries over a 2-year period, while over 72% sustain at least 1 injury.28

With such a high incidence of injury in female athletes, resulting in significant time lost and healthcare expense, the need to develop interventions with the potential to decrease injury risk is apparent. Several studies support the use of interventions such as neuromuscular training programs (NMTP) to reduce the incidence of lower extremity injuries.9,11,15,17,31 The most effective programs emphasize several common components, including plyometric training in combination with biomechanical feedback and technique training.8,21 Implementation of a NMTP that focuses on core stability exercises is advocated to prevent lower extremity injury, namely in female athletes who have deficits in trunk proprioception and neuromuscular control.18 Importantly, poor core stability and decreased muscular synergy of the trunk and hip stabilizers have been theorized to decrease performance in power activities and to increase the incidence of injury secondary to lack of control of

**STUDY DESIGN:** Controlled cohort repeated-measures experimental design.

**OBJECTIVES:** To determine if a neuromuscular training program (NMTP) focused on core stability and lower extremity strength would affect performance on the star excursion balance test (SEBT). We hypothesized that NMTP would improve SEBT performance in the experimental group and there would be no side-to-side differences in either group.

**BACKGROUND:** The SEBT is a functional screening tool that is used to assess dynamic stability, monitor rehabilitation progress, assess deficits following an injury, and identify athletes at high risk for lower extremity injury. The SEBT requires lower extremity coordination, balance, flexibility, and strength.

**METHODS:** Twenty uninjured female soccer players (13 experimental, 7 control) participated. Players trained together as a team, so group allocation was not randomized. The SEBT was administered prior to and following 8 weeks of NMTP in the experimental group and 8 weeks of no NMTP in the control group. A 3-way mixed-model ANOVA was used to determine the effect of group (experimental versus control), training (pretraining versus posttraining), and limb (right versus left).

**RESULTS:** After participation in a NMTP, subjects demonstrated a significant improvement in the SEBT composite score (mean ± SD) on the right limb (pretraining, 96.4% ± 11.7%; posttraining, 104.6% ± 6.1%; P = .03) and the left limb (pretraining, 96.9% ± 10.1%; posttraining, 103.4% ± 8.0%; P = .04). The control group had no change on the SEBT composite score for the right (pretraining, 95.7% ± 5.2%; posttraining, 94.4% ± 5.2%; P = .15) or the left (97.4% ± 7.2%; 93.6% ± 5.0%; P = .09) limb. Further analysis identified significant improvement for the SEBT in the posterolateral direction on both the right (P = .008) and left (P = .040) limb and the posteromedial direction of the left limb (P = .028) in the experimental group.

**CONCLUSION:** Female soccer players demonstrated an improved performance on the SEBT after NMTP that focused on core stability and lower extremity strength.


**KEY WORDS:** core stability, core strengthening, injury prevention training, trunk neuromuscular control

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the center of mass, especially in female athletes.1,2,3

Targeted NMTP are designed to reduce injury risk, and include interventions that focus on increased control of the center of mass. As the center of mass moves away from the base of support, there is an increased potential for biomechanical deviations to occur in the lower extremity. An improved ability to control this movement has the potential to decrease excessive forces on the lower extremity and ultimately decrease injury risk.4

The star excursion balance test (SEBT) is a functional screening tool developed to assess lower extremity dynamic stability, monitor rehabilitation progress, assess deficits following injury, and identify athletes at high risk for lower extremity injury.4,5,14,16,23,25-27 The SEBT requires neuromuscular characteristics such as lower extremity coordination, balance, flexibility, and strength.4,5,16,27 Plisky et al5,27 found that female athletes who had a composite reach distance on the SEBT of less than 94% of their limb length were 6.5 times more likely to have a lower extremity injury. As a result, the SEBT may be a useful tool to assess the efficacy of training programs designed to reduce injury risk.

The purpose of this study was to determine if an 8-week NMTP that focused on core stability and lower extremity strength could improve performance on the SEBT. We hypothesized that the neuromuscular training group would show significant improvements on the SEBT composite score that would not be seen in a control group. In addition, we hypothesized there would be no side-to-side differences in the SEBT composite score in either the experimental or the control group.

**METHODS**

**Subjects**

Twenty subjects (13 experimental, 7 control) with no prior history of lower extremity injury were recruited from 2 soccer teams to participate in this study. Data from prior work suggested that a minimum of 7 subjects in each group would be required to meet statistical power, with the alpha level set at .05 and beta at .80, assuming the mean difference would be a 10% improvement with a standard deviation of 7.5%. The subjects were allocated by team to participate in the experimental or control group. The subjects in each group were similar in terms of age, height, and body mass (Table 1). The subjects participated in an identical level of play and were exposed to similar soccer activity between pretraining and posttraining measurements.

To be included in the study, each subject had to be an active member of a soccer team at the high school or competitive level and free from injury prior to participation in the study. Subjects were excluded if they failed to complete the pretest or posttest, sustained an unrelated injury that limited their ability to complete the NMTP, or failed to participate in a minimum of 80% of the NMPT training sessions (13 of 16 sessions). Four subjects in the experimental group were excluded due to experiencing an injury unrelated to the NMTP (n = 1) or lack of training compliance (n = 3). These subjects were not retested at the 8-week follow-up. The data from 16 subjects (9 experimental, 7 controls) were used for final statistical analysis.

**Procedure**

Prior to testing, all subjects and their parent/guardian received and signed an informed consent approved by Cincinnati Children’s Hospital Medical Center’s Institutional Review Board, which stated how the subject’s rights would be protected. Initial testing included all demographic and anthropometric assessments of height, mass, and limb length. Subjects were interviewed to determine prior injury history. The experimental group participated in 8 weeks of biweekly neuromuscular training, while the control group did not participate in the intervention or other training outside of their normal activities. Posttraining testing occurred 8 weeks after the pretraining test session.

### Table 1: Demographic Data

| Variable | Experimental Group | Control Group | P Value
<table>
<thead>
<tr>
<th></th>
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<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Age (y)</td>
<td>15.4 ± 1.5</td>
<td>14.7 ± 0.8</td>
<td>.26</td>
</tr>
<tr>
<td>Height (cm)</td>
<td>163.9 ± 50.0</td>
<td>163.6 ± 48.8</td>
<td>.90</td>
</tr>
<tr>
<td>Mass (kg)</td>
<td>56.1 ± 6.1</td>
<td>51.5 ± 5.5</td>
<td>.14</td>
</tr>
</tbody>
</table>

Values are mean ± SD. No between-group differences.
tions, or (4) the reach foot did not return to the starting position prior to reaching in another direction. The process was then repeated while standing on the other lower extremity. The order of limb testing was counterbalance randomized by the tester. The subject’s limb length measurements, from the most distal end of the anterior superior iliac spine to the most distal end of the lateral malleolus on each limb, were taken and recorded. In previous work, the SEBT has demonstrated good intrater reliability, with an intraclass correlation coefficient (ICC) of 0.67 to 0.96. In this study, intrater reliability for the SEBT composite score and all 3 individual reach directions was good to excellent (Table 2). The SEBT composite score was calculated by dividing the sum of the max-

<table>
<thead>
<tr>
<th>Stance Foot</th>
<th>Anterior</th>
<th>Posterolateral</th>
<th>Posteriomedial</th>
<th>Composite</th>
</tr>
</thead>
<tbody>
<tr>
<td>Right</td>
<td>0.94</td>
<td>0.83</td>
<td>0.89</td>
<td>0.92</td>
</tr>
<tr>
<td>Left</td>
<td>0.96</td>
<td>0.81</td>
<td>0.90</td>
<td>0.96</td>
</tr>
</tbody>
</table>

Intracluster Reliability (ICC) on the Star Excursion Balance Test Composite Score and All 3 Reach Directions

**Table 2**

**Figure 1.** Subject performing the star excursion balance test on the left lower extremity in the posterolateral direction.

**Table 3**

Five Phases of the Core Stability Portion of Neuromuscular Training Program

<table>
<thead>
<tr>
<th>Reference</th>
<th>Phase 1</th>
<th>Phase 2</th>
<th>Phase 3</th>
<th>Phase 4</th>
<th>Phase 5</th>
</tr>
</thead>
<tbody>
<tr>
<td>Hewett 1999; Mandelbaum 2005</td>
<td>Lateral jump and hold</td>
<td>Lateral jumps</td>
<td>Lateral hop and hold</td>
<td>Lateral hops</td>
<td>X-hops</td>
</tr>
<tr>
<td>Hewett 1999</td>
<td>Step-hold</td>
<td>Jump single-leg hold</td>
<td>Hop-hold</td>
<td>Hop-hold</td>
<td>Crossover-hop-hold</td>
</tr>
<tr>
<td>Myer 2007</td>
<td>BOSU (round) toe touch swimmers</td>
<td>BOSU (round) swimmers with partner perturbations*</td>
<td>Prone bridge (elbows and knees) hip extension opposite shoulder flexion*</td>
<td>Prone bridge (elbows and toes) hip extension opposite shoulder flexion*</td>
<td>Swiss ball bilateral kneel with partner perturbations</td>
</tr>
<tr>
<td>Myer 2007</td>
<td>BOSU (round) double-knee hold</td>
<td>BOSU (round) single-knee hold</td>
<td>Swiss ball bilateral kneel with partner perturbations</td>
<td>Swiss ball bilateral kneel with partner perturbations</td>
<td>Swiss ball bilateral kneel</td>
</tr>
<tr>
<td>Myklebust 2003; Petersen 2005</td>
<td>Single-leg lateral Airex hop-hold</td>
<td>Single-leg lateral BOSU (round) hop-hold</td>
<td>Single leg 4-way BOSU (round) hop-hold</td>
<td>Single leg 4-way BOSU (round) hop-hold with ball catch</td>
<td>Swiss ball bilateral kneel</td>
</tr>
<tr>
<td>Hewett 1999</td>
<td>Single-tuck jump soft landing</td>
<td>Double-tuck jump</td>
<td>Repeated-tuck jump</td>
<td>Side-to-side barrier tuck jumps</td>
<td>Side-to-side reaction barrier tuck jumps</td>
</tr>
<tr>
<td>Mandelbaum 2005</td>
<td>Front lunges</td>
<td>Walking lunges</td>
<td>Walking lunges unilaterally weighted</td>
<td>Walking lunges with plate crossover</td>
<td>Walking lunges with unilateral shoulder press</td>
</tr>
<tr>
<td>Hewett 1999</td>
<td>Lunge jumps*</td>
<td>Scissor jumps*</td>
<td>Lunge jumps unilaterally weighted*</td>
<td>Scissor jumps unilaterally weighted*</td>
<td>Scissor jumps with ball swim*</td>
</tr>
<tr>
<td>Mandelbaum 2005</td>
<td>BOSU (flat) double-leg pelvic bridges*</td>
<td>BOSU (flat) single-leg pelvic bridges*</td>
<td>BOSU (round) single-leg pelvic bridges with weight*</td>
<td>Supine Swiss ball hamstring curl*</td>
<td>Russian hamstring curl with lateral touch*</td>
</tr>
<tr>
<td>Myklebust 2003; Petersen 2005</td>
<td>Single-leg 90° hop hold</td>
<td>Single-leg 90° Airex hop-hold (Figure 3)</td>
<td>Single-leg 180° Airex hop-hold reaction ball catch</td>
<td>Single-leg 180° Airex hop-hold reaction ball catch</td>
<td>Single-leg 180° Airex hop-hold reaction ball catch</td>
</tr>
<tr>
<td>Myer 2007</td>
<td>BOSU (round) lateral crunch</td>
<td>Box lateral crunch</td>
<td>BOSU (round) lateral crunch with ball catch</td>
<td>Swiss ball lateral crunch</td>
<td>Swiss ball lateral crunch with ball catch</td>
</tr>
<tr>
<td>Myklebust 2003; Petersen 2005</td>
<td>Box double-crunch</td>
<td>Box swivel double-crunch</td>
<td>BOSU (round) swivel ball touches (feet up)</td>
<td>BOSU (round) double-crunch</td>
<td>BOSU (round) swivel double-crunch</td>
</tr>
<tr>
<td>Myer 2007</td>
<td>Swiss ball back hyperextension*</td>
<td>Swiss ball back hyperextension*</td>
<td>Swiss ball hyperextensions with back fly*</td>
<td>Swiss ball hyperextensions with ball reach lateral*</td>
<td>Swiss ball hyperextensions with lateral ball catch*</td>
</tr>
</tbody>
</table>

* Online video available and www.jospt.org.
mum reach distance in the anterior (A), posteromedial (PM), and posterolateral (PL) directions by 3 times the limb length (LL) of the individual, then multiplied by 100 \{[(A + PM + PL)/(LL × 3)] × 100\}.

**Training Program**

The NMTP was adapted from previous epidemiologic and interventional investigations that have reported reductions in lower extremity injury risk factors. The exercises in this program were selected from injury prevention research to address lower extremity strength and core stability. Core stability is defined as dynamic trunk control which allows for the production, transfer, and control of force and motion to distal segments of the kinetic chain. The goal of this NMTP was to improve the athlete’s ability to control the center of mass during dynamic activities.

The biweekly training of the experimental group was conducted by 4 physical therapists who were also certified strength and conditioning specialists, and 1 student physical therapist. The subject-therapist ratio was 4:1 for each session. The experimental group participated in biweekly training sessions for a total of 16 sessions during a competitive season. The NMTP took place on 2 nonconsecutive days of the week over an 8-week time frame. Each session consisted of a 5-minute warm-up using an agility ladder, 2 45-minute increments of lower extremity strength and core stability training, and a 5-minute cool-down that included static and dynamic stretches. The core stability component was divided into 5 phases of progressive exercises. Two or 3 days were spent on each phase. The lower extremity strengthening program consisted of 2 groups of exercises which were performed on alternating training sessions. These exercises were progressed using periodization techniques. This NMTP did not include exercises that emulated the SEBT.
The NMTP was designed to gradually progress lower extremity strength and core stability by incorporating exercises that increase lateral trunk perturbations. The exercise progressions were developed from previous biomechanical investigations that reported reductions in knee abduction load in female athletes.\textsuperscript{17-20} Initially, a low volume was used for the high-intensity exercises until correct technique was attained. When the athlete could perform the exercise with proper mechanics as determined by the instructor, the volume was increased. The instructors gave verbal and visual feedback with each exercise to the subjects. Athletes executed each exercise using only proper technique and were required to stop if they could not perform the exercise with correct biomechanics. The exercises were progressed from stable surfaces to dynamic surfaces such as Airex pads (Perform Better Inc, Cranston, RI), BOSU trainers (BOSU Balance Trainer [Fitness Quest Inc], Canton, OH), and Swiss balls (Perform Better Inc), to increase demands on lower extremity strength and core stability. The subjects were required to maintain proper technique, while external perturbations (ball toss, unanticipated movement to the base of support) were applied to increase difficulty of the task.

**TABLE 4**

<table>
<thead>
<tr>
<th>Example of Lower Extremity Strength Training Component of the Neuromuscular Training Program</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Strength training, day 1</strong></td>
</tr>
<tr>
<td>• Dumbbell hang snatch</td>
</tr>
<tr>
<td>• Barbell squat</td>
</tr>
<tr>
<td>• Barbell bench press</td>
</tr>
<tr>
<td>• Assisted Russian hamstring curl*</td>
</tr>
<tr>
<td>• Dumbbell shoulder press</td>
</tr>
<tr>
<td>• Hamstring curls</td>
</tr>
<tr>
<td>• Latissimus pull-down</td>
</tr>
<tr>
<td>• Lateral lunges</td>
</tr>
<tr>
<td>• Seated row</td>
</tr>
<tr>
<td>• BOSU (flat), deep hold*</td>
</tr>
</tbody>
</table>

* Explanation of exercise in Myer et al.\textsuperscript{17-18}

**Statistical Analysis**

Unpaired \( t \) tests were used to assess differences in demographic and anthropometric data between groups. The SEBT scores were used as the dependant variables. Group comparisons were done with a 2-by-2-by-2 mixed-model analysis of variance (ANOVA) to determine the effect of training (pretraining versus posttraining), group (experimental versus control), and limb (right versus left) on the outcome of the SEBT composite and individual directions scores. Statistical analyses were conducted in SPSS, Version 15.0 (SPSS Inc, Chicago, IL). Statistical significance was established a priori at \( P\leq.05 \).

**RESULTS**

Comparison of the demographic data between the experimental and control group showed no significant difference in age, height, or mass \( (P>.05) \) (TABLE 1). Pretraining SEBT composite scores showed no significant side-to-side difference within subjects or between groups (experimental versus control) \( (P>.05) \).

There was a significant training-by-group interaction \( (F = 5.71, P = .024) \), with no effect of limb \( (F=0.51, P = .479) \) for the SEBT composite score. Subjects in the experimental group improved performance of the SEBT composite score on both limbs after 8 weeks of training, while no change was observed in the control group. Partial \( \eta^2 \) effect size was determined to be 0.169. Partial \( \eta^2 \) effect size statistics demonstrate the proportion of variance of the dependant variable explained by the independent variable. Values can range from 0 to 1, with small \( (0.01) \), medium \( (0.06) \), or large \( (0.138) \) effect size. The results indicate that there is a large effect size according to this classification.\textsuperscript{3} The improvement seen on the SEBT occurred despite the NMTP not replicating the SEBT. The SEBT composite score improved from a mean \( \pm \) SD of 96.4% \( \pm \) 11.7% to 104.6% \( \pm \) 6.1% of limb length on the right lower extremity \( (P = .03) \) and from 96.9% \( \pm \) 10.1% to 103.4% \( \pm \) 8.0% of limb length on the left lower extremity \( (P = .04) \), following the NMTP. Conversely, there was no significant change in the SEBT composite score of either the right \( (95.7% \pm 5.2% \text{ to } 94.4\% \pm 5.2\% ; P = .15) \) or the left \( (97.4\% \pm 7.2\% \text{ to } 93.6\% \pm 5.0\% ; P = .09) \) limb in the control group (FIGURE 2).

Analysis of change in each individual reach direction revealed a significant interaction for group (experimental versus control) by training (pretraining versus posttraining) for both the right \( (P = .008) \) and left \( (P = .040) \) limb in the posterolateral direction, and the left limb \( (P = .028) \) in the posteromedial direction, for the subjects in the experimental group. No differences were seen for the right limb \( (P = .226) \) in the posteromedial direction and for neither the right \( (P = .321) \) nor left \( (P = .193) \) limb in the anterior direction for the experimental group. A summary of data is presented in TABLE 5.

**DISCUSSION**

Prior to training, both the experimental and the control groups of female athletes demonstrated similar performance on the SEBT in all measured variables. Following a NMTP,
the SEBT composite score significantly improved in the training group compared to the control group, who did not participate in a NMTP. Improvement in the SEBT composite score in the NMTP group appeared to be dependent on an improvement in the posteromedial and posterolateral reach, as indicated by the independent reach analysis. No differences in reach were found in the anterior direction. Improvements in the posterolateral and posteromedial direction are likely the result of improved neuromuscular control and dynamic balance, and less related to lower extremity strength, as was suggested by Thorpe and Ebersole.32

The NMTP design was based on injury prevention research.9,30,31,33,34,35,36,37,38,39,40 Each aspect of the NMTP was enhanced with verbal feedback and visual demonstration to improve the athletes biomechanical technique.39,40 Current literature supports the use of NMTP that incorporate core stability as part of treatment programs to prevent injury of the ankle or knee.41,42 Decreased neuromuscular control of the trunk appears to influence dynamic stability of the lower extremity during high-speed athletic maneuvers.42

In a systematic review by Thacker et al.,43 6 prospective studies that addressed training programs that all proved to have reduced knee injuries were chosen. The 6 programs consisted of neuromuscular, proprioception, and/or acceleration training. Of the 6 studies, 4 were randomized controlled studies, but none reported blinding of the assessor or the details of the randomization of the subjects. The training programs demonstrated positive results, with significantly reduced knee injury rates compared to controls who did not participate in a training program.43 Other studies have also confirmed improved postural control and balance following rehabilitation and training programs in individuals with chronic ankle instability.5,44 The individuals in the NMTP in the current study showed improvements in the SEBT composite scores when compared to nontrained controls. However, its effect on knee or ankle injury rate was not assessed in this study. The SEBT may have the potential to be a corollary outcome measure that can be utilized to compare the efficacy of programs that reduce injury rates.45

Prior research indicates that isolated strength measures may not have an effect on the SEBT score. Thorpe and Ebersole46 compared recreational and collegiate female soccer student athletes and found no difference in isokinetic strength. They also showed that there was a low to moderate correlation between SEBT performances and lower extremity strength. Therefore, other factors, such as muscle activation and proprioception, may have a stronger relative relationship to the SEBT performance than non–weight-bearing strength testing. In addition, neither group of the above study participated in a NMTP that might have contributed to the lack of change on the SEBT.

Robinson and Gribble29 suggested that improvements in the SEBT were not due to strength or core stability but, rather, to increased knee and hip flexion on the stance limb. Their study consisted of 20 participants from a university setting who did not undergo any intervention program. Stepwise regression revealed that hip flexion and knee flexion, separately and in combination, accounted for 62% to 95% of the variance in reach distances.29 It is important to consider that Robinson and Gribble29 did not measure lower extremity strength. It is possible that participants who showed increased knee and hip flexion potentially had more lower extremity strength compared to the subjects who had less knee and hip flexion angles.

Sato and Mokha30 looked at the effects of a core strength training program...
concluded that the SEBT is an easy and practical tool that can be used prior to competition to assess neuromuscular factors more comprehensively than strength alone. The SEBT has also been examined to determine the correlation between anterior cruciate ligament injury with the lack of postural control and was found to successfully demonstrate limitations in individuals who were anterior cruciate ligament deficient compared with asymptomatic individuals. Individuals who were anterior cruciate ligament deficient had significantly lower reach scores on both the involved and uninvolved extremity compared to uninjured controls. Following the NMTP, there was no difference in composite score between limbs in the control group or in the experimental group. This may be due to the design of the NMTP, which focused on the performance of exercises equally on each limb and likely contributed to the lack of a limb effect. Establishing limb symmetry was important because limb dominance and side-to-side imbalance in lower extremity measures have been found to be a risk factor for anterior cruciate ligament injury. The SEBT has successfully been used to demonstrate asymmetrical impairments in functional balance on the involved side in individuals with chronic ankle instability or anterior cruciate ligament deficiency compared to uninjured controls. Training and rehabilitation programs have also been reported to reduce the side-to-side asymmetry in functional balance. 

**Conclusion**

**Neuromuscular training that focused on lower extremity strength and core stability significantly improved the composite SEBT scores in female soccer players. The SEBT composite score was enhanced to 103% following participation in the NMTP.**

**Key Points**

**Findings:** An 8-week duration neuromuscular training program that focused on lower extremity strength and core stability improved performance on the SEBT in female soccer players.

**Implication:** Further investigation is needed to determine if neuromuscular training that improves performance on the SEBT also decreases in-season injury rates in female athletes.

**Caution:** Training was performed in a small group within a narrow age range, without the benefits of random assignment and blinding of the investigators.

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