Comparative Effects of 6-Week Balance, Gluteus Medius Strength, and Combined Programs on Dynamic Postural Control

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Context: There are few outcomes-based studies that address hip strategy and gluteus medius strength (GMS) for maintaining dynamic postural control. Objective: To determine whether GMS training, proprioception training, or a combination of the 2 has an effect on dynamic postural control. Design: Pretest–posttest, repeated measures. Setting: Sports-medicine clinic. Participants: 48 healthy male and female college students obtained via sample of convenience. Interventions: Three 6-wk programs including exercises for proprioception, GMS, and combined. Main Outcomes Measures: Eight Star Excursion Balance Test (SEBT) reach distances and GMS for the dominant leg. Results: There was no significant difference between groups. The combination group demonstrated the most improvements in SEBT reach distances, whereas the GMS group demonstrated the most improvement in GMS. Conclusion: Use of exercises for proprioception, GMS, or a combination of the 2 will help improve dynamic postural control in healthy, active individuals.

Keywords: ankle, proprioception, hip, neuromuscular

Ankle sprains are one of the most common injuries in sports. An estimated 10% to 45% of all injuries in running and jumping sports are ankle sprains, with approximately 27,000 ankle sprains per day in the United States, or 1 per every 10,000 people. Of those ankle sprains, recurrent ankle sprains can lead to chronic ankle instability, creating mechanical and functional deficits. Both can create long-term complications, with proprioceptive deficits affecting the ability of both the ankle and the hip strategy in maintaining dynamic postural control.

There are 2 strategies for maintaining dynamic postural control: a hip strategy and an ankle strategy. Generally, the ankle strategy, in which the peroneal muscles assist in maintaining balance, is the method most often used by healthy individuals. The hip strategy, although most often seen in the elderly, is adopted by previously healthy individuals who have sustained an ankle sprain. In this strategy,
the gluteus medius is used to correct posture and keep an individual balanced and erect. Recent studies have shown that the gluteus medius muscle is weak after an ankle sprain, but it is not known whether weakness was evident before the sprain. Very infrequently does an individual train to strengthen the gluteus medius muscle when attempting to increase dynamic postural control either before or after a lateral ankle sprain. In general, when rehabilitating a sprained ankle, ankle-strength training and proprioception training are most often used to regain losses in balance that may have occurred.

The Star Excursion Balance Test (SEBT) is often used to assess dynamic postural control. It is a functional balance test that uses a unilateral stance on the center of an asterisk (star) taped on the floor and a maximal reach along each of the asterisk’s 8 lines. The SEBT has been used to evaluate dynamic postural control after a lateral ankle sprain but has not been used to evaluate gluteus medius weakness. Several studies have evaluated proprioceptive training programs’ effect on semidynamic and dynamic balance. To our knowledge, there are no studies in the literature that have evaluated the effect on dynamic postural control of strength training for the gluteus medius in healthy or injured subjects, nor have studies evaluated the efficacy of gluteus medius strength training versus the efficacy of ankle neuromuscular training (proprioception, dynamic postural control, and joint-position-sense-training exercises) for their effects on dynamic postural control. Researchers have previously investigated EMG activity elicited from weight-bearing and non-weight-bearing gluteus medius exercises. Those studies identified specific exercises that elicit moderate to high muscle activity important for gluteus medius strengthening and that have been recommended to use in prevention and rehabilitation programs. Those studies, however, did not investigate whether the recommended exercises actually facilitate gluteus medius strength gains or improvement in dynamic postural control after a training period. Because this was the first study to incorporate evidence-based and best-clinical-practice exercises that would activate proximal and distal lower extremity muscles, we wanted to observe the differences in healthy subjects first because pain could limit how injured subjects perform and therefore limit the results of the study. Therefore, the purpose of this study was to determine the effect that gluteus medius muscle strength training, proprioception training, and a combination of the 2 would have on dynamic postural control in healthy subjects.

**Methods**

There were 2 separate designs for this study. The SEBT section of the study was a 2 × 4 × 8 factorial design. Independent variables were test (pretest and posttest), group (proprioceptive training [PT] exercises, gluteus medius strength training [GMST] exercises, combination [COMBO], and control), and direction (anterior, anterolateral, lateral, posterolateral, posterior, posteromedial, medial, and anteromedial). The dependent variable was the normalized reach distance recorded in each of the 8 directions. The GMST section was a 2 × 4 factorial design. Independent variables were test (pretest and posttest) and group (PT exercises, GMST exercises, COMBO, and control). The dependent variable was the normalized gluteus medius strength measurement.
Subjects

Sixty college-age subjects were recruited. Each was a healthy individual with no history of lower extremity injuries in the 6 months leading up to the study, as well as no lower extremity surgery in the past year. Exclusion criteria included neurological, vestibular, and visual disorder in the past 6 months and use of medication that could affect one’s ability to balance. If subjects were currently participating in a balance-training or GMST program, they were excluded from the study. Subjects in the experimental groups had to attend at least 14 of the 18 training sessions (approximately 77% attendance) and return for posttesting in order for their results to be used in this study. Twelve of the subjects dropped out or were removed from the study by the primary investigator because they either missed too many training sessions or did not return for one or both posttesting sessions.

Sample size was determined a priori using a power-analysis table to determine statistical power at 80% and from the number of subjects in previously published training literature comparing experimental and control groups. Fifteen subjects were randomly assigned to each of the 3 experimental groups or to the control group using stratified randomization for gender and activity. Forty-eight subjects (25 men and 23 women) completed the entire study. The mean age of the subjects was 22.06 ± 1.58 years, height 171.87 ± 9.52 cm, and mass 75.72 ± 15.79 kg. The GMST group completed the study with 13 subjects, and the COMBO and PT groups each completed the study with 12 subjects. The control group completed the study with 11 subjects. This study was approved by the institution’s office of research compliance.

Instrumentation

Assessment of dynamic postural control using balance tasks has recently become more commonplace in clinical physical therapy and traditional athletic training settings.7 Dynamic postural control tests such as excursion and functional-reach tests are superior to basic single-leg-stance tests.27 The SEBT is a simple method of testing dynamic postural control and offers a simple, reliable, low-cost alternative to more expensive, refined instruments available today. The SEBT was first introduced by Gary Gray in 1995 as a functional balance test that uses a unilateral stance on the center of an asterisk (star) with the contralateral limb reaching as far as possible along each of the asterisk’s 8 lines.21,22 The lines extend out from the center of the asterisk at 45° increments. Each line has a specific name in relation to which leg is being tested (the leg the participant is standing on is the leg being tested). The 8 directions are named anterolateral, anterior, anteromedial, medial, posteromedial, posterior, posterolateral, and lateral respective to the foot that is weight bearing.21,22,27 The participant stands on 1 leg in the center of the asterisk, maximally reaches with the contralateral leg down each line, and moves in either a clockwise or counterclockwise direction based on the dominant leg. The test requires 6 practice reaches in each of the 8 directions and 3 recorded test reaches. Each reach, or trial, should be held for 1 second for a reading to be taken, and the contralateral foot should never touch down or the trial will be nullified.

The SEBT has been shown to have high reliability for testing dynamic postural control of those with and without functional ankle instability.5,21,28 Hertel et al28
found intratester reliability of the SEBT to be between .78 and .96. In addition, Olmsted et al. reported that the SEBT appears to be sensitive in detecting reach deficits between athletes with functional ankle instability and healthy athletes, but the SEBT has not been found valid for determining dynamic postural control. Kinzey determined that the SEBT has moderate reliability and an intraclass correlation coefficient (ICC) of .86 to .98 for assessing dynamic balance. The ICC of the SEBT for our study was .971 with a range from .957 to .981. The pretest SEBT ICC was .950 with a range of .925 to .969, and the posttest SEBT ICC was .980 with a range of .963 to .989.

A digital scale (XPress XBL Bench Scale, Model XBL150L-XID, Mettler-Toledo, Inc, Columbus, OH) was used to weigh the subjects and compare their weights with their gluteus medius strength scores. The scale accurately weighs to the closest 0.1 lb. A Lafayette manual muscle test system (MMTS; Model 01163, Lafayette Instruments, Lafayette, IN) handheld dynamometer was used to test the subjects’ hip-abduction strength. The MMTS measures the static force produced by a muscle against the force pad. This handheld dynamometer can effectively measure static force ranging from 0 to 300 lb with an accuracy of 0.5 lb. It is important that the subject perform 3 practice trials, with the average of the 3 used for data collection. A related study, using a similar handheld dynamometer, found a high reliability for measuring hip-abduction strength using a nylon strap, with an ICC of .928. Our study recorded an ICC of .980 with a range of .963 to .989 for gluteus medius strength testing using the MMTS.

Procedures

Only subjects who met all the inclusion criteria were invited to participate in the study. They were assigned using stratified randomization to 1 of 4 groups: PT, GMST, COMBO, or control.

Times were established for subjects to meet with the researcher 3 times a week for 6 weeks, approximately 20 min/session, to perform PT exercises, GMST exercises, or a combination of the 2. The dominant leg was used for the training sessions. Leg dominance was determined by asking the subjects which leg they would use to kick a ball. All exercises were performed at a local sports-medicine clinic to serve as an environmental control. The primary researcher administered and supervised all testing and exercising sessions. For pretesting and posttesting the subjects completed the SEBT and the Lafayette MMTS for gluteus medius strength on different days. At the conclusion of the last exercise session, the subjects performed their posttest for the SEBT and gluteus medius strength. The posttest was performed to the exact same specifications as the pretest and was completed within 1 week after the final training session of the sixth week.

Intervention

**Control Group.** The control group was not required to attend any sessions for the training exercises. The researcher was in contact with the subjects of this group weekly to obtain information on any activities they were performing, such as weightlifting, running, or swimming, and to see that they were not participating in any PT or GMST programs.
**PT Group.** Proprioceptive exercises are exercises that increase the body’s ability to detect motion in the foot and make postural adjustments accordingly. Proprioception training is most often performed using static or dynamic balance exercises. The subjects in the PT group performed a battery of exercises that changed from week to week, using their dominant leg. Exercises 1 through 3 included fixed-surface balancing with eyes open, fixed-surface balancing with eyes closed, and fixed-surface balancing while picking up objects. A tilt board (ECO Pro Rocker Board, Model 80314, Power Systems, Inc, Knoxville, TN) was then added for additional balance training for exercises 4 through 9. Tilt-board balancing started with the board in a dorsiflexion/plantar-flexion pattern with eyes open, as well as closed. Then the subject performed tilt-board balancing with the board positioned in an inversion/eversion pattern with eyes open and then closed. This was followed with the tilt board placed on a diagonal as subjects performed balance tasks with the eyes open and then closed. Wobble-board (ECO Pro Wobble Board, Model 80312, Power Systems, Inc, Knoxville, TN) balancing was performed with eyes open and then closed for exercises 10 and 11. The last exercises performed were functional hops with eyes open and then with eyes closed on landing. These exercises were performed starting at 15 seconds with 45-second breaks between exercises in the first week. Five seconds were either added to the exercise or decreased from the rest period each week until by the fourth week the 2 were equal at 30 seconds. A detailed description of the weekly progression can be seen in Table 1.

**GMST Group.** The GMST group performed 6 exercises for the 6-week training period (Table 2). These exercises were selected from typical rehabilitation programs that focus on strengthening the hip abductors and from EMG studies.

### Table 1 Proprioception Training Program

<table>
<thead>
<tr>
<th>Week</th>
<th>Sets</th>
<th>Exercises</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>15 s each, 45 s rest between</td>
<td>FEO, FEC, FPO, TEO1, TEC1, TEO2, TEO3, TEO3, TEC3</td>
</tr>
<tr>
<td>2</td>
<td>20 s each, 40 s rest between</td>
<td>FEO, FEC, FPO, TEO1, TEC1, TEO2, TEO3, TEO3, WEO × 2</td>
</tr>
<tr>
<td>3</td>
<td>25 s each, 35 s rest between</td>
<td>FEO, FEC, FPO, TEO2, TEC2, TEO3, TEC3, WEO × 2, WEC</td>
</tr>
<tr>
<td>4</td>
<td>30 s each, 30 s rest between</td>
<td>FEC, FPO, TEO2 × 2, TEC2 × 2, WEO × 2, WEC × 2</td>
</tr>
<tr>
<td>5</td>
<td>30 s each, 30 s rest between</td>
<td>FEC, FPO, TEC2, WEO × 2, WEC × 2, (FHO) × 2</td>
</tr>
<tr>
<td>6</td>
<td>30 s each, 30 s rest between</td>
<td>FEC, FPO, TEO2, TEC2, WEO, WEC, FHO × 2, FHC</td>
</tr>
</tbody>
</table>

Abbreviations: FEO, fixed surface, eyes open; FEC, fixed surface, eyes closed; FPO, fixed surface, picking up objects; TEO1, tilt board, dorsiflexion/plantar flexion, eyes open; TEC1, tilt board, dorsiflexion/plantar flexion, eyes closed; TEO2, tilt board, inversion/eversion, eyes open; TEO3, tilt board, inversion/eversion, eyes closed; TEO3, tilt board, diagonal placement, eyes open; TEC3, tilt board, diagonal placement, eyes closed; WEO, wobble board, eyes open; WEC, wobble board, eyes closed; FHO, functional hop, eyes open; FHC, functional hop, eyes closed.
on muscle activation of the gluteus medius.24–26,34 We found only 1 study33 that evaluated the gluteus medius and other selected muscles after a 6-week intervention program. The first exercise was a side-lying hip-abduction exercise24,26 using a blue (“extra heavy”) Thera-Band (Model 20050, The Hygenic Corp, Akron, OH); subjects performed 3 sets of 10 repetitions of this exercise for the first 2 weeks, increasing to 3 sets of 15 repetitions the third and fourth weeks and 3 sets of 20 the final 2 weeks. Rest periods were 60 seconds between sets. Next, the subjects walked for 3 minutes around an 80-m track,32,34 carrying a dumbbell in the hand opposite the dominant leg. Each subject started with the weight at 5% of body weight for the first 2 weeks, 10% of body weight for the third and fourth weeks, and 15% of body weight for the final 2 weeks. The subjects then performed gorilla walking,32,33 or lateral walking with a Thera-Band wrapped around both legs positioned just above the knees. The exercises started with 3 sets of 20 seconds using a blue Thera-Band for the first 2 weeks, 3 sets of 30 seconds the third and fourth weeks, and 3 sets of 40 seconds for the final 2 weeks. Rest periods were 60 seconds between sets. The fourth exercise was standing hip abduction24 using a multihip machine (Maximus MX506, Model MX506, Cybex International, Inc, Fairfield, CT). Subjects placed the moving arm pad just above the lateral knee on the lateral femoral condyle while completing 3 sets of 10 repetitions. The weight used was adjusted according to the pretest strength values recorded for each subject. For the first 2 weeks, 50% of the tested value was used. The force was increased to 60% of the tested value for the third and fourth weeks and 70% for the final 2 weeks. The next exercise was a single-leg squat.24,25,33 The subject squatted approximately 45° while standing on the dominant leg. A verbal cue was given to each subject by the primary investigator telling them to stop and return to the starting position when visually 45° was reached.32 Two sets of 5 squats were completed the first 2 weeks, 3 sets of 5 squats the third and fourth weeks, and 4 sets of 5 squats the final 2 weeks. Finally, the subject completed lateral step-downs.25,33 The subject stood on a 6-in step on the dominant leg and was instructed to not place weight on the contralateral foot when touching. While standing on the step, the dominant knee was flexed until the contralateral foot barely touched the ground next to the step. The subject then returned to the starting position. Two sets of 5 step-downs for the first 2 weeks, 3 sets of 5 step-downs for the third and fourth weeks, and 4

<table>
<thead>
<tr>
<th>Weeks</th>
<th>Exercises</th>
</tr>
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<tbody>
<tr>
<td>1 and 2</td>
<td>SLAB, 3 × 10; WW, 5% BW; GW, 3 × 20 s; MHAB, 50% test value, 3 × 10; SLS, 2 × 5; LSD, 2 × 5</td>
</tr>
<tr>
<td>3 and 4</td>
<td>SLAB, 3 × 15; WW, 10% BW; GW, 3 × 30 s; MHAB, 60%, 3 × 10; SLS, 3 × 5; LSD, 3 × 5</td>
</tr>
<tr>
<td>5 and 6</td>
<td>SLAB, 3 × 20; WW, 15% BW; GW, 3 × 40 s; MHAB, 70%, 3 × 10; SLS, 4 × 5; LSD, 4 × 5</td>
</tr>
</tbody>
</table>

Abbreviations: SLAB, side-lying hip abduction, blue Thera-Band; WW, walking with weight opposite hand, 3 min; BW, body weight; GW, gorilla walking, blue Thera-Band; MHAB, multihip abduction; SLS, single-leg squat; LSD, lateral step-down.
sets of 5 step-downs for the final 2 weeks were performed. Rest periods were 60 seconds between sets.

**COMBO Group.** This group performed all of the exercises for the PT group and the GMST group. The PT and GMST exercises were performed in a random order as decided according to training equipment availability.

**Pretest and Posttest**

Initially, subjects were oriented to the SEBT. They had their true leg length measured in a supine position before testing to normalize the excursion measurements. They underwent a warm-up session of 5 minutes on a stationary bicycle at 120 rpm followed by 5 minutes of static quadriceps, hamstrings, and gastrocnemius stretching. Each subject took a 5-minute break and then started with 6 trials of excursions for each of the 8 directions on the SEBT. A 5-minute rest was given before the subject underwent the pretest to avoid the possibility of fatigue or a learning effect. Subjects were asked to randomly select index cards with SEBT directions on the back of each to determine the starting excursion direction. With starting direction randomly selected, the subjects moved in either a clockwise or counterclockwise direction depending on whether the dominant leg was left or right, respectively, until all 8 directions were completed. Subjects were instructed to touch down very gently at the farthest reach point possible along each of the 8 lines (Figure 1). Each trial was held for at least 1 second in order for the primary investigator to make a recording. If the subject touched down with the nondominant leg providing considerable support, such as more than a tap of the toe or weight placed on the ball of the foot, that trial was nullified. Trials were also nullified if the dominant leg was lifted off the ground or if the subject could not maintain balance. The subject returned to the static unilateral-stance position after each reach trial and remained in that position for at least 10 seconds. The 3 trials in each reach direction were averaged and normalized to the individual’s leg length.

![Figure 1](image)

*Figure 1 — Subject performing the Star Excursion Balance Test for the anterolateral direction.*
On a separate testing day, either the next day or the day thereafter, the subjects completed the gluteus medius strength testing. Before testing, each subject was weighed using a digital scale to normalize the strength values to the subject’s body weight. A Lafayette MMTS handheld dynamometer was used to test the subjects’ gluteus medius strength. The subject was side-lying on the nondominant side with the dominant hip in a truly abducted position. The dominant hip was approximated visually to be at 10° of abduction before testing. The force pad of the handheld dynamometer was placed just above the knee joint on the lateral femoral condyle. The subject took 3 practice trials. The dynamometer was zeroed, and then the subject was instructed to abduct the top leg from the bottom leg by building up force for 2 seconds and then a maximal effort for 4 seconds. The value on the dynamometer was recorded and then the dynamometer was zeroed out again before the next trial. The subject had 15 seconds of rest between trials. The 3 trials were averaged and normalized to the individual’s body weight.

Data Analysis

On coded sheets, the anterior, anterolateral, lateral, posterolateral, posterior, posteromedial, medial, and anteromedial reach distances were recorded. An average of these excursions was calculated from the 3 trials of each dependent variable for each subject and recorded. To determine the normalization to leg length for the SEBT, the primary investigator divided the average excursion length for each direction by the leg length and then multiplied by 100.

On separate coded sheets, the gluteus medius strength values were recorded. To determine the normalization to body weight for gluteus medius strength, the primary investigator divided the average gluteus medius strength by the subject’s body weight and then multiplied by 100. On test completion by all subjects, values were entered into a spreadsheet on SPSS Version 14.0 for Windows (SPSS Inc, Chicago, IL).

Statistical Analysis

Descriptive analysis consisted of means and standard deviations of all subjects for the SEBT and gluteus medius strength. For the SEBT, a $2 \times 4 \times 8$ repeated-measures ANOVA was used to determine main effects and interactions. To determine the main effects and interactions of gluteus medius strength, a $2 \times 3$ repeated-measures ANOVA was used. Tukey post hoc tests and pairwise comparisons were run if main effects were evident. The level of significance used for all analyses was $P = .05$. Follow-up pretest and posttesting data analyses were used to determine variability between the groups.

Results

SEBT

Descriptive statistics for all 4 groups are shown in Table 3 and Figures 2 and 3. There was a significant interaction for test by group ($F_{3,47} = 6.145, P = .001, ES = .295, \beta = .946$), with a significant main effect for test ($F_{1,47} = 190.825, P < .001, ES = .813, \beta = 1.000$) and direction ($F_{1,47} = 32.646, P = .000, ES = .763, \beta = 1.000$).
There was no significant main effect for group \((F_{3,47} = .631, P = .599, \text{ES} = .041, \beta = .171)\) or additional interactions for direction by group \((F_{3,47} = .680, P = .569, \text{ES} = .044, \beta = .182)\), test by direction \((F_{1,47} = 3.303, P = .076, \text{ES} = .070, \beta = .428)\), or test by direction by group \((F_{3,47} = 1.571, P = .210, \text{ES} = .097, \beta = .385)\). All pretest/posttest distances were significant at \(P < .001\). All 3 experimental groups improved reach distances in all 8 directions from pretest to posttest. The range of differences between pretest and posttest for the 8 reach distances for experimental groups were COMBO 2.85 ± 6.22 to 6.26 ± 3.19, GMST 1.53 ± 2.14 to 7.62 ± 7.96, and PT 0.99 ± 2.19 to 5.65 ± 3.91. The COMBO group demonstrated the
Figure 2 — Mean Star Excursion Balance Test reach distances by test for all subjects. A = anterior; AM = anteromedial; M = medial; PM = posteromedial; P = posterior; PL = posterolateral; L = lateral; AL = anterolateral. All directions were significant at \( P = .05 \) (% reach distance/leg length \( \times 100 \)).

Figure 3 — Mean Star Excursion Balance Test reach distances by test for all groups. No significance for groups at \( P = .05 \) (% reach distance/leg length \( \times 100 \)).
most improvement for 4 of the 8 reach distances (anterior, medial, posteromedial, and posterior), followed by GMST for 3 reach distances (posterolateral, lateral, and anterolateral) and the PT group with only 1 (anteromedial).

For follow-up pretesting and posttesting, there were no significant differences found for pretest or posttest reach distances between groups for all directions on the SEBT.

**Gluteus Medius Strength**

Descriptive statistics for all 4 groups are shown in Table 4 and Figure 4. There was a significant interaction for test by group ($F_{3,44} = 5.172, P = .004, ES = .261, \beta = .900$) and test ($F_{1,46} = 51.782, P = .000, ES = .541, \beta = 1.000$). No significant main

<table>
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<tr>
<th>Combination (n = 12)</th>
<th>Gluteus Medius Strength (n = 13)</th>
<th>Proprioception (n = 12)</th>
<th>Control (n = 11)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pretest</td>
<td>33.04 ± 5.13</td>
<td>33.24 ± 3.90</td>
<td>32.29 ± 4.99</td>
</tr>
<tr>
<td>Posttest</td>
<td>34.74 ± 5.35</td>
<td>35.28 ± 4.02</td>
<td>32.99 ± 4.79</td>
</tr>
<tr>
<td>Pretest-to-posttest difference</td>
<td>1.70 ± 1.55</td>
<td>2.05 ± 1.31</td>
<td>0.70 ± 0.71</td>
</tr>
</tbody>
</table>

Abbreviations: %MAXABD, average force in pounds/body weight $\times 100$.

**Figure 4** — Mean pretest and posttest gluteus medius strength recordings by test for all groups. No significance for groups at $P = .05$ (% average force in pounds/body weight $\times 100$).
effect was found for group between subjects ($F_{3,44} = .883$, $P = .458$, ES = .057, $\beta = .227$). Only pretest/posttest GMST (33.2 ± 3.9, 35.2 ± 4.0, $P < .001$) were significant. The other 3 groups showed little improvement. The GMST group showed the greatest improvement in gluteus medius strength (2.05 ± 1.31), followed by the COMBO group (1.70 ± 1.55) and the PT group (0.70 ± 0.71). The control group showed the least improvement (0.45 ± 0.91).

We found no significant differences for follow-up pretest or posttest values between groups for gluteus medius strength.

Comments

The purpose of the current study was to determine the effect that gluteus medius muscle strength training, proprioceptive training, or a combination of the 2 would have on dynamic postural control in healthy subjects. We hypothesized that the SEBT would be affected differently depending on the type of exercise program completed. This was not supported by the results because there was not a significant difference between groups for the SEBT, but the current data do suggest that all 3 training programs resulted in significant improvements from pretest to posttest. The COMBO group demonstrated the most improvement, followed by the GMST and the PT groups. Likewise, it was hypothesized that there would be a difference between the training groups and the control group for gluteus medius strength measurements. Similar to the SEBT, this was not evident. There were differences evident with the experimental groups for pretest and posttest results, with the GMST group demonstrating the greatest improvement. The COMBO group and the PT group showed slight improvement, and the control group showed the least improvement. There were significant interactions for test by group for both the SEBT and gluteus medius strength. In both cases, pretest and posttest results were different for the 3 experimental groups.

SEBT

What is most important about this study is that the differences between pretest and posttest reach directions after the training programs indicated improvements. With all groups, the posterior reach direction was always the greatest and the lateral and anterolateral reach directions were the least. The posteromedial, posterior, and posterolateral reach directions revealed significant gains across all groups except the control group. The control group had the least improvement from pretest to posttest, and the COMBO group and GMST group showed the most improvement. The COMBO group experienced the greatest mean improvements in the posteromedial (5.75 ± 3.84), posterior (6.26 ± 3.19), and posterolateral (6.14 ± 7.30) reach directions; the GMST group’s improvements were slightly less (5.13 ± 4.94, 5.65 ± 3.91, and 5.46 ± 4.39, respectively). The PT group’s mean improvements were notably less than those of the COMBO and GMST groups (3.38 ± 3.00, 4.77 ± 5.00, and 6.24 ± 5.66, respectively) on those same directions. The control group showed the least mean improvements, of 2.49 ± 2.36, 3.24 ± 3.63, and 2.97 ± 5.33, respectively. Why there were improvements evident may be related to the use of PT and GMST exercises that incorporated ankle and hip strategies and the ease or difficulty of the 8 directions.
It cannot be stated empirically that these improvements in dynamic postural control are related to the subjects’ using the hip and ankle strategy throughout the training period, because EMG data were not collected. Generally, young, healthy, active individuals like those in this study use the ankle strategy before the hip strategy to alter or correct center of mass. Using the ankle strategy, an individual maintains postural control by firing the peroneal muscles.\(^7\) In older individuals or those with ankle injuries, the gluteus medius and other hip abductors compensate for weakened ankle musculature and maintain postural control.\(^7,32\) This proximal compensation to postural sway of center of mass is often seen in individuals with lateral ankle sprains and those with functional instability in the ankle.\(^2,5,23,32\)

In an EMG study by Beckman and Buchanan,\(^36\) an increase in gluteus medius activity during sudden ankle inversion was noted in healthy subjects, as well as those with functionally unstable ankles. It is for this reason that it becomes very difficult to train individuals, healthy or injured, for purely ankle-strategy balancing. Some of the individuals in the PT group may have used the hip strategy to maintain balance during their training and, therefore, were able to improve strength in the gluteus medius. The proprioception exercises were performed on 1 foot. Every exercise, including hopping and balancing on unstable surfaces, was performed in a unilateral dominant-leg stance. Furthermore, the additional loss of balance experienced with the eyes closed and standing on unstable surfaces for certain exercises may have activated the somatosensory system, as well as the gluteus medius muscle in the dominant leg. This can also be said for the COMBO group because both PT and GMST exercises were used. It is postulated that the subjects performing GMST exercises (gluteus medius strength and combination) had the greatest gains in SEBT reach distances because they trained the gluteus medius, the primary muscle involved in the hip strategy of dynamic postural control.

Our study does not indicate whether proprioception exercises performed on 1 foot or strength gains in the gluteus medius were responsible for the dynamic postural control improvements in healthy subjects. Correlations between strength gains and functional improvements were very low. Other studies have alluded to the importance of hip-muscle strength for daily living and sports\(^24\) and improvement in function.\(^25,33\) Boling et al\(^33\) noted that after a 6-week training program for patellofemoral pain syndrome there was a decrease in pain and an increase in function after the use of weight-bearing exercises. Although improvement was evident, gluteus medius onset and duration pretest and posttest values during a stair-stepping task did not differ between the patellofemoral pain syndrome group and the control group. Bolgla and Uh\(^\text{I}\text{I}\)\(^24\) stated that hip-strengthening exercises have important functional implications because they enable patients to regain muscle strength needed to perform daily activity and sport. This was not a training study, so it is not known if there is a relationship between strength gains and functional improvement. This lack of evidence led Ayotte et al\(^25\) to suggest that additional EMG studies of hip muscles might include onset and timing of muscle activation in these exercises and a comparison with functional activities. Thus, as either gluteus medius strength training, proprioception training, or a combination of both will be effective in improving SEBT reach directions, more information is needed to understand the precise nature of the relationships between strength gains and functional improvements.
The results of our study and others like those of Piegaro\textsuperscript{37} and Samson\textsuperscript{38} showed changes in reach distances pretest to posttest for the posteromedial, posterior, and posterolateral directions. Those authors hypothesized that the posterior directions were the easiest of the reach directions, and it is for this reason that even the control group showed improvements from pretest to posttest. Despite having the lowest overall SEBT pretest means, the COMBO group showed the greatest improvement between pretest and posttest. The anterior, anteromedial, and medial reach directions were not the easiest to perform, but they were easier than lateral and anterolateral and changed moderately between pretest and posttest. Among all subjects, the lateral and anterolateral reach directions were less for pretest and posttest than any of the other directions. One reason for this may be that the 2 directions appeared to be the most difficult. Studies have alluded to the difficulty of each of the reach directions based on their results. Samson\textsuperscript{38} and Piegaro\textsuperscript{37} indicated that the lateral and anterolateral directions were among the lowest excursions recorded. A shorter reach direction would imply more difficulty or a lack of dynamic postural control for that particular direction. Furthermore, shorter reach distances for the anterior direction may be related to the need for greater quadriceps strength for balance than hip-abduction strength.\textsuperscript{27,31}

Although it was not evident, we expected to see a significant difference between the groups performing the PT exercises (PT and COMBO) and the groups performing only gluteus medius strength training or no training (control). Furthermore, we felt that the COMBO group would demonstrate the most improvement because more exercises were incorporated by including PT and GMST exercises. Despite the COMBO group’s showing the most improvement, it was still not significantly different between the groups. A reason that differences were not evident may be that the homogeneous subject population was evenly distributed across all 4 groups. In our study, subjects were placed into the 4 groups using a randomized stratification to guarantee that all active subjects were evenly distributed into the control and experimental groups. In fact, there were no pretest or posttest differences between the groups found with follow-up analyses. Similarities were found between all groups in many demographics including gender, age, height, and weight. Based on results from our study moderately active healthy subjects will achieve gains in dynamic postural control in spite of the group in which they are placed as overall pretest to posttest reach distances were notably different. It is interesting that even the no-exercise group improved from pretest to posttest in 5 of the 8 directions. Perhaps this is related to individual variability within the group, because standard deviations ranged from 10.37 to 14.89.

This is the first study to assess the effect of PT and GMST exercises on dynamic postural control; there are no other studies with which to compare our results. However, there are 3 other training studies\textsuperscript{37,39,40} that reported group results similar to ours using active, healthy subjects. Blackburn et al\textsuperscript{39} tested 32 healthy, physically active subjects on the Bass test, a hop-and-land test for dynamic balance. In their study, the PT group was subjected to 6 weeks of exercises such as resistance-band kicks, single-leg standing on a foam surface, single-leg hops, and BAPS-board single-leg standing. That study also had an ankle-strength group and a combined proprioception/strength group but found no significant differences between groups. The study by Riemann et al\textsuperscript{40} was performed on 26 recreationally active subjects and tested ankle kinesthesia and postural control. Unlike our study, their 4-week study
used only BAPS-board proprioceptive exercises. However, much like our study, they found no significant difference between experimental and control groups for static or functional postural control.

To our knowledge, the study by Piegaro\textsuperscript{37} is the only study other than our own that used the SEBT to determine dynamic postural control before and after a training program. Piegaro\textsuperscript{37} used the same PT program\textsuperscript{23} as our study; however, the training period in that study lasted only 4 weeks. Piegaro also used the SEBT on healthy college students (N = 39). There were significant differences between pretest and posttest reach distances in the medial, posterior, and lateral directions and a time-by-group interaction for posteromedial and anterolateral.\textsuperscript{37} As with the other 2 studies and our own, there were no significant difference between groups. This may indicate that longer training programs are necessary for healthy subjects.

In contrast, 2 other training studies, one by Powers et al\textsuperscript{20} and one by Bernier and Perrin,\textsuperscript{23} were conducted on individuals with a history of functional ankle instability. Powers et al\textsuperscript{20} used a PT program consisting solely of resistance-band kicks on 38 college-age individuals. The study determined that the 6-week program caused no significant change from pretest to posttest in static balance on a force plate. Bernier and Perrin,\textsuperscript{23} on the other hand, used a combination of balance training on fixed and unstable surfaces, as well as hopping exercises. Using the Balance System by Chattanooga, results from their 6-week program achieved significant differences for semidynamic postural stability on anterior/posterior and medial/lateral modified equilibrium scores between groups. Although we used the same PT program we postulated that the reason we did not see significant differences between groups was that we used healthy subjects rather than those with functional ankle instability. Healthy individuals should not have dynamic balance or ankle proprioception abnormalities that predispose them to poor dynamic stability that requires retraining.

**Gluteus Medius Strength**

Because this is the first study to evaluate a strengthening program of the gluteus medius for dynamic postural control, there are no comparison studies. Our study focused on determining the effect of a combination of gluteus medius strength training and proprioceptive training on dynamic postural control. This is why the primary focus was not an increase in gluteus medius strength but rather whether the training programs improved dynamic postural control.

Our study indicated some clinical relevance in successfully improving gluteus medius strength in all groups, especially in the COMBO and GMST groups. Overall pretest and posttest gluteus medius strength values were notably different. The GMST group showed the greatest improvement in gluteus medius strength (2.05 ± 1.31), followed by the COMBO group (1.70 ± 1.55) and the PT group (0.70 ± 0.71). The control group showed the least improvement (0.45 ± 0.91). The groups who performed the GMST exercises did not perform sets and repetitions between 85% and 100% of individual 1-repetition maximum to overload the muscle. Resistance was increased by using only 10% to 15% of body weight. In addition, Thera-Bands were used to provide resistance. Although strength gains were the greatest with the GMST group, strength did not increase significantly in this group in comparison with the other 3 groups. Either different GMST exercises should be incorporated or similar exercises with a different protocol including resistance or weekly progression...
may be required to maximize strength gains. The subjects in the PT group were able to increase gluteus medius strength because the PT exercises were performed on 1 foot. Every exercise, including hopping and balancing on unstable surfaces, was performed in a unilateral dominant-leg stance.

Most of the studies conducted on testing the strength of the gluteus medius have been performed on injured subjects with ankle sprains, iliobial band pain, or patellofemoral pain syndrome and do not provide strengthening suggestions in regard to sets, repetitions, or resistance. Another study recommended strengthening the gluteus medius when it is in a weakened state because of its involvement in dynamic postural control and locomotion during gait. That study, by Ogiwara and Sugiura, suggested using progressive resistance exercises with a 10-repetition maximum. Progressive resistance exercises have become the most commonly employed method for regaining gluteus medius strength in the clinical setting, but there is not a simple way to determine an individual’s 10-repetition maximum to ensure adequate resistance for strengthening. Although 10-repetition maximum is suggested by Ogiwara and Sugiura for rehabilitating injured athletes, it may not have been the most appropriate choice for training healthy subjects, especially when the goal is placing an overload force on the muscles. Following guidelines such as those of the National Academy of Sports Medicine or using more than resistance bands might be necessary to strengthen the gluteus medius. The National Academy of Sports Medicine’s guidelines for strength training follow the individual’s 1-repetition maximum. Using 4 to 6 sets of 1 to 5 repetitions that are between 85% and 100% of an individual’s 1-repetition maximum 4 times per week for all GMST group exercises may have yielded more improvement in the GMST or COMBO group. The overload principle to stress the gluteus medius by performing exercises using the subject’s body weight or a load in excess of body weight in place of resistance-band training should also be considered.

The exercises developed as a training program to strengthen the gluteus medius have not been evaluated collectively to improve dynamic postural control. These exercises were selected from typical rehabilitation programs that focused on strengthening the hip abductors and from EMG studies on muscle activation of the gluteus medius. We found only 1 study that evaluated the gluteus medius and other selected muscles after a 6-week patellofemoral intervention program. Wilson used the functional method of strengthening the gluteus medius employed in the current study. He had healthy subjects strengthen the gluteus medius by carrying a dumbbell in the contralateral hand. The subjects used a dumbbell in the range of 5% to 15% of their body weight by walking while carrying the weight. The study determined through side-lying manual muscle testing, as well as a standing Trendelenburg sign, that this effectively strengthened the gluteus medius. “Arc walking” is another strengthening method that Wilson used. In arc walking, the individual walks while attached to a secure structure by a resistance band. The individual walks in an arc pattern around the origin of the resistance band while keeping his or her toes pointed at the band. The lateral sidestepping against resistance was shown to strengthen the gluteus medius also, using the side-lying manual muscle test and Trendelenburg sign. The arc-walking exercise used by Wilson was very similar to the gorilla-walking exercise used in this study. Both use hip abduction while in a standing position against an elastic resistance. Gorilla walking was chosen for this study because it requires hip abduction against direct resistance as opposed to resistance applied to
the waist as in arc walking. Open kinetic chain exercises are most often employed to strengthen the gluteus medius in the clinical setting and have been evaluated using EMG. Generally, the gluteus medius is strengthened using a side-lying straight-leg raise as the hip is moved into abduction.\textsuperscript{24,26,32,42} This is usually performed against an elastic resistance or an ankle cuff weight. The side-lying hip-abduction exercise in this study used a blue, or “extra heavy,” latex rubber resistance band while the standing hip abduction\textsuperscript{24} was performed on the Cybex multihip machine. Two other closed kinetic chain exercises, single-leg squats\textsuperscript{24,25,33} and lateral step-downs,\textsuperscript{25,33} normally performed as part of a typical patellofemoral rehabilitation or strengthening program were also included. These exercises use an individual’s body weight as resistance to strengthen the gluteus medius.

**Clinical Implications**

Although this study presented statistical significance, its true benefits lie in the clinical relevance. Our study found that 6 weeks of proprioceptive training, gluteus medius strengthening, or a combination program will increase SEBT reach distances in all directions, as well as slightly increase gluteus medius strength. The 2 groups that performed gluteus medius strengthening completed the study with a greater increase in gluteus medius strength than did the PT and control groups. In addition, the SEBT reach distances among the GMST and COMBO groups demonstrated greater improvements in most SEBT reach directions than in the control and PT groups. PT exercises, GMST exercises, or a combination of the 2 may have implications for preventive ankle-training programs for healthy, active individuals.

The exercises used in our study are typically used in the rehabilitation setting when attempting to strengthen the gluteus medius or overcome somatosensory-facilitation deficits. Somatosensory-facilitation exercises have been reported in the literature for ankle rehabilitation.\textsuperscript{25} The exercises developed as a training program to strengthen the gluteus medius muscle have only been evaluated by EMG studies\textsuperscript{24–26,34} and only 1 training study.\textsuperscript{33} Those studies, however, did not investigate whether the recommended exercises actually facilitate gluteus medius strength gains or improvement in dynamic postural control after a training period. The exercises used in our study have been assumed to show the greatest effects for ankle rehabilitation when performed in a clinical setting.\textsuperscript{24–26,30,32–34,41,42}

A limitation of this study may be that we used healthy subjects. When evaluating a training program for ankle injuries, that study population should be used. However, because this was the first study to incorporate evidence-based and best-clinical-practice exercises that would activate proximal and distal lower extremity muscles, we wanted to observe the differences in healthy subjects first; pain could limit how injured subjects perform and therefore limit the results of those studies. In our study, a sample of convenience of novice subjects in regard to the training program was used. Further investigation of exercises incorporated in the 3 experimental groups in a pathological population would be appropriate.

**Conclusion**

The results from our study indicate that a combination of gluteus medius strength training and proprioceptive training does not demonstrate more improvement in
Dynamic postural control than proprioceptive training alone. However, the enhancement of dynamic postural control recognized after 6 weeks of either gluteus medius strength training or proprioceptive training is clinically relevant. Although there was no significant difference between groups for gluteus medius strength, it is apparent that the groups performing gluteus medius strengthening exercises showed improved gluteus medius strength pretest to posttest. In the clinical setting, these training programs would be used by individuals with lower extremity injuries, thus resulting in greater improvement in dynamic postural control using hip and ankle strategies. Gluteus medius strengthening used as a supplement to a lower extremity rehabilitation program may improve dynamic balance more than proprioceptive training alone.

References


