2006

The comparative effects of a six-week balance training program, gluteus medius strength training program, and combined balance training/gluteus medius strength training program on dynamic postural control

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The Comparative Effects of a Six-Week Balance Training Program, Gluteus Medius Strength Training Program, and Combined Balance Training/Gluteus Medius Strength Training Program on Dynamic Postural Control

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Thesis submitted to the
School of Physical Education
at West Virginia University
in partial fulfillment of the requirements
for the degree of

Master of Science
in
Athletic Training

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School of Physical Education

Morgantown, West Virginia
2006

Keywords: ankle, proprioception, hip, neuromuscular, postural control

ABSTRACT

The Comparative Effects of a Six-Week Balance Training Program, Gluteus Medius Strength Training Program, and Combined Balance Training/Gluteus Medius Strength Training Program on Dynamic Postural Control

Vincent J. Leavey

Little is known about proprioception, gluteus medius strength, or combination training programs for improving dynamic balance. The purpose of this study was to assess the outcome of six weeks of gluteus medius strength training, proprioception training, and a combination of the two on dynamic balance. The study was a 2x4x8 and a 2x4 factorial design with three experimental groups and a control group. This study included 48 healthy, physically active, college-aged subjects. The six-week protocol for the experimental groups was conducted following a specific program three times a week for an average of 30-minutes. The proprioception training program included a battery of exercises that advanced from week to week. The gluteus medius training program utilized exercises that focused on strengthening the gluteus medius. Pre and post-test measurements of dynamic balance were conducted using the Star Excursion Balance Test (SEBT) and the Manual Muscle Testing System for gluteus medius (GM). Testing was conducted one week prior to and following the six-week exercise protocol. Significant differences were found for test, direction and test by group on the SEBT for all eight reach directions and for test and test by group for GM. There was no difference between groups. In conclusion, gluteus medius strength training and/or proprioception training may be used as a supplement to improve dynamic balance among healthy subjects.

ACKNOWLEDGEMENTS

I would like to extend a huge thank you out to my family: Dad, Mom, Mandy, and Jim. I cannot thank you enough for always encouraging me to do my best without adding any additional pressure. There is no way for me to tell you just how much I appreciate you being there for me and supporting me financially and emotionally throughout the past 24 years. I'm doing my best to keep you proud.

I would like to thank all of my fellow graduate athletic trainers from the past two years. We really had some great times together and I wish you all the best in the future. In addition, thank you very much for taking part in my research, because without you this would not have been possible.

I would like to thank my club sports and intramural athletes. Your assistance with this study was much appreciated.

Dr. Sandrey, thank you for everything. Your encouragement and direction have helped me complete this study with only a few small bumps along the way. I cannot express how much help you were to me in developing an idea and making it a reality. The great amount of research I have read in the past two years has helped me immensely during this thesis study and will only benefit me in the future. It is for that reason that I thank you for making me a better researcher and athletic trainer.

I would like to thank Gregory Dahmer for being a member of my committee. You cannot understand how much the knowledge you have imparted upon me has helped me in writing this thesis and in valuing the importance of human biomechanics. Thank you for your encouragement and assistance in making this thesis better.

I would also like to thank Dr. Carson for being a member of my committee. Your expertise has made this paper more consistent and fluent. I wish I could explain how much I appreciate your time and effort in helping me enhance the quality of this paper.

Mike Curley and Jack Brautigam, thank you very much. Without having the equipment and facilities available at HealthWorks Rehab and Fitness, this research never would have been possible. Thank you very much for your generosity.

Last but never least, Crystal. Thank you so much for everything. You are an incredible person with great spirit, and I am extremely lucky for having you in my life. Having someone to call when times got rough has helped me immensely through the past two years. You will never know how much I appreciate everything you do for me. I wish there were a way to repay you for everything. We have had great times together, and your constant encouragement makes me want to achieve more and more. I am absolutely indebted to you and cannot thank you enough. I cannot wait to spend the rest of my life with you. I love you, always and forever.

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INTRODUCTION

Ankle sprains are one of the most common injuries in sports today.[1-26] Eighty-five to ninety-five percent of all ankle ligament injuries are lateral ankle sprains (LAS) caused by an inversion mechanism.[1,2,5,6,15,18,22,24,27] An estimated 10 to 45 percent of all injuries in running and jumping sports are ankle sprains.[1,2,9,11,15,] There are about 27,000 ankle sprains per day in the United States, or one per every 10,000 people.[1,11] Of those ankle sprains, recurrent ankle sprains can lead to chronic ankle instability creating mechanical and functional deficits.[1,2,4,5,7,21,26,28-33] Both can create long term complications with proprioceptive deficits affecting the ability of both the ankle and hip strategy in maintaining dynamic postural control.[28-33]

There are two strategies for maintaining dynamic postural control: a hip strategy and an ankle strategy.[34,35] Generally, the ankle strategy, in which the peroneal muscles maintain 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 sustain an ankle sprain. In this strategy, the gluteus medius is used to correct posture and keep an individual balanced and erect.[23,34-36] Recent studies have shown that the gluteus medius muscle is weak following ankle sprains.[2,20,35] Usually an individual does not train to strengthen the gluteus medius muscle when attempting to increase dynamic postural control following a lateral ankle sprain. Specifically, in rehabilitating the sprained ankle, ankle strength training and proprioception training is utilized to regain losses in balance that may have occurred.[21,37-44]

The Star Excursion Balance Test (SEBT) is often used as an assessment of an individual's dynamic postural control. The Star Excursion Balance Test is a functional balance test that uses a unilateral stance on the center of an asterisk (star) and a maximal reach down each of the asterisk's eight lines.[45-47] The SEBT has been used to evaluate dynamic postural control following a lateral ankle sprain, but has not been used to evaluate gluteus medius weakness. Several studies[10,19,21,25,35] have evaluated proprioceptive training programs on semidynamic and dynamic balance. To the authors knowledge, there are no known studies in the literature that have evaluated the effect of strength training the gluteus medius on dynamic postural control in healthy or injured subjects. Nor have these studies evaluated the efficacy of gluteus medius strength training, ankle neuromuscular training (proprioception, dynamic postural control, and joint position sense training exercises), or a combination of the two, for their effects on dynamic postural control.[20,35,46,48] Therefore, the purpose of this study was to determine if gluteus medius muscle strength training, proprioception training, or a combination of the two will have an effect on dynamic postural control.

METHODS

There were two separate designs for this study. This study was a 2 x 4 x 8 factorial design as well as a 2 x 4. Independent variables of both designs were test and group. Test existed on two levels (pre and post). The group existed on four levels (proprioception training exercises, gluteus medius strength training exercises, combination, and control). An additional independent variable for the first design was the eight reach directions for the SEBT. The dependent variable in the first design was direction (anterior, anterolateral, lateral, posterolateral, posterior, posteromedial, medial, and anteromedial). The dependent variable of the second design was the gluteus medius strength measurement.

Subjects

This study began with 60 subjects in total, all of whom were students at West Virginia University. Each of the subjects was a healthy individual with an unremarkable history of lower extremity injury in the six months leading up to the study as well as no lower extremity surgery in the past year. Subjects in experimental groups attended at least 14 of the 18 training periods (approximately 77 percent attendance) and returned for post-testing in order for their results to be included 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 post-testing sessions.

Fifteen subjects were randomly assigned to each of the three experimental groups or to the control group using a stratified randomization for gender and activity. Forty-eight subjects (25 males and 23 females) completed the entire study. The mean age of the subjects was 22.06 ± 1.58 years. The mean height of all subjects was 171.87 ± 9.52 centimeters, while the mean weight was 75.72 ± 15.79 kilograms The gluteus medius strength training group completed the study with thirteen subjects (n=13) while the combination and proprioception training groups each completed the study with twelve subjects (n=12). The control group completed the study with eleven subjects (n=11). Complete descriptive statistics for subject demographics can be seen in Tables D1 and D2.

Instrumentation

Using balance tasks to assess dynamic postural control has recently become more commonplace in the clinical physical therapy and traditional athletic training settings.[13] Dynamic postural control tests such as excursion and functional reach tests are superior to basic single leg stance (SLS) tests.[49] The Star Excursion Balance Test is a simple method of testing an individual's dynamic postural control. The SEBT, which was first introduced by Gary Gray in 1995, is a functional balance test that uses a unilateral stance on the center of an asterisk (star) and a maximal reach down each of the asterisk's eight lines.[45-47] The SEBT offers a simple, reliable, low-cost alternative to more expensive, refined instruments available today.[20] The lines extend out from the center of the asterisk at 45 degree increments on a grid. 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 eight directions are named anterolateral (AL), anterior (A), anteromedial (AM), medial (M), posteromedial (PM), posterior (P), posterolateral (PL), and lateral (L) respective to the foot that is weight-bearing.[45-47,49-51] The SEBT is generally placed directly on a non-slick floor using tape, eight tape measures, and a protractor. The participant unilaterally stands in the center of the asterisk and maximally reaches with the contralateral leg down each line.[20] The test requires six practice reaches in each of the eight directions and three recorded test reaches. Each reach, or trial, should be held for one second for recording of measurements.

Each trial is measured from the center of the asterisk and the three trials are averaged and compared to the participant's height or true leg length. Another way to compare SEBT excursions is to add the averages from each of the eight directions and then multiply them by the participant's height. This does not allow the examiner to specifically point out directions in which the participant is lacking in dynamic postural control, but it does provide a simple method of comparing one participant's overall dynamic postural control to that of others'.[19] The further the reach, the greater the demand is on the dynamic postural control of the weight-bearing leg. [28,45-47,49] The participant returns to the static unilateral stance position following each reach and remains there for 10-15 seconds before the next trial. The reaches are completed in one direction before moving on to another direction and should be completed in sequential order either clockwise (CW) or counterclockwise (CCW). During the SEBT, the individual's dynamic postural control constantly corrects as his or her center of mass migrates from over the base of support in all directions.[52] Some factors to be considered when testing an individual using the SEBT are balance disorders, foot type, past injuries/surgeries, flexibility, and shoe condition.[51-52]

The star excursion balance test (SEBT) has been reported to have high reliability for testing dynamic postural control of those with and without functional ankle instability.[10,20,46,50,53,96] Hertel et al.[53] found intratester reliability of the SEBT between .78 and .96. Also, Olmsted et al[54] stated after her study that the SEBT appears to be sensitive in detecting reach deficits between athletes with functional ankle instability and healthy athletes, but the validity for SEBT has not been determined. Kinzey[47] determined that the SEBT has moderate reliability for assessing dynamic balance and has an Intraclass Correlation Coefficient (ICC) of .86 to .98 for assessing dynamic balance. The $ICC_{2,1}$ for this study of the Star Excursion Balance Test was .971 with a range from .957 to .981. The pre-test Star Excursion Balance Test $ICC_{2,1}$ was .950 with a range from .925 to .969, and the post-test Star Excursion Balance Test $ICC_{2,1}$ was .980 with a range from .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 to their gluteus medius strength scores. The scale accurately weighs to the closest 0.1 pounds. A Lafayette Manual Muscle Test System (Model 01163, Lafayette Instruments, Lafayette, IN) hand-held dynamometer was used to test the subjects' hip abduction strength. The Manual Muscle Test System (MMTS) measures the force produced when a muscle contracts by using the muscle to cause a force against the force pad. This hand-held dynamometer can effectively measure static force ranging from 0 to 300 pounds with an accuracy of 0.5 lbs. Two related studies,[55,56] using a similar hand-held dynamometer, found high reliability for measuring hip-abduction strength using a nylon strap with an $ICC_{2,1}$ of .928 . This study recorded an $ICC_{2,1}$ of .980 with a range of .963 to .989 for gluteus medius strength testing using the MMTS.

Procedures

Subjects were contacted and asked to attend a meeting where they were provided with an Informed Consent Form, an Authorization to Use or Disclose Protected Health Information Form, and a Subject Demographics Questionnaire. The study was described to the potential subjects to make an informed decision about whether to participate or not. Any questions from the potential subject pool were answered and explained. The potential subjects were then asked to fill out the Informed Consent Form (Table C1), the Authorization to Use or Disclose Protected Health Information Form (Table C2), and Subject Demographics Questionnaire (Table C3) truthfully and to the best of their ability. The researcher then reviewed the forms for completeness and noted if subjects fit the inclusion criteria, and not the exclusion criteria. If subjects fit the inclusion criteria, they were contacted by the researcher to scheduled a time to perform the pre-test Star Excursion Balance Test and gluteus medius strength testing.

Times were established for subjects to meet with the researcher three times a week over six weeks for approximately 20 minutes per session to perform their proprioceptive exercises, gluteus medius strengthening exercises, or a combination of the two. The dominant leg was used for the training sessions. Leg dominance was determined by the leg the subjects would have used to kick a ball. All exercises were performed at HealthWorks Rehab and Fitness in Morgantown, WV to serve as an environmental control. The primary researcher administered and supervised all testing and exercising sessions. At the conclusion of the last exercise session, the subjects performed their post-test for the SEBT and gluteus medius strength. The post-test was performed to the exact specifications as the pre-test, and was completed within the week following the final training session of the sixth week.

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 adhering to the guidelines.

Proprioceptive training group: Proprioceptive exercises are those exercises that increase the body's ability to detect motion in the foot and make postural adjustments accordingly. Proprioceptive training is most often performed using static or dynamic balance exercises.[48] The subjects within the proprioception group performed a battery of exercises that changed from week to week.[48] Exercises one through three included fixed surface balancing with eyes open (Figure C1), 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 added for additional balance training for exercises four through nine. Tilt board balancing occurred with the board in a dorsiflexion/plantar flexion pattern with eyes open (Figure C2) as well as closed. Next the subject performed tilt board balancing with the board positioned in an inversion/eversion pattern with eyes open (Figure C3) and then closed. The subject performed tilt board balancing with the board placed on a diagonal with the eyes open (Figure C4) 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 ten and eleven (Figure E5). The last exercises performed were the functional hops with eyes open and then with eyes closed upon landing (Figures C6 and C7). These exercises were performed for 15 seconds with 45 second breaks between exercises in the first week. Time was then added to the exercises and taken away from the rest periods until the two were equal at 30 seconds by week four. A detailed description of the weekly progression can be seen in Table C4.

Gluteus medius strength training group: This group performed six exercises for the six week training period (Table C5). These exercises have not been validated by other studies to increase gluteus medius strength, but they were selected from typical rehabilitation programs performed in sports medicine clinics and athletic training facilities that focus on strengthening the hip abductors. The first exercise (Figure 8) was a side-lying hip abduction exercise using a blue (“Extra Heavy”) Thera-Band (Model 20050, The Hygenic Corporation, Akron, OH). The subjects performed three sets of 10 repetitions of this exercise for the first two weeks, increasing to three sets of 15 repetitions the third and fourth weeks, and three sets of 20 the final two weeks. Next the subject walked for three minutes around an 80 meter track at HealthWorks Rehab and Fitness. The subject carried a dumbbell in the hand opposite the dominant leg. The weight was started at five percent of body weight for the first two weeks, 10 percent of body weight for the third and fourth weeks, and 15 percent of body weight for the final two weeks (Figure C9). Gorilla walking, or lateral walking with a Thera-Band wrapped around both legs and placed just above the knees was next (Figure C10). The subject walked for three sets of 20 seconds using a blue (“Extra Heavy”) Thera-Band for the first two weeks, three sets of 30 seconds the third and fourth weeks, and three sets of 40 seconds for the final two weeks. The fourth exercise (Figure C11) was standing hip abduction using a multi-hip machine (Maximus MX506, Model MX506, CYBEX International, Inc., Fairfield, CT). The moving arm pad was placed just above the lateral knee on the lateral femoral condyle while completing three sets of 10 repetitions. The weight used was adjusted according to the pre-test strength values recorded for each subject. For the first two weeks, 50 percent of the tested value was used. The force was increased to 60 percent of the tested value for the third and fourth weeks and 70 percent for the final two weeks. The next exercise was a single leg squat (Figure C12). The subject performed a squat approximately 45 degrees while standing on the dominant leg. Each subject was cued when to stop and return to the starting position by the primary investigator. Two sets of five squats were completed the first two weeks, three sets of five squats were completed the third and fourth weeks, and four sets of five squats were completed the final two weeks. Finally, the subject completed lateral step-downs (Figure C13). The subject stood on a six inch step on the dominant leg. The subjects were instructed to bend the knee until the contralateral foot barely touched the ground next to the step, and then return to the starting position. Two sets of five step-downs for the first two weeks, three sets of five step-downs for the third and fourth weeks, and four sets of five step-downs for the final two weeks were performed.

Combination group: This group performed all of the exercises for the proprioception training group and the gluteus medius strength training group. The proprioception and gluteus medius strength exercises were performed in a random order as decided by convenience of training equipment availability.

Pre- and Post-Test

Initially, every subject was oriented to the Star Excursion Balance Test (Figure C14). A detailed description of Star Excursion Balance Test procedures can be found in Table C6. The subjects had their true leg length measured prior to testing in order to normalize the excursion measurements.[45,46] They underwent a warm-up session of five minutes on a stationary bicycle at 120 revolutions per minute (RPM) followed by five minutes of static quadriceps, hamstrings, and calf stretching (Figures C15, C16, and C17). The subject took a five minute break and then started with six trials of excursions for each of the eight directions on the SEBT. A five minute rest was given before the subject underwent the pre-test. Subjects were asked to randomly select index cards with different directions on the back of each to determine the starting excursion direction. Right-leg dominant subjects started with the direction they selected on the card and continued in a counterclockwise direction until all eight directions were completed. Left-leg dominant subjects started with the direction they selected on the card and continued in a clockwise direction until all eight directions were completed (Figures C18, 19, and 20). Each subject then underwent the three trials which were recorded on a data sheet (Tables C7 and C8) for each reach direction on the SEBT. Subjects were instructed to touch down very gently at the furthest reach point possible along each of the eight lines. Each trial was held for at least one second in order for the primary investigator to make a recording. If the subject touched down with the non-dominant leg to provide considerable support, that trial was nullified.[45,46,49,52] 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 following each reach trial and remained in that position for at least 10 seconds.[45,46] The three trials in each reach direction were averaged and normalized to the individual's leg length. To avoid a possibility for fatigue and/or a learning effect, there was a rest period before starting the actual trials.

On a separate testing day, the subjects were scheduled to have their gluteus medius strength measured. A detailed description of gluteus medius strength testing procedures can be seen in Table C9. First, the subject's were weighed using a digital scale to be used to normalize the strength values to the subject's body weight. The scale had an accuracy of 0.1 pounds. A Lafayette Manual Muscle Test System (Model 01163, Lafayette Instruments, Lafayette, IN) hand-held dynamometer was used to test the subjects' gluteus medius (hip abduction) strength. The subject was side-lying on the non-dominant side. The dominant hip was at approximately 10 degrees of abduction prior to testing.[55] The force pad of the hand-held dynamometer was placed just above the knee joint on the lateral femoral condyle (Figure C21).[56] The subject took three practice trials and three trials were recorded on a data sheet (Tables C10 and C11).[55,56] The dynamometer was zeroed, and then the subject was instructed to abduct the dominant leg by building up force for two seconds and then applying a maximal effort for four seconds.[56] 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 three trials were averaged and were 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 three trials of each dependent variable for each subject and recorded. Upon test completion of all subjects, values were entered into a spreadsheet on SPSS. To normalize 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 (Tables C10 and C11). To normalize 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.

Statistical Analysis

Descriptive analysis consisted of means and standard deviations of all subjects for the SEBT and gluteus medius strength. A one-way Multivariate Analysis of Variance (ANOVA) was calculated for pre-test scores for each the SEBT and gluteus medius strength to determine if there were differences between the groups. A three-way Repeated Measures ANOVA was used to determine main effects and interactions for the SEBT. A two-way Repeated Measures

ANOVA was used to determine the main effects and interactions of gluteus medius strength. Tukey post-hoc tests and pairwise comparisons were run to determine if differences existed between pre-test and post-test results. A P value of 0.05 was used for all analyses.

RESULTS

Star Excursion Balance Test

Descriptive statistics for the pre-test and post-test data for the Star Excursion Balance Test and the differences between pre-test and post-test SEBT performance by each group can be found in Tables D3, D4, and D5 as well as in Figures D1 to D10. There were no significant differences found for pre-test or post-test reach distances between groups for all directions on the Star Excursion Balance Test. Results for the one-way MANOVA's for pre- and post-test Star Excursion Balance Test data can be seen in Tables D6 and D7. For the three-way repeated measures ANOVA, a significant main effect was found within subjects for test ($F_{1,47} = 190.825$, $P < .001$, ES = .813, ß = 1.000) and direction ($F_{1,47} = 32.646$, $P < .001$, ES = .763, ß = 1.000). A within subjects interaction was found significant for test by group ($F_{3,47} = 6.145$, $P = .001$, ES = .295, ß = .946). There were no significant interactions found for direction by group ($F_{3,47} = .680$, $P = .569$, ES = .044, ß = 182), test by direction ($F_{1,47} = 3.303$, $P = .076$, ES = .070, ß = .428), and test by direction by group ($F_{3,47} = 1.571$, $P = .210$, ES = .097, ß = .385). There was no significant main effect found between subjects for group ($F_{3,47} = .631$, $P = .599$, ES = .041, ß = .171). The main effects and interactions can be seen in detail in Table D8. Pairwise comparisons indicated that all pre-test to post-test Star Excursion Balance Test results are significant at a $P \leq 0.05$ level. Results of the paired samples t-tests for each reach direction can be seen in Table D9. Tukey post hoc tests show no significance when comparing groups. Complete results of Tukey post hoc tests can be seen in Table D10.

Gluteus Medius Strength

Descriptive statistics for the pre-test and post-test data for gluteus medius strength can be found in Table D11 as well as in Figures D11 and D12. There were no significant differences found for pre-test ($F_{3,47}$ = .439, P = .726, ES = .029, ß = .131) or post-test ($F_{3,47}$ = 1.454, P = .240, ES = .090, ß = .358) values between groups for gluteus medius strength. One-way ANOVA's for pre-test and post-test gluteus medius strength data between groups can be seen in Table D12. Significant main effects were seen for test ($F_{1,46}$ = 51.782, P < .001, ES = .541, ß = 1.000) while a significant interaction was seen for test by group ($F_{3,44}$ = 5.172, P = .004, ES = .261, ß =.900) within subjects. No significant main effect was found for group between subjects ($F_{3,44}$ = .883, P = .458, ES = .057, ß = .227). The main effects and interactions can be seen in detail in Table D13. A pairwise comparison found a significance (t = -6.580, P < .001) between pre-test and post-test gluteus medius strength values. Tukey post hoc tests show no significance when comparing groups. Complete results of Tukey post hoc tests can be seen in Table D14.

DISCUSSION

Star Excursion Balance Test

The statistical analysis for the Star Excursion Balance Test did not yield any significant results with regard to our experimental hypotheses. There was no significant difference in reach distances in all eight directions from pre-training to post-training in the three experimental groups. Also, there was no significant difference between the three experimental groups and the control group in any of the eight reach directions either pre-test or post-test. Furthermore, there was no significant difference between the proprioception training group and the combination group for any of the reach directions either pre-test or post-test. In addition, there was no significant difference in any of the eight reach directions between the combination group and the control group. Therefore, the four experimental hypotheses for the Star Excursion Balance Test were rejected.

For this study, results for within subjects found significant main effects for both test and direction. Despite there being no significance between groups, overall pre-test to post-test reach distances were notably different. With all groups, the posterior (P) reach direction was always the greatest while the lateral (L) and anterolateral (AL) reach directions were the least. In addition, a within and between subjects interaction was found significant for test by group. This interaction indicates that the specific test (either pre- or post-test) influenced the reach distances recorded by the groups. On the contrary, pre- and post-test pairwise comparisons of each of the eight SEBT reach directions were significant at the $P \leq 0.05$ level. No significant interactions were found for direction by group, test by direction, and test by direction by group.

Despite no significant differences, it is apparent that all groups improved their reach distances in three of the directions. The posteromedial, posterior, and posterolateral reach directions noted significant gains across all groups except for the control group. The control group had the least improvement from pre-test to post-test, while the combination group and gluteus medius strength training group showed the most improvement. The combination and gluteus medius strength training groups were able to show improved SEBT reach distances because the gluteus medius strength training exercises they performed was able to train thehip strategy of dynamic postural control. The combination 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, while the gluteus medius strength training group's improvements were slightly less (5.13 ± 4.94, 5.65 ± 3.91, and 5.46 ± 4.39, respectively). The proprioception training group's mean improvements were notably less than the combination and gluteus medius strength training 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. The results of this study and others like Piegaro,[57] Samson,[58] and Gribble and Hertel,[45] noted changes in reach distances pre-test to post-test for the posteromedial, posterior, and posterolateral directions. They hypothesized that the posterior reach directions were the easiest of the reach directions, and it is for this reason that even the control group showed improvements from pre-test to post-test. Group pre-test and post-test performance means from each reach direction can be seen in Figures D1, D2, D3, D4, and D5. Figure D6 indicates that despite having the lowest overall Star Excursion Balance Test pre-test means, the combination group showed the greatest improvement between pre-test and post-test. The anterior, anteromedial and medial reach directions were not the easiest to perform, however they were easier than lateral and anterolatereal and indicated a moderate change between pre-test and post-test.

Among all subjects, the lateral and anterolateral reach directions indicated the least improvements for pre-test and post-test than any of the other directions. One reason for this may be that the two directions appeared to be the most difficult. This is apparent by the graph in Figure D7 which indicates both pre-test and post-test means for each reach direction for each group. Studies have alluded to the difficulty of each of the reach directions based on their results. Gribble and Hertel,[45] Samson,[58] and Piegaro[57] all indicated that the lateral and anterolateral directions were among the lowest excursions recorded. A shorter reach direction would imply more difficulty and/or a lack of dynamic postural control for that particular reach direction. The differences between pre-test and post-test SEBT reach distances can be seen for all groups in Figure D8, while separate pre-test and post-test reach distances for each group can be seen in Figures D9 and D10. Although there were no significant differences found within these results, the graphs indicate differences that may be clinically relevant.

Although there were differences pre-test and post-test with reach directions following the training programs, this study also expected to see significant difference between the groups performing the proprioception exercises (proprioception and combination) and the groups performing only gluteus medius strength training or no training (control). However, no such significance was found. Perhaps this suggests that either gluteus medius strength training, proprioception training, or a combination of both will be effective in improving SEBT reach directions. However, the combination group trained both hip and ankle strategy with the training programs included in this study.

Why significant results wee not evident could be that all of the subjects were healthy. Healthy individuals should have no dynamic balance or ankle proprioception abnormalities that would typically be seen in individuals with chronic ankle instability or following an acute ankle injury. Because of no history of injury among healthy subjects, neuromotor systems are intact and require no re-training. In this case, when healthy individuals were trained for lower extremity proprioception, they had no significant difference in pre-test to post-test dynamic postural control. It is proposed that healthy individuals should undergo more than a six-week classic rehabilitation-type program for proprioception in order to achieve gains in dynamic postural control.

There are other training studies that reported group results similar to this study using healthy subjects. Blackburn et al.[59] and Riemann et al.,[60] also conducted studies using active, healthy subjects. The study by Blackburn et al. tested 32 healthy, physically active subjects on the Bass Test, a hop and land test for dynamic balance, to find a significant difference between the control group and proprioception group. The Bass Test is performed by having subjects complete a pattern of hopping and landing on a series of 10 marks that have been placed on the floor in a standardized manner. Subjects were required to completely cover each mark with their metatarsal heads while maintaining their balance for as long as possible with the calcaneus lifted off of the ground for up to five seconds. In their study, the proprioception group used exercises such as resistance band kicks, single-leg standing on a foam surface, single-leg hops, and BAPS board single-leg standing for six weeks. The study also had an ankle strength group and a combined proprioception/strength group, however, this study found significant differences between groups.[59] The study by Riemann et al.[60] was performed on 26 recreationally active and tested ankle kinesthesia and postural control. Unlike this study, the one by Riemann et al.[60] used simply BAPS board proprioceptive exercises. However, much like this study, there was no significant difference between experimental and control groups for static or functional postural control.

Piegaro[57] used a proprioceptive training program very similar to the one used for this study, however, the training period in the Piegaro study lasted only four weeks. Piegaro also tested his subjects using the Star Excursion Balance Test on healthy college students (N=39). He noted significant differences between pre-test and post-test reach distances in the medial, posterior, and lateral directions, and a time by group interaction for posteromedial and anterolateral.[57] He also found no significant difference between groups. To our knowledge, the study by Piegaro is the only other study that has used the Star Excursion Balance Test to determine dynamic postural control before and after a training program.

In contrast, two other training studies, one by Powers et al.[41] and one by Bernier and Perrin,[48] were conducted on individuals with a history of functional ankle instability. Powers et al.[41] used a proprioception training program consisting solely of resistance band kicks on 38 college-aged individuals. The study determined that the six-week program caused no significant change from pre-test to post-test in static balance on a force plate. Bernier and Perrin,[48] on the other hand, used a combination of a s balance training on fixed and unstable surfaces as well as hopping exercises. Using the Balance System by Chattanooga, their six-week program achieved significant differences for semi-dynamic postural stability on anterior/posterior and medial/lateral modified equilibrium scores between groups. Although this study used the same proprioceptive training program it was hypothesized that the reason why there were no significant differences between groups was that it used healthy subjects rather than those with functional ankle instability.

Why this occurred may be related to the ankle and hip strategies that are used to maintain balance in healthy subjects. Generally, young, healthy, active individuals, like the ones in this study use the ankle strategy before the hip strategy for altering/correcting center of mass. Using the ankle strategy, an individual maintains postural control by firing the peroneal muscles.[13,61] In older individuals or those with ankle injuries, the gluteus medius and other hip abductors compensate for weakened ankle musculature and maintain postural control.[13,62,65] 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.[2,10,48,65] An increase in gluteus medius activity during sudden ankle inversion in healthy subjects as well as those with functionally unstable ankles was noted in an EMG study by Schmitz et al.[64] 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 proprioception group may have used the hip strategy to maintain balance during their training, and therefore, were able to improve strength in the gluteus medius without training, which may have affected the results of this study. It is proposed that the subjects performing the gluteus medius strength training exercises (gluteus medius strength and combination) had the greatest gains in SEBT reach distances because they trained the gluteus medius, the primary muscle involved with the hip strategy of dynamic postural control.

The randomized stratification used to divide subjects into four groups guaranteed that all active subjects were evenly distributed into the control and experimental groups. The descriptive statistics for the groups can be seen in Tables D1 and D2, which show similarities between all groups in many demographics including gender, age, height, and weight. Also, all of the subjects were relatively active individuals, but none would be classified as "high level" athletes. It is also suggested from the results that moderately active, healthy subjects will achieve gains in dynamic postural control in spite of the group into which they were placed. In addition, healthy subjects may require a training period in excess of the six-week program developed for this study. A training period of eight or ten weeks may have achieved more statistically significant results. The healthy subjects had no neuromotor dysfunction or other abnormality that may have predisposed them to poor dynamic postural stability. Therefore, the subjects in this study might not have acquired the benefits from any of the training programs that would be noted in subjects with functional ankle instability.

Despite the effect size for some of this study's data being moderate to large, the small sample size used for this study undoubtedly affected the significance and power. The groups started at 15 subjects each and finished with the gluteus medius strength group (n=13) having the most, the combination and proprioception groups (n=12) in the middle, and the control group having the fewest (n=11). If the groups each had 20 (N=80) or 30 (N=120) subjects finish the study, the results may have been much different.

Gluteus Medius Strength

The statistical analysis for gluteus medius strength testing did not yield any significant results with regard to our experimental hypothesis. There was no significant difference in gluteus medius strength measurements from pre-training to post-training between the two experimental groups performing six weeks of gluteus medius strength training and the control group. Also, there was no significant difference between the gluteus medius strength training groups and the proprioception and control groups for gluteus medius strength values. Therefore, the two experimental hypotheses for gluteus medius strength testing were rejected.

For this study, results for within subjects found significant main effects for test. Despite there being no significant differences for pre-test data among the subjects, overall pre-test to post-test gluteus medius strength values were notably different. The gluteus medius strength group showed the greatest improvement in gluteus medius strength (2.05 ± 1.31) followed by the combination group (1.70 ± 1.55) and the proprioception group (0.70 ± 0.71). The control group showed the least improvement (0.45 ± 0.91). Even though the between subjects factor for group was not significant, the graphs in Figures D11 and D12 show increases in gluteus medius strength among those who performed gluteus medius strengthening. In addition, a within subjects interaction was found significant for test by group. This interaction indicates that the specific test (either pre- or post-test) influenced the gluteus medius strength values recorded for the groups.

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

The exercises developed as a training program for strengthening the gluteus medius have not been evaluated collectively as being reliable or valid in the literature. They were typically used in a rehabilitation setting when attempting to strengthen a weak gluteus medius, and it is assumed from past studies that the gluteus medius muscle was involved while performing the exercises.[62,65,66] Wilson[65] used the functional method of strengthening the gluteus medius also employed in this study. He used healthy subjects to strengthen the gluteus medius by carrying a dumbbell in the contralateral hand. The subjects used a dumbbell in the range of five to 15 percent of the individual's body weight by walking while carrying the weight. The study determined through side-lying manual muscle testing as well as a standing Trendelenburg sign (dropping in contralateral hip during a unilateral stance) that this effectively strengthened the gluteus medius.[65] "Arc walking" is another strengthening method that Wilson[65] used in his study. In arc walking, the individual walks while attached to a secure structure by a resistance band. The individual then 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 a resistance was shown to strengthen the gluteus medius also using the side-lying manual muscle test and Trendelenburg sign.[65] The arc walking exercise utilized by Wilson[65] 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 for strengthening the GM in the clinical setting. Generally, the GM is strengthened using a side-lying straight leg raise as the hip is moved into abduction.[65,66] This is usually performed against an elastic resistance or an ankle cuff weight. Earl[62] suggests using the open kinetic chain exercise called hip hikes, or standing hip abduction.[62] This study utilized open kinetic chain exercises in both the side-lying and standing positions. The side-lying hip abduction exercise used in this study used a blue, or Extra Heavy, latex rubber resistance band while the standing hip abduction was performed on the multi-hip machine. Two other closed kinetic chain exercises normally performed as part of typical lower extremity rehabilitation and/or strengthening program were also included. Single-leg squats and lateral step-downs, although not found in rehabilitation or strengthening literature for strengthening the gluteus medius, are often used in the clinical setting. These exercises use an individual's body weight as resistance to strengthen the gluteus medius.

Most of the studies conducted on testing the strength of the gluteus medius have been performed on injured subjects with ankle sprains, iliotibial band pain, or patellofemoral pain syndrome and do not give any strengthening suggestions.[55,65,67] Another study recommends strengthening the gluteus medius when it is found to be in a weakened state because of its involvement in dynamic postural control and locomotion during gait.[66] This study by Ogiwara and Sugiura[66] suggested the use of progressive resistance exercises using a ten-repetition-maximum. Progressive resistance exercises have become the most commonly employed method for regaining the strength of the gluteus medius in the clinical setting, but there is not a simple way to determine an individual's ten-repetition-maximum to ensure adequate resistance for strengthening. Although ten-repetition-maximum is the suggestion by Ogiwara and Sugiura[66] for rehabilitating injured athletes, it may not have been the most appropriate choice for training healthy subjects when the goal is strengthening. The weight increments used did not place an overload force on the muscles, thus additional weight or exercises that are purely strength related are needed. Following the National Academy of Sports Medicine's[71] guidelines for strength training (four to six sets of one to five repetitions that are between 85 and 100 percent of an individual's one repetition maximum four times per week) for all gluteus medius strength training group exercises may have yielded significant results. A suggestion would be to perform exercises using 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.

This study has indicated some clinical significance in successfully improving gluteus medius strength in all groups, especially among those in the combination and gluteus medius strength groups. It is quite possible that the groups who performed these exercises did not perform enough sets and reps of these exercises or did not have enough resistance while performing them to maximize strength. Despite lack of significant differences between groups the subjects in the proprioception group were still able to benefit from a strengthened gluteus medius because of the proprioception training exercises being performed on one foot. Every exercise, including hopping and balancing on unstable surfaces, was performed in a unilateral dominant leg stance. However, there was no statistical significance between the groups which suggests the gluteus medius may require more than the exercises performed to increase strength.

Clinical Implications

Although this study presented statistical significance, the true benefits of this study lies in its clinical relevance. This study indicated that six weeks of proprioception 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 two groups that performed gluteus medius strengthening completed the study with greater increase in gluteus medius strength than did the proprioception and control groups. In addition the SEBT reach distances among the gluteus medius strengthening and combination groups demonstrated greater improvements in most SEBT reach directions when compared to the control and proprioception training groups.

This study will be beneficial in the clinical setting for increasing the dynamic postural control of healthy individuals. Improvements were seen in both Star Excursion Balance Test reach distances as well as gluteus medius strength recordings regardless of group. The combination group demonstrated the most improvements in SEBT reach distances while the gluteus medius strength training group demonstrated the most improvement in gluteus medius strength. The results indicate that in spite of the training performed for the six-week period, improvements were seen among all groups in both SEBT reach distances and gluteus medius strength. In summary, the use of proprioception exercises, gluteus medius strength exercises, or a combination of the two will help improve dynamic postural control among healthy, active individuals.

CONCLUSION

This study has indicated that a combination of gluteus medius strength training and proprioception training does not demonstrate an improvement in dynamic postural control more so than proprioception training alone. However, the enhancement of dynamic postural control recognized following six weeks of either gluteus medius strength training or proprioception training is clinically relevant. Although there was no significant difference between pre-test and post-test values of gluteus medius strength, it is apparent that the groups performing gluteus medius strengthening exercises showed improved gluteus medius strength. In the clinical setting, these training programs would be performed on individuals with lower extremity injuries, which should result in greater improvement in dynamic postural control using hip and ankle strategy. However, it is rare that an individual with a lower extremity injury will perform gluteus medius strengthening to increase dynamic postural control. This study indicates that, although not statistically significant, gluteus medius strengthening used as a supplement to a lower extremity rehabilitation program may improve dynamic balance greater than proprioception training alone.

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APPENDICES

APPENDIX A

THE PROBLEM

Research Question

There have been few studies conducted on gluteus medius strength and its effect on dynamic postural control of the lower extremity.[4,27,39,65-66] The studies that have been completed have found that individuals with weak hip abductors (the gluteus medius muscle in particular) are at risk to experience chronic ankle sprains. Although it is postulated that chronic ankle sprains are caused by faulty dynamic postural control of the lower extremity, these past studies have not attempted to verify if the weakness within the gluteus medius is connected to the changes that occur in dynamic postural control.[27,65,71] Nor have these 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), which are typically included in a rehabilitation program following an ankle injury, for their effects on dynamic postural control.[20,45,49]

Using observations like the ones developed by the National Academy of Sports Medicine's Performance Enhancement Specialist Certification, ATC's will find malalignments, abnormalities, and/or tight or weak muscles.[71] Generally, ATC's do their best to correct any and all of these findings in their athletes. Occasionally, however, some of the imbalances within the athletes are not recognized and are therefore not modified until an injury occurs. The weakness of the gluteus medius is one of those imbalances often not recognized or treated.

It is very rare that an individual trains to strengthen the gluteus medius muscle to increase dynamic postural control while using the hip strategy. The hip strategy, although most often seen in the elderly, is one of the two methods adopted by individuals for dynamic postural control. In this strategy, the gluteus medius is used to correct posture and keep an individual balanced and erect.[34,35,44] In the studies conducted thus far, it is apparent that a weak gluteus medius can lead to chronic ankle sprains.[71,72] Taking this analogy one step further, I would like to determine whether a change in the strength of the gluteus medius following a training program will help decrease the number of ankle sprains athletes may suffer.

Therefore, the following research question is being proposed: Will a six-week gluteus medius strength training program, when used in addition to typical proprioception training exercises performed as rehabilitation for lower extremity injuries, increase Star Excursion Balance Test reach directions in healthy subjects?

Experimental Hypotheses

1. There will be a significant difference in Star Excursion Balance Test reach distances in all eight directions from pre-training to post-training in the three experimental groups.

2. There will be a significant difference between the three experimental groups and the control group reach distances in all eight directions of the Star Excursion Balance Test.

3. There will be a significant difference between the proprioception training group and the combination group for Star Excursion Balance Test reach distances in all eight directions.

4. There will be a significant difference in Star Excursion Balance Test reach distances in all eight directions between the combination experimental group and the control group.

5. There will be a significant difference in pre-training to post-training gluteus medius strength values between the two experimental groups performing six-weeks of gluteus medius strength training and the control group.

6. There will be a significant difference between the gluteus medius strength training groups and the proprioception/control groups for gluteus medius strength values.

Assumptions

1. All participants in this study will meet all of the inclusion criteria while no participant shall be incorporated if (s)he meets any exclusion criteria. The inclusion criteria will be all individuals involved are healthy, college-aged subjects (18-25) with no lower extremity injuries in the past six months and no history of surgery on the dominant leg.

2. Participants will give maximum effort and perform to the best of his/her ability during training periods and pre/post testing.

3. The Star Excursion Balance Test will challenge the dynamic postural control of the lower extremity of the subject on the dominant leg.

4. The Star Excursion Balance Test is valid and reliable for assessing dynamic postural control.

5. The participants will be compliant with their designated training programs and will return for post-testing.

6. Six weeks of dynamic postural control training will cause a change in overall dynamic postural control.

7. Six weeks of gluteus medius strength training will cause a change in the strength of the gluteus medius muscle for hip abduction.

8. The principle investigator will be reliable in recording measurements for the Star Excursion Balance Test as well as gluteus medius strength.

9. The Lafayette MMT system is a valid and reliable method in assessing gluteus medius strength.

Delimitations

1. The small sample size may not be generalizable to the population as a whole.

2. Participants for the study are healthy college students from a single university.

Operational Definitions

1. Ankle Injury – Any harm caused to the distal tibia, distal fibula, tarsal bones, metatarsal bones, or ligaments, muscles, or tendons surrounding these bones when the ankle is placed in extremes of physiological ROM.

2. Ankle Instability – A decreased ability to stabilize oneself during any activity or during stationary standing caused by the ankle ligaments, musculature, or bones.[20,22]

3. Contralateral - Referring to the opposite side of the body.

4. Dominant Leg – Preferred leg used when kicking a soccer ball.

5. Dynamic Postural Control – The ability to maintain equilibrium when not in a static state (movement is occurring through jumping, walking, kicking, or some other activity).[19,47]

6. Gluteus Medius – A hip abductor that originates just below the iliac crest on the ilium and inserts into the greater trochanter.[66,71]

7. Golgi Tendon Organ – Receptors found at the junction of the tendons and muscle fibers that respond to both stretch and contraction of the muscle.

8. Hip Abduction – Moving the lower extremity at the hip joint away from the midline of the body (away from the contralateral lower extremity).

9. Hip Strategy – A method of maintaining dynamic postural control by concentrically contracting the gluteus medius instead of the peroneals.[34,44]

10. Joint Position Sense - The body's conscious awareness of joint position and movement resulting from the proprioceptive input to the central nervous system.[40]

11. Mechanoreceptor – A sensory receptor that responds to mechanical energy such as touch or pressure.

12. Muscle Spindle – Sensory receptors within the muscles that responds to stretch only.

13. One Repetition Maximum – Performing a muscle contraction using a resistance or weight at which the individual will only be able to perform one repetition.

14. Proprioception - The specialized variation of the sensory modality of touch that encompasses the sensation of movement (kinesthesia) and joint position (joint position sense).[12,59]

15. Rehabilitation – Exercises and modalities used in order to help promote healing and return a person with an injury to pre-injury state.

16. Stability – The ability to stabilize oneself while stationary or during movement on a flat or odd surface.[25]

17. Star Excursion Balance Test – A grid placed on a level floor that has eight lines extending at 45 degree increments from the center of the grid (anterior, anterolateral, lateral, posterolateral, posterior, posteromedial, medial, anteromedial) on which a

subject maintains a single-leg stance while reaching with the other leg to touch as far as possible along each line.[45,47,49,53]

18. Strength Training – Performing exercises (four to six sets of one to five repetitions) that are between 85 and 100 percent of an individual's one repetition maximum four times per week.[65]

19. Unilateral – Referring to one side of the body only (a unilateral stance is standing on one leg only).

Limitations

1. Participants may drop out of the study at any time.

2. Participants may not be compliant with the training programs.

3. Participants may not return to complete post-testing.

Significance of the Study

To the author's knowledge, this study will be the first in determining whether or not strength training of the gluteus medius muscle (which has been found to be weak in chronic ankle sprain athletes) will help increase dynamic postural control and strength of the gluteus medius muscle. This study is suggesting that chronic ankle sprains are caused by functional instability related to faulty neuromotor control within and surrounding the ankle. If this training program can show an increase in Star Excursion Balance Test scores following a six-week gluteus medius strength training program combined with a six-week dynamic postural control training program versus a six-week dynamic postural control training program alone, then the next step in the protocol would be to evaluate gluteus medius strength training following a chronic ankle sprain.

This study will hopefully bring new knowledge to ATC's as well as other allied health professionals and those that practice sports medicine. If this study is able to determine that performing gluteus medius strength training for six weeks (when added to dynamic postural control training) is more effective than a six-week dynamic postural control training program alone to increase Star Excursion Balance reach directions, then ATC's will be able to incorporate additional preventative measures for lateral ankle sprains. In an age where technology is advancing and in a setting where preventative techniques encompass new bracing and taping styles, ATC's could benefit from having knowledge of a simple prevention technique that will not cost them any additional time or money.

This study will provide alternative prevention techniques for ankle sprains. With better prevention comes less occurrence of injury and less days away from participation. I believe that if I am able to determine that gluteus medius training is as effective as dynamic postural control training in healthy subjects (or as a supplement to dynamic postural control training), this study can be repeated with subjects who experience chronic ankle sprains. If gluteus medius strength training can in fact increase Star Excursion Balance Test reaches (and therefore dynamic postural control), it is a simple way for the ATC to prevent chronic ankle injuries among his or her athletes. This will save the ATC hours a day by not having to spend valuable time taping ankles as well as being cost effective.

Finally, I hope to build upon the current knowledge base that exists in sports medicine in preventing chronic ankle sprains. If there is a more effective way to prevent injuries by increasing dynamic postural control in the lower extremity, then many people will benefit from this knowledge. ATC's will be able to more effectively treat athletes and keep them healthy, and the athletes will simply be able to participate in sports with less occurrence of chronic ankle sprains.

APPENDIX B

LITERATURE REVIEW

Introduction

Dynamic postural control training is often used in the clinical setting by both Certified Athletic Trainers (ATC's) and Physical Therapists (PT's) when rehabilitating ankle injuries.[17,21,37-43] The dynamic postural control and proprioception training has been shown to increase postural balance within the ankle that a sprain or strain may have caused.[37,38,48,76,77] However, strength training of the gluteus medius (GM) following an ankle injury has not been well established. Recent studies[2,36,20] have shown that the GM muscle is often temporarily weakened immediately following ankle sprains, and to the same extent, the GM was also found to be permanently weak in those individuals that suffer from chronic unilateral ankle sprains. The weakened GM may increase faulty dynamic postural control, alter the biomechanics of the entire lower extremity, and lead to faulty movements rendering individuals to be prone to future ankle injuries.[68,78,79] In order to understand the theory behind strength and/or dynamic postural control training programs, the anatomy of the ankle as well as that of the GM must first be understood. This review of the literature will address the following areas: the ankle; the GM; proprioception and neuromuscular control; dynamic postural control; and studies performed on proprioceptive training.

The Ankle

Ankle ligament injuries (sprains) are one of the most common injuries in sports today.[1-26,41,53] Eighty-five to ninety-five percent of all ankle ligament injuries are lateral ankle sprains caused by an inversion mechanism.[1,2,5,6,15,18,22,24,27] An estimated 10 to 45 percent of all injuries in running and jumping sports are ankle sprains.[1,2, 9,11,15,22,23] There are about 27,000 ankle sprains per day in the United States, or one per every 10,000 people.[1,11] Overall, about two million ankles are sprained each year.[80] Ten percent of all emergency room visits are deemed necessary because of ankle injuries.[9]

Subtalar joint anatomy: The subtalar joint is a plane synovial joint that encompasses the inferior surface of the talus and the superior surfaces of the calcaneus and navicular. The subtalar joint converts torque between the lower leg (internal and external rotation) and the foot (pronation and supination) with eversion and inversion motions.[13] There are two separate cavities within the subtalar joint: the posterior and the anterior. The floor of the anterior cavity is formed by the plantar calcaneo-navicular ("spring") ligament. The cavities are separated by the sinus tarsi and the canalis tarsi and have separate ligaments and joint capsules.[13] Despite their separation, the two cavities share an axis of rotation which is usually 42 degrees upwardly tilted and 23 degrees medially angled.[13,14] These cavities are more thoroughly described in detail in Table B1.

Table B1. Cavities of the Subtalar Joint[13]

Cavity	Surrounding Structures
Posterior Subtalar Joint	Inferior posterior facet of the talus and the superior posterior facet of the calcaneus
Anterior Subtalar Joint (A.K.A. talocalcaneonavicular)	Head of the talus, the anterior-superior facets, the sustentaculum tali of the calcaneus, and the concave proximal surface of the tarsal navicular

The talus is the primary weight-bearing bone in the ankle. It has been referred to as the mechanical keystone at the apex of the foot.[81] The talus has a body, a neck, and a head, and the superior portion, or the trochlea, articulates with the mortise formed by the tibia and fibula. Subtalar neutral is considered the most stable position for the talus to be in anatomically and biomechanically. Subtalar neutral, or a position in which joint measurements are taken occurs when the joint "locks in" while palpating the head and tail of the talus of a subject in a prone position. The foot should be moved into abduction and adduction until the head and tail are felt evenly under both the thumb and forefinger.[3]

The ankle ligaments can be divided into three groups: lateral, medial, and syndesmosis. The lateral ligaments are the most commonly sprained of the ankle ligaments. These ligaments are responsible for about 87 percent of the resistance to inversion of the talus when the ankle is non-weight-bearing.[27] During weight-bearing activities, however, the ligaments are the sole source of subtalar joint stability. The ligaments are described in detail in Table B2.

B2. Ligaments of the Ankle[9,13,82]

Ligament	Distal Attachment	Proximal Attachment	Function
Anterior Talofibular*	Neck of the talus	Lateral malleolus	Primary restraint against plantar flexion and internal rotation of foot and inversion
Calcaneofibular*	Lateral surface of calcaneus	Tip of lateral malleolus	Prevents inversion
Posterior Talofibular*	Lateral tubercle of the talus	Lateral malleolar fossa	Prevents inversion
Lateral Talocalcaneal*	Posterolateral calcaneus	Posterolateral talus	Prevents excessive inversion and supination
Cervical*	Cervical tubercle of calcaneus	Neck of the talus	Assists in prevention of inversion
Anterior Tibiotalar#	Superior posterior portion of navicular	Inferior medial malleolus	Prevention of eversion
Tibionavicular#	Sustenaculum tali of calcaneus & navicular bone	Inferior medial malleolus	Prevention of eversion
Tibiocalcaneal#	Sustentaculum tali of calcaneus	Inferior medial malleolus	Prevention of eversion
Posterior Tibiotalar#	Medial tubercle of talus and sustentaculum tali of calcaneus	Inferior medial malleolus	Prevention of eversion

* Lateral ligament
# Medial (deltoid) ligament

The motions of inversion and eversion occur at the subtalar joint. All of the muscles that act on the subtalar joint receive their vascular supply from the posterior tibial artery or the peroneal artery, a branch of the posterior tibial artery.[82] The inverters of the subtalar joint are the anterior and posterior tibialis muscles. The everters are the peroneals (tertius, longus, and brevis).[82] These muscles are described in detail in Table B3.

Table B3. Muscles Acting on the Subtalar Joint[82]

Muscle	Origin	Insertion	Action
Tibialis Anterior*	Lateral condyle and superior 1/2 of lateral surface of tibia^	Medial & inferior surfaces of medial cuneiform and base of 1st metatarsal	Dorsiflexion & inversion
Tibialis Posterior*	Posterior surface of tibia inferior to soleal line & posterior surface of fibula^	Tuberosity of navicular, cuneiform, & cuboid; bases of metatarsals 2,3, & 4	Plantarflexion and inversion
Peroneus Tertius*	Inferior 1/3 of anterior surface of fibula^	Dorsum of base of 5th metatarsal	Dorsiflexion & aids in eversion
Peroneus Longus#	Head & superior 2/3 of lateral surface of fibula	Base of 1st metatarsal & medial cuneiform	Eversion & plantarflexion
Peroneus Brevis#	Inferior 2/3 of lateral surface of fibula	Dorsal surface of tuberosity on lateral side of base of 5th metatarsal	Eversion & plantarflexion

* Innervated by deep peroneal nerve
\# Innervated by superficial peroneal nerve
^ Also originates on interosseous membrane

The peroneals are all dynamic stabilizers of the ankle as they are musculotendinous units that cross the subtalar joint. When static stabilizers are compromised, the dynamic stabilizers must compensate and keep the joint steady.[1,9,17] The talocrural joint, though it does not allow inversion or eversion, plays a role in LAS. Most LAS are caused by inversion combined with plantarflexion (a motion made possible by the talocrural joint). The muscles that cause dorsiflexion and plantarflexion at the talocrural joint of the ankle are described in Table B4.

Functional ankle instability: A positive history of LAS is a risk factor for future ankle injuries. Past LAS will decrease the static stabilizing mechanism of the lateral ankle ligament complex causing a "functional instability" within the ankle.[1,2,4,5,7,21,80] In fact, as many as 80 percent of all individuals suffering from LAS will have a re-injury at some point in the future.[7,8,10,14,19,22,41,53] Some thirty percent of the LAS sufferers will experience residual dysfunction more than nine months after the initial injury.[2]

Functional ankle instability is defined as recurrent ankle sprains over a period of time or a feeling of "giving way" in the foot and/or ankle as a result of articular deafferentation.[19,26,41]

Table B4. Muscles Acting on the Talocrural Joint[82]

Muscle	Origin	Insertion	Action
Gastrocnemius*	Lateral aspect of lateral femoral condyle & popliteal surface of femur above medial condyle	Posterior surface of calcaneus via calcaneal (Achilles) tendon	Plantarflexion with an extended knee
Soleus*	Posterior aspect of head of fibula, superior ¼ of posterior surface of soleal line of tibia & medial border of tibia	Posterior surface of calcaneus via calcaneal (Achilles) tendon	Plantarflexion independent of knee position
Plantaris*	Inferior end of lateral supracondylar line of femur & oblique popliteal ligament	Posterior surface of calcaneus via calcaneal (Achilles) tendon	Weakly assists plantarflexion
Flexor Hallucis Longus*	Inferior 2/3 of posterior surface of fibula^	Base of distal phalanx of hallux	Flexion of great toe & weak plantarflexion of ankle
Flexor Digitorum Longus*	Medial part of posterior surface of tibia inferior to soleal line & via a broad tendon to fibula	Base of distal phalanges of lateral 4 digits	Flexion of lateral 4 digits & plantarflexion of ankle
Extensor Hallucis Longus	Middle part of anterior surface of fibula^	Dorsal aspect of base of distal phalanx of great toes	Extension of great toe and dorsiflexion
Extensor Digitorum Longus#	Lateral condyle of tibia & superior 3/4 of medial surface of fibula^	Middle and distal phalanges of lateral 4 digits	Extension of lateral 4 digits & dorsiflexion of ankle

* Innervated by tibial nerve
\# Innervated by deep peroneal nerve
^ Also originates on interosseous membrane

Functional instability of the ankle, or the most common and serious residual disability after LAS, is defined as a motion beyond voluntary control but not exceeding the physiologic range of motion.[83] This is seen in individuals that have had a history of three or more LAS within the past five years.[84] It is recognized in 10 to 42 percent of those individuals suffering from an acute ankle sprain and results from altered proprioceptive sense.[5,6,27,11,12,14,18,20,22,27,30,48,76,84,85] Chronic ankle dysfunction and residual symptoms (pain, swelling, decreased range of motion) will be seen in 40-75 percent of LAS sufferers.[25] Mechanical instability, however, is an objective measurement of laxity within a joint. A mechanical instability of the ankle would be considered motion within the subtalar joint beyond the physiologic range of motion.[83] Although important, functional instability will be addressed more than with mechanical instability of the ankle.

Biomechanics: There are two areas of biomechanics: kinetics and kinematics. Kinetics is the study of forces that produce motion or maintain equilibrium. Kinematics, on the other hand, is the area that describes motion (through location, direction, and magnitude) without regard to the forces causing the motion.[38,86] Lower body, starting at the toes, forms a kinematic chain, or a series of joints linked together. Motion at one of the joints will cause motion at an adjacent joint, just as a malalignment at one joint may cause a compensation at a joint above or below.[86] Movement of the ankle cannot occur around only one axis. Ankle motion is a combination of dorsiflexion or plantarflexion along with slight internal or external rotation and anterior or posterior translation of the talus on the tibia.[87]

Ankle motion can be described in regard to the planes in which the motion is occurring and also the axes around which that movement is taking place. Dorsiflexion and plantar flexion of the ankle occur in the sagittal plane around a coronal. Also, some rotation occurs in the ankle mortise in both the transverse plane (abduction/adduction) about a vertical axis and the frontal plane (inversion/eversion) about an anteroposterior axis.[85] In neutral, the talocrural joint's true axis is considered to run through the fibular malleolus and the body of the talus. It then runs through or just inferior to the tibial malleolus. Considering the positioning of the malleoli, the axis is laterally rotated 20 to 30 degrees in the transverse plane and slanted about 10 degrees down on the lateral side.[85] Subtalar joint motion is a complex twisting that is the result of triplanar motion of the talus around a single oblique axis. Therefore the subtalar joint has only one degree of freedom into supination and pronation.[85] Ankle range of motion will vary between individuals, but generally, 20 degrees of dorsiflexion from neutral is considered normal. Plantar flexion measures will vary usually between 30 and 50 degrees from neutral.[85,88] Inversion and eversion values usually range between 30 to 35 and 25 to 20 degrees, respectively.[88]

Foot position may be abnormal in individuals with altered or deficient proprioceptive ability rendering the foot as an unstable base of support for the proximal lower extremity.[5] This instability may cause future ankle sprains or proximal problems at the knees, hips, pelvis, or low back. The proper biomechanical alignment of the lower extremity, when viewed from an anterior angle, shows a knee that is directly over its base of support and is neither in varus nor valgus. From the lateral view, the knee should not be more anterior than the toes during a squat. Also, the lower leg and back should be parallel during a squat and when landing from a height.[78] During landing, the body's weight is decelerated using trunk, hip, and leg musculature.[89] Joints of the lower extremity all work together and are linked by the kinematic chain. A dysfunction at one level will have an effect at multiple other levels throughout the chain.[39]

During weight acceptance, the subtalar joint moves into pronation in order to absorb shock. While pronated, the foot becomes more flexible (by "unlocking" at the midtarsal joint) for adjusting to uneven ground surfaces.[52] This pronation is better suited to help the foot maintain balance. When the foot is preparing for push off, it is supinated and much more rigid. In the supinated position, dynamic postural control is more difficult to maintain because of the smaller base of support provided. In individuals with functional ankle instability, the foot tends to supinate more easily and is then at risk for LAS.[52,86]

Compressive forces will vary throughout phases of gait as well as position of foot and ankle. In normal bilateral weight bearing, 77 to 90 percent of the force from the body's weight is transmitted through the tibial plafond to the talar dome. The remaining 10 to 23 percent is placed on the medial, or tibial, and lateral, or fibular, talar facets.[85] When inversion is increased, the force upon the medial facet is increased as is the force on the lateral facet during eversion. In the early stance phase of gait, the compressive forces transmitted to the ankle are less than 20 percent of body weight. The compressive force can be as high as five times body weight during the late stance phase of normal gait. In addition , a shear force of eight times body weight can act upon the ankle during heel off.[90]

Structural foot type may affect postural sway during static and dynamic postural control.[52] Hyperpronated and hypersupinated subtalar joints may be less able to control postural sway. Orthotics have been shown to significantly reduce postural sway in those with LAS. They provided an increased structural support to both the medial and lateral sides of the foot. This support does not allow the increased subtalar joint movement that occurs in LAS patients.[27]

The Gluteus Medius

The gluteus medius plays many important roles. It has been shown to become significantly active during midstance and terminal stance of gait in order to provide pelvic stabilization during a normal gait cycle.[64,65] The GM may also be a very important dynamic stabilizer of the hip and pelvis as well as the core during a sudden loss of balance.[64,65]

Gluteus medius anatomy: The gluteus medius is the primary hip abductor that also assists in hip internal rotation. Another important function of the GM is to keep the pelvis level when the contralateral lower extremity is raised.[82] Also, posterior fibers of the GM have been shown to aid in hip extension and external rotation while the anterior fibers assist internal rotation.[65]

Although the gluteus medius is found deep to the gluteus maximus, it can be palpated inferior to the iliac crest and posterior to the tensor fascia lata.[75,82] It is a “fan-shaped” muscle that originates on the external surface of the ilium between the anterior and posterior gluteal lines and inserts on the lateral surface of the greater trochanter of the femur. The GM gets its vascular supply from the superior gluteal artery and is innervated by the superior gluteal nerve.[82]

Biomechanics of the gluteus medius: The GM is a very important muscle of the lower extremity. It is the primary abductor of the hip as well as an important "anti-gravity" muscle of the lower extremity that is vital to postural control. It stabilizes the trunk and pelvis laterally during gait and single-leg standing.[66] When an injury occurs distal to the hip on the lower extremity, the kinematic chain above and below that site are altered. Generally, when an injury occurs at the ankle and the peroneal muscles cannot stabilize posture as they would prior to the injury, the GM will compensate. This theory will be further discussed in the Dynamic Postural Control section of this literature review.

Gluteus medius weakness: There have been reports of peroneal (evertor) muscle weakness following LAS as well as a weak peroneal muscle group being a positive risk factor for future LAS. [1, 2,16,48] Functional ankle instability has been shown to cause peroneal muscle weakness and increased peroneal reaction time.[2,48] However, little research has been conducted on the hip abductor group (the GM in particular) following LAS in the presence of functional ankle instability. Gluteus medius (GM) strength has, for the most part, been ignored when it comes to distal lower extremity injuries.[89] However, one study[62] noted an altered activation of the hip abductors associated with lower extremity injuries including LAS.

Generally, GM weakness has been associated with the elderly and those individuals with nervous system disorders. It is not often that the young, athletic population with no history of injury is evaluated for GM weakness.[65] It has been stated, however, that "the possibility that a localized joint injury could influence the strength of muscle remote from the site has implications for both preventative and therapeutic approaches."[91] One study[2] found a premature recruitment of hip musculature used to achieve dynamic postural control in individuals with unilateral poor functional ankle instability following a history of LAS. Both local sensation and motor function were shown to be altered on the ipsilateral hip muscles in patients with unilateral ankle sprains.[92] Another study[64] found a general weakness of ipsilateral hip musculature in individuals with unilateral LAS.

Gluteus medius strength has been found to be decreased in individuals with other lower extremity injuries as well. Subjects with patellofemoral pain have been shown to have significantly lower (about 26 percent) isometric hip abduction strength values than their healthy, age-matched counterparts.[55] Runners with iliotibial band syndrome have also demonstrated a weakness in hip abduction.[67] When weak, the gluteals cannot decelerate the landing appropriately by slowing the movements of internal rotation and adduction.[89]

There have been various measurement techniques developed for use in determining the strength of the GM. Performing isometric contractions of the GM has been performed in studies evaluating strength. One way is to have the subject in a side-lying position with a pillow between his or her legs to allow the superior leg (leg being tested) to be in about 10 degrees of abduction. A strap is then placed just proximal to the iliac crest and secured around the underside of the table to stabilize the subject's trunk. A hand-held dynamometer is then placed directly over the lateral knee joint and is held in place by another strap secured around the table. The subject is then asked to perform one practice trial of hip abduction then three experimental trials with 15 seconds of rest between each. The peak value is recorded from each of the three experimental trials.[55]

Other ways to test the GM strength are to look at EMG activity to note muscle activity or the Trendelenburg test for muscle weakness. Single leg squat and lateral stepdown exercises were performed in one study[13] that identified the GM as firing stronger when the participant was wearing foot orthotics as opposed to not wearing orthotics. Though it does not correlate well to isometric GM strength, the Trendelenburg test can be used to functionally examine the GM. The Trendelenburg test uses a single leg stance (SLS) as the level of the pelvis and hips is observed from a distance by the examiner. If the pelvis drops on the non-weight-bearing side, the GM (and other hip abductors) on the weight-bearing side are said to be weak.[36,56,65]

A single leg squat test further assesses the strength of the GM by having the participant perform a Trendelenburg test and then perform a squat once in a SLS position. The examiner again watches from a distance and assesses the GM strength. If the participant allows his or her knee to move medially (genu valgum) the GM is weak.[36,56] A manual muscle test of the GM with the individual side-lying is another appropriate method for assessing GM weakness. If the individual's GM is weak, he or she will compensate by also contracting the tensor fascia lata (flexing the hip), externally rotating, or contracting the quadratus lumborum ("hiking" the hip).[65] Finally, functional tests, such as jumping, hopping, and running, can be used as indirect measurements of muscular strength.[56]

Strength training: Rehabilitation exercises for LAS have traditionally included strength training of the peroneal and other dynamic stabilizing muscles of the ankle.[1,11] Six weeks of strength training of the peroneal muscles performed 3 times per week using Thera-Band latex tubing (increasing in intensity throughout the training period) showed improvements in joint position sense among individuals with functionally unstable ankles.[69] The GM however is rarely, if ever, strengthened following LAS despite its involvement in dynamic postural control.

Very often the GM is overlooked following LAS, and the peroneal muscles are instead the focal point of strengthening.[41] Most of the studies conducted on strengthening the GM have been prescriptive studies performed on injured subjects with iliotibial band pain or patellofemoral pain syndrome.[55,67] However, there has been little research establishing a link between strength training the gluteus medius following LAS.

Because of its involvement in dynamic postural control and locomotion during gait, it is essential to strengthen the GM when it is found to be in a weakened state.[66] One implication for strengthening the GM, as well as testing the strength of the GM, is progressive resistance exercises. Progressive resistance exercises, or PRE, were developed by DeLorme and are based on the principle of the ten-repetition-maximum, or 10 RM. The 10 RM is the "maximum load an individual can exert against gravity no more or less than 10 times with his/her maximum effort."[66] PRE has become the most commonly employed method for regaining the strength of the GM, but there still appears to be no simple way to calculate the 10 RM of the GM.[66]

Open kinetic chain (OKC) exercises, in which the distal segment (the foot in this case) is free-moving, are most often employed for strengthening the GM. Generally, the GM is strengthened using a side-lying straight leg raise as the hip is moved into abduction.[65,66] This can be performed against a resistance using a Thera-Band or an ankle cuff weight or against gravity alone. Another OKC exercise for GM strengthening is standing hip hikes (for abduction on the frontal plane).[62] A novel idea discussed by Wilson[65] shows a more functional method of strengthening the GM. It states that by carrying a weight in the contralateral hand somewhere between 5 and 15 percent of the individual's body weight, the GM will be strengthened.[65]

For general strengthening following an injury, Hertel and Denegar[38] suggests using high repetition, low resistance exercises prior to using high resistance exercises and power training. A six week rehabilitation protocol focused on GM strengthening in runners with iliotibial band syndrome indicated that 90 percent were pain free and returned to pre-injury activity level. Fredericson et al. hypothesized that the increase in hip abduction strength causes greater hip adduction and internal rotation during running and therefore minimized the valgus vector at the knee.[67] As hip flexion increases from 0 to 90 degrees, the moment arm of the GM increases. This puts the GM at a mechanical advantage to cause hip internal rotation.[64]

"Arc walking" is another strengthening method in which the individual walks with a resistance band around his or her waist that is tied off to a secure structure. The individual is instructed to walk in an arc around the origin of the resistance band while keeping his or her toes pointed at the band. The lateral sidestepping against a resistance will ensure that strengthening and postural control gains occur.[65] Overall, the GM is largely involved in lower extremity injuries and should therefore be included in all lower extremity rehabilitation programs.[64,96]

Proprioception and Neuromuscular Control

Proprioception is the special variance of the sense of touch that encompasses the sensation of joint movement, or kinesthesia, and joint position sense.[5,15,17,26,37,40,48,74] Joint position sense is a result from afferent input being sent to the central nervous system (CNS) from various sensory receptors and allowing precise movements and reflexes to occur.[37,74,92] If the afferent input is accurate, the efferent response will be a controlled, coordinated motion.[5]

Proprioception is also defined as "the reception of stimuli produced within an organism."[84] Proprioception uses both the peripheral nerves and the central nervous system integrated together to produce an awareness to one's surroundings.[84] Proprioception occurs when the Golgi tendon organs (receptors within the muscle that are sensitive to tension during muscle contraction) and muscle spindles (receptors within the muscle that sense muscle length and rate of length change) within the muscles along with the receptors in the skin, ligaments, and joint capsules sense movement and convey it to the CNS through neural afferent pathways.[42,74,76,84,92]

Mechanoreceptors are specialized neuroepithelial structures found in skin, ligaments, muscular, and tendons that surround joints.[93] Mechanoreceptors receive and send information about functional and mechanical deformation to the CNS. The information is translated into afferent neural signals that will increase when an increase in deformation occurs.[74,93] Specific cutaneous mechanorecptors are described in Tables B5.

Table B5. Specific Cutaneous Mechanoreceptors[74,75]

Type of Mechanoreceptor	Location	Sensory Information	Adaptation Rate
Pacinian Corpuscles	Deep dermis or hypodermis	Deep cutaneous pressure, vibration, & proprioception	Rapid
Meissner's Corpuscles	Dermal papillae of hairless skin	Touch, pressure, & slow vibrations	Rapid
Ruffini Ends	Dermis	Continuous touch or pressure & depression or stretch of skin	Slow
Hair Follicles	Along the axis of strands of hair	Light touch & bending of hair	Rapid

There are two types of muscle mechanoreceptors: muscle spindles and Golgi tendon organs (GTO's). Muscle spindles are sensititve to stretch while GTO's are sensititve to tension. Afferent neural fibers carry information from the muscle spindles to the CNS and then divide into branches that choose from one of several different pathways. One pathway completes the reflex arc by directly stimulating efferent motor neurons that lead back to the muscle(s) that was stretched. This reflex will cause a muscle contraction in response to the muscle being stretched. Golgi tendon organs (GTO's), however, will fire when a muscle/tendon is contracted and becomes tense. The firing activity of the GTO's afferent neuron supplies the motor control systems, in the brain and locally, with constant information regarding muscle tension. The basic purpose of the GTO's is to protect a muscle from damage by relaxing a muscle that is being contracted excessively. When the GTO's sense changes in tension within a muscle or tendon, they will transmit information along afferent pathways to the CNS. The efferent responses the CNS sends back are called polysynaptic reflexes. These reflexes inhibit the motor neurons of the contracting muscle causing it to relax before damage occurs. Simple descriptions of muscle mechanoreceptors can be found in Table B6.[27,74]

Table B6. Specific Muscle Mechanoreceptors[27,74,75]

Type of Mechanoreceptor	Location	Sensory Information	Adaptation Rate
Muscle Spindles	Muscle belly enclosed in connective tissue capsules	Sense changes in muscle length or rate of muscle length change and send that afferent information to the CNS	Slow
Golgi Tendon Organs	Tendons near musculotendinous junction	Sense changes in muscle tension or rate of musculotendinous tension change	Slow

Joint mechanoreceptors are sensitive to joint movements at the end ranges of motion. Joint mechanoreceptors will sense an increase in the tension of a ligament and send afferent messages to the spinal cord. The spinal cord then sends an efferent signal to the muscles surrounding a joint to slow or change the direction of the movement. The joint mechanoreceptors are also responsible for sensing and sending information to the spinal cord about joint position.[28] "Joint mechanoreceptors provide information to the visual, auditory and proprioceptive movement systems which aid in the regulation of balance."[48,74] There are four types of joint mechanoreceptors. They are described in detail in Table B7.

Table B7. Specific Joint Mechanoreceptors[74,75]

Type of Mechanoreceptor	Location	Sensory Information	Adaptation Rate
Type I	In stratum of joint capsule	Very slight movements & tension on the capsule	Slow
Type II	In synovial membrane & fibrous layers of joint capsule & fat pad	Very slight movements & tension on the capsule (at the end ranges of motion)	Rapid
Type III	In ligaments	Larger movements (at the end ranges of motion)	Slow
Type VI	Within joint	Noxious stimulus	Rapid

Once afferent information is sent upward, there are three levels of motor control within the CNS that can respond with an efferent motor response. The spinal cord is the first level of motor control. It is responsible for reflexes, direct motor responses to peripheral sensory information and simple patterns of motor coordination. The second level, the brain stem, helps control postural equilibrium through excitatory or inhibitory synapses. Finally, the third level is the cerebral cortex. The cortex encodes the muscles to be contracted, the magnitude of contraction, and the direction of movement. The cerebral cortex is also in charge of planning movements that will require activating more than one muscle.[42]

Proprioceptive sensation includes both the position sense of a static limb as well as the position of that limb as it moves through space.[84] Specifically at the ankle, it is the ability to detect motion of the foot and make postural adjustments in response to the motion detected.[48] The ability to sense the position of the foot prior to heel strike is of utmost importance when attempting to prevent LAS.[5,48] When an injury occurs in a joint, the joint loses its ability to gauge stresses placed upon it and react to it appropriately.[37,84] The ankle sprain itself might cause damage not only to the ligaments and the joint capsule but also to the neural structures within the capsule causing decreased neural afferent input and, therefore, neuromuscular control.[12,53,84] In fact, neural fibers have less tensile strength than do ligamentous fibers, and they are therefore damaged quite easily during joint sprains.[12] This decrease in neuromuscular control and so-called "joint deafferentation" following an injury may be the reason for re-injury.[12,37] Injuries may also cause a reduction in the velocity of nerve conduction.[53]

Injuries to the ankle will almost always cause an overall decrease in neuromuscular control and proprioception within the ankle.[53,84] Pain and swelling will inhibit normal neuromuscular control patterns by blocking the alpha efferent pathways while facilitating gamma efferent pathways. This will cause an inability of the individual to volitionally contract certain muscles around the injured joint while other muscles will reflexively spasm accompanied by hypersensitivity to joint movement and muscle stretching.[38]

Dynamic Postural Control

Dynamic postural control has been called "the single most important component of athletic ability" because it is required for all movements.[76] Dynamic postural control is needed for activities of daily living such as walking, stair climbing, and running.[47] Tools for determining dynamic postural control ability have been used to quantify the amount of functional impairment within the injured area, especially following LAS.[13] Nakagawa[19] states that assessing postural control with balance testing during closed-chained functional tasks provides information on the overall function of the joints and their proprioceptive and neuromuscular-control abilities.

It has been noted that "physical activity appears to be an important determinant of dynamic balance."[61] Raty[61] was able to show that continued involvement in athletics and light leisure activities lends itself to better dynamic postural control. Despite the fact of the importance of physical activity, there have been few studies performed to determine the effect of LAS on the performance of dynamic postural control tasks. It is hypothesized that individuals with LAS and/or functional ankle instability will exhibit decreased postural control statically and dynamically.[19] Riemann and Lephart[42] have stated that functional ankle instability or LAS will cause a disruption of postural control.

There are three levels of dynamic postural control: spinal, brainstem, and cognitive awareness.[37] The spinal level causes reflexes to occur with short, quick movements. Altered sensory receptors will impede the execution of reflex responses that are meant to occur for protective reasons.[38] The brainstem level receives information from the mechanorecptors located within the joints (somatosensory), the vestibular centers in the semicircular canals for equilibrium, and visual inputs from the ocular centers.[12,13,47,48,52,76,84] These three "balance senses" work together to maintain postural control at all times, and if one is impaired, the other two must compensate.[17,19,39,48] The final level, cognitive awareness, is associated with joint and body position. This level determines fine motor movements and muscle memory from repetition of motions.[37,52]

Postural control, often more simply referred to as balance, is often measured by having an individual stand on one foot for as long as possible.[20,52,84] Variations can be added to challenge the individual performing the test. Closing the eyes, varying the trunk position or standing surface, and adding arm or leg movements are simple additions to make balancing more challenging.[26,37,60] Balance, in essence, is maintaining the body's center of mass (COM) over the body's base of support (the feet) or a "physical equilibrium" in order to stay in an upright position.[13,47,52,84,96] The body uses a "reflex mechanism" to maintain the body's COM over the feet.[22]

There are two strategies for maintaining dynamic postural control. The younger, healthy, active population generally uses the ankle strategy for altering/correcting COM. In the ankle strategy, the postural control is preserved by firing the lateral peroneal (everting) muscles of the ankle.[13,61] In the older population or in other cases when the ankle provides inadequate sensory information regarding kinesthesia and joint position sense, the hip musculature (the GM in particular) will compensate and maintain postural control. This proximal compensation to postural sway of COM is often seen in LAS individuals and those with functional instability in the ankle.[2,10,48] A study discussed by Schmitz et al.[64] showed an increase in GM activity during sudden ankle inversion in healthy and in functionally unstable ankle subjects. Further, the GM controls the lateral weight transfer during forward oriented whole body movements.[61] Runge[44] states "postural tasks that require 'hip strategy' to maintain equilibrium may be more dependent upon vestibular input for response selection and control than other tasks." It has been shown that patients with vestibular deficiencies will fail to initiate the hip strategy while healthy individuals generally switch to a hip strategy from an ankle strategy and will instead fall or take a step.[44]

Individuals with functional ankle instability were shown to take a significantly longer amount of time to restore their single leg postural control following sudden inversion perturbations than did healthy control subjects. Functional ankle instability will allow the COM to traverse outside the base of support caused by decreased proprioceptive input.[10,39,76,92] It is suggested that an individual with a functional ankle instability will make postural corrections at the hip more often than will those healthy individuals without ankle instability.[51] One study[95] found female soccer players with LAS were more likely to use the hip strategy during SLS on the injured leg while they used the ankle strategy for postural corrections on the uninjured side. The examiner stated that the change in postural control strategy can be attributed to the alteration in weight-bearing forces at the subtalar joint following LAS. Another author suggests the use of orthotics to correct the subtalar joint will return the individuals to the ankle strategy or postural control.[51] These balance corrections are triggered by the proprioceptive capabilities of both the lower extremity and the trunk.[94]

It has been suggested that the increased postural sway and, therefore, decreased postural control and balance can be attributed to the disturbance of proprioceptive sensory receptors.[19] One study[95] found that postural sway increases even if a few sensory inputs have been disrupted.

Also, dynamic postural control, like joint position sense and kinesthetic awareness, may also be decreased by fatigue.[10]

Studies on Proprioceptive Training

Proprioceptive training is often less addressed during rehabilitation than are restoring full range of motion (ROM) and functional strength.[84] Proprioceptive training is very important following an injury because it allows for dynamic joint stability and prevents excessive strain on the joints and muscles, especially in the physically active.[15,27,37,38,41,48,52] The goal of proprioceptive training following an injury is to retrain the afferent pathways to enhance the sensation of joint movement.[40] Closed kinetic chain (CKC) exercises have been shown to redevelop lower extremity neuromuscular control following an injury.[12,37]

There have been a large number of proprioception training programs developed in prescriptive studies following lower extremity injuries as well as others that are merely attempting to increase the lower extremity's proprioceptive ability. They recommend using single leg standing and then progressing to wobble boards and ankle discs.[17,84] One study[76] suggests using T-Band kicks with a heavy resistance while unilaterally standing, also called "steamboats." The study used 50 kicks in each of four directions (medial, lateral, anterior, and posterior). The study also had the subjects perform square hopping 4 times for 20 seconds. In addition, single-leg standing was included in the study on a foam surface for 3 sets of 20 seconds. Finally, the subjects were placed in a single-leg stance on a BAPS board (between level 3 and 5) for 3 sets of 20 seconds.[76]

Also, fatigue, much like injury, may impair the kinesthetic and joint position sensation properties of joint structures.[10,74] Because "functional (ankle) instability stemming from neuromuscular and proprioceptive deficits is hypothesized to be a major contributing factor to chronic ankle instability," it is vital to re-train the ankle for proprioception and neuromuscular control following LAS.[53]

Postural awareness should be stressed throughout the rehabilitation of all injuries in order to avoid undo stress on the body, especially injured areas.[38] It has been reported that six weeks of disk balance training and coordination balance training greatly improved dynamic postural control in most subjects.[48] Dynamic postural control is often accomplished through a functional task while maintaining one's base of support.[45,46] Dynamic postural control exercises must be included in the rehabilitation of an injured joint.[10-12,17,21,46,53,77,84]

Five studies have been performed on proprioception training on healthy subjects as well as following an injury and in those with a chronic instability. Studies by Blackburn et al.[59] and Powers et al.[41] used Thera-Band kicks (tying an elastic resistance to the contralateral ankle and performing quick kicks while maintaining a single leg stance) for six-weeks for proprioception training. The Blackburn et al. study showed significant difference between the proprioception training group and the control group for dynamic balance. However, the Powers et al. study found no significant difference between pre-test and post-test results for static balance in any group. Riemann et al.,[60] using a BAPS board for four-weeks to train proprioception, found no significant differences for postural control but did find significant differences in ankle kinesthesia between the experimental and control groups. Finally, studies by Piegaro[57] and Bernier and Perrin[48] both used a combination of balance training on fixed and unstable surfaces as well as hopping exercises. Bernier and Perrin's six-week program achieved significant differences on anterior/posterior and medial/lateral modified equilibrium scores between groups. Piegaro[57] used the same program as Bernier and Perrin but shortened it to four-weeks. He found significant differences in pre-test to post-test anterior reach direction distances among those in the experimental group. These studies are briefly described in Table B8 below. This study uses a proprioceptive program to the exact specifications of the Bernier and Perrin study.

Table B8. Proprioception Training Studies

Author	Subjects	Training Period	Results
Piegaro[57]	39 healthy college students	4 weeks	Significant differences from pre-test to post-test reaches into anterior direction of SEBT
Bernier and Perrin[48]	48 individuals between 18 and 32 with a history of chronic ankle instability	6 weeks	Significant differences from pre-test to post-test in anterior/posterior and medial/lateral directions of modified equilibrium score
Blackburn et al.[59]	32 physically active healthy individuals between 18 and 25	6 weeks	Significant difference in dynamic balance between control group and proprioception experimental group
Powers et al.[41]	38 individuals with a mean age of 21.6 with functional ankle instability	6 weeks	No significant differences in any group pre-test to post-test regarding static balance
Riemann et al.[60]	26 healthy recreationally active individuals	4 weeks	Significantly increased ankle kinesthesia, no significant difference in postural control

Summary

The ankle is one of the most commonly injured joints in the body. The ankle is a distal link of the kinematic chain. When injured or unstable, other structures must compensate for the ankle. The gluteus medius is often found to be weak in individuals with lower extremity injuries. Lower extremity injuries, including lateral ankle sprains, will cause disturbances of the normal proprioceptive receptors. With decreased proprioceptive ability and neuromuscular control, dynamic postural control is diminished. Dynamic postural control is a vital part of the rehabilitation of any injury and can be assessed using the star excursion balance test.

APPENDIX C

ADDITIONAL METHODS

Table C1. Informed Consent

THE COMPARATIVE EFFECTS OF A SIX-WEEK BALANCE TRAINING PROGRAM, GLUTEUS MEDIUS STRENGTH TRAINING PROGRAM, AND COMBINED BALANCE TRAINING/GLUTEUS MEDIUS STRENGTH TRAINING PROGRAM ON DYNAMIC POSTURAL CONTROL

Introduction

I, _________________________, have been invited to participate in this research study, which has been explained to me by Vincent J. Leavey, ATC, PES. He is conducting this research under the supervision of Michelle A. Sandrey, PhD, ATC to fulfill the requirements for a master's thesis in Athletic Training in the School of Physical Education at West Virginia University.

Purpose of the Study

The purpose of this study is to determine if gluteus medius muscle strength training, proprioception training, or a combination of the two will have an affect on dynamic postural control.

Description of Procedures

This study will be conducted at HealthWorks Rehab & Fitness, 943 Maple Drive, Morgantown, WV 26505.

Orientation Procedures
At an orientation meeting the purpose of this study will be explained to me. I will be given an informed consent form explaining my rights as a research subject and a demographic/inclusion criteria questionnaire. If I am one of sixty eligible subjects, I will be contacted by the principal investigator and will schedule a time for my testing. I will have a one in four chance of being randomly assigned to either of the training groups or the control group. I will be asked for my full cooperation and to work to the best of my ability. My involvement in this will initially take sixty minutes for a pre-testing session. This will be followed by meeting with the researcher three times a week for twenty minutes over a six week period. A final sixty minutes of post-testing will conclude my participation.

Interventions

I will be tested using the Star Excursion Balance Test. Testing will be administered and supervised by the principal investigator at HealthWorks Rehab & Fitness, 943 Maple Drive, Morgantown, WV 26505. Prior to testing, the device and procedure will be explained to my satisfaction.

THE COMPARATIVE EFFECTS OF A SIX-WEEK BALANCE TRAINING PROGRAM, GLUTEUS MEDIUS STRENGTH TRAINING PROGRAM, AND COMBINED BALANCE TRAINING/GLUTEUS MEDIUS STRENGTH TRAINING PROGRAM ON DYNAMIC POSTURAL CONTROL

I will have my leg length measured prior to testing in order to normalize my scores to my height. A tape measure will be used to measure the distance between the top of my hip bone to the center of the ankle on the same leg. I will warm up on a stationary bike for 10 minutes at a self-selected pace and then stretch my quadriceps, hamstrings, and calves for 5 minutes. I will then take a five minute break. Next I will be instructed to stand in the center of the Star Excursion Balance Test on my dominant leg (leg I would use to kick a ball). I will be instructed to reach with my non-dominant leg as far as possible down one of the eight lines which will be randomly selected using a series of index cards. The lines are to the following directions: front, front right corner, right, back right corner, back, back left corner, left, and front left corner. If I am reaching with my right leg, I will start with the direction on the index card I choose randomly and then go around the star in a counterclockwise manner and clockwise if I am reaching with my left leg. I will be instructed to hold the position of furthest reach for two seconds. I will reach as far down each line as I possibly can without losing my balance six times as practice to become familiar with the test. I will then take a five minute break and then will complete three test trials down each of the eight lines with fifteen seconds of rest between each trial. The average of my three trials will be recorded.

Trials will be discarded and repeated if I am unable to maintain my balance at any point in the trial and place my non-dominant foot on the floor. While performing on the Star Excursion Balance Test, it is likely that I will not lose my balance because I will be performing the test with my eyes open. However, I will be instructed to touch down with my non-dominant leg if I feel I am losing my balance. The principal investigator will also be standing beside me if I am unable to touch down with my non-dominant leg.

Following each test, the primary investigator will record the distances of each trial on a data sheet. If all data has been correctly recorded, my testing session will be completed. At this time, I will be asked by the primary researcher for any questions or comments. A time will then be set for my gluteus medius strength to be tested.

On a separate date, I will have my hip abduction (moving one leg away from the other leg) strength tested using a Lafayette Manual Muscle Test System (Model 01163, Lafayette

Industries, Lafayette, IN). Testing will be administered and supervised by the principal investigator at HealthWorks Rehab & Fitness, 943 Maple Drive, Morgantown, WV 26505. Prior to testing, the device and procedure will be explained to my satisfaction.

First I will be weighed using a digital scale to normalize my scores to my body weight. I will lie on my side (opposite of my dominant leg) on a table. I will slightly abduct my dominant leg. A strap will then be wrapped under the table and over my dominant leg just above my knee. A Manual Muscle Test System will then be placed under the strap to measure the force I produce into hip abduction. I will then complete 3 trials of hip abduction. During each trial, I will abduct my hip by taking 2 seconds to build up force and then hold that maximal effort for 4 seconds. I will rest for 15 seconds between each trial.

Following each test, the primary investigator will record the distances of each SEBT trial and each trial of gluteus medius strength outputs on data sheets. If all data has been correctly recorded, my testing session will be completed. At this time, I will be asked by the primary researcher for any questions or comments.

The data from my testing session will be averaged with the data from the rest of the subjects for analysis.

This entire process for SEBT and gluteus medius strength will be repeated at the conclusion of my six week training period.

After the initial testing, I will perform a six week training period. According to the group I am randomly assigned to, I will perform those exercises with the researcher three times a week for twenty minutes per session. If I am randomly assigned to the control group, I will contact the researcher once a week to let them know which other activities outside daily activities I have been participating.

If I am in the control group, I will perform the pre- and post-testing procedures. I will not perform any of the training exercises of the other groups.

If I am in the proprioception training group, I will perform exercises that involve balancing exercises and exercises that will train my joint position sense in my dominant leg. I will perform a battery of exercises that have been proven to improve my proprioception. The exercises I will perform will change from week to week but will include balancing on a fixed surface, balancing on a tilt board, balancing on a wobble board, and functionally hopping.

If I am in the gluteus medius strength training group, I will perform exercises to strengthen hip abduction on my dominant leg. I will perform 6 exercises including side-lying hip abduction with an elastic band, walking with a dumbbell in my non-dominant hand at a weight adjusted for my body weight, sideways walking with an elastic band tied around my knees, hip abduction on a machine, and single leg squatting.

If I am in the combination group, I will perform the exercises from both the gluteus medius strength training group as well as the proprioception training group.

THE COMPARATIVE EFFECTS OF A SIX-WEEK BALANCE TRAINING PROGRAM, GLUTEUS MEDIUS STRENGTH TRAINING PROGRAM, AND COMBINED BALANCE TRAINING/GLUTEUS MEDIUS STRENGTH TRAINING PROGRAM ON DYNAMIC POSTURAL CONTROL

Risks and Discomforts

There are no known or expected risks from participating in this study. The only known or expected discomfort may be mild muscle soreness in my dominant lower extremity with performing the proprioceptive and/or strength exercises. While performing on the Star Excursion Balance Test, it is likely that I will not lose my balance because I will be performing the test with my eyes open. However, I will be instructed to touch down with my non-dominant leg if I feel I am losing my balance. The principal investigator will also be standing beside me if I am unable to touch down with my non-dominant leg. Some soreness may be experienced in my hip following gluteus medius strengthening. There may be some soreness experienced in my lower leg following the balance training exercises, but it should be minimal at worst. Should any injury occur, I understand that Vincent J. Leavey, ATC, PES will provide first aid and make any necessary medical referral at my expense.

Alternative

I understand that I do not have to participate in this study. No negative actions will be taken against me if I choose not to participate.

Benefits

I understand that this study is not expected to be of direct benefit to me, but the knowledge gained may be of benefit to others.

Financial Considerations

I understand that I will receive no monetary compensation for completing this study.

Contact Persons

For more information about this research, I can contact Vincent J. Leavey, ATC, PES at (609) 680-4981 or at vleavey@mix.wvu.edu or, Michelle A. Sandrey, PhD, ATC at (304) 293-3295 Ext. 5220 or at msandrey@mail.wvu.edu. For information regarding my rights as a research subject, I may contact the Executive Secretary of the Review Board at (304) 293-7073.

Confidentiality

I understand that any information about me obtained as a result of my participation in this research will be kept as confidential as legally possible. Identifying information on the informed consent form and demographic/injury history questionnaire will be kept confidential by assigning a code number to each informed consent form and demographic/injury history questionnaire.

I understand that my research records and test results, just like hospital records, may be subpoenaed by court order. In any publications that result from this research, neither my name nor any information from which I might be identified will be published without my consent.

Voluntary Participation

Participation in this study is voluntary. I understand that I am free to withdraw my consent to participate in this study at any time and that such refusal to participate will not affect my future care, my employee status at West Virginia University, or my class standing or grades. Refusal to participate or withdrawal will involve no penalty to me. I have been given the opportunity to ask questions about the research, and I have received answers concerning areas I did not understand. In the event new information becomes available that may affect my willingness to continue to participate in this study, this information will be given to me so I may make an informed decision about my participation.

Upon signing this form I will receive a copy.

I willingly consent to participate in this research.

Signature of Subject Date/Time

Signature of Principal Investigator Date/Time

Table C2. Authorization to Use or Disclose Protected Health Information

Authorization to Use or Disclose Protected Health Information (PHI)

West Virginia University

I hereby voluntarily authorize the use or disclosure of my individually identifiable health information as described below.

Patient Name:	____________________	ID Number:	____________________
Date of Birth:	____________________	IRB Protocol #:	16727

Persons/organizations providing the protected health information (e.g. hospitals):

Individual subjects affiliated with West Virginia University Athletic Training and West Virginia University Club Sports & Intramurals

Persons/organizations receiving the information (e.g. investigators, clinical coordinators, sponsor, FDA):

Vincent J. Leavey, ATC, PES
Michelle A. Sandrey, PhD, ATC

The following information will be used:

A self-report injury history questionnaire (lower extremity injuries within the past six months, surgery to the lower extremity in the past year, visual disorders, nerve problems, medications being taken that may affect balance, or chronic ankle injuries).

The information is being disclosed for the following purposes (Start with the Title of the study and include additional information e.g. screening and recruiting subjects; analyzing research data, or other specified purposes):

The Comparative Effects of a Six-Week Balance Training Program, Gluteus Medius Strength Training Program, and Combined Balance Training/Gluteus Medius Strength Training Program on Dynamic Postural Control. Information will be used to screen subjects for inclusion and exclusion criteria of the study.

I may revoke this authorization at any time by notifying the Principal Investigator in writing at:

Vincent J. Leavey , ATC, PES
School of Physical Education
P.O. Box 6116
Morgantown, WV 26505

If I do revoke my authorization, any information previously disclosed cannot be withdrawn. Once information about me is disclosed in accordance with this authorization, the recipient may redisclose it and the information may no longer be protected by federal privacy regulations.

Authorization to Use or Disclose Protected Health Information (Contd.)

I may refuse to sign this authorization form. My clinical treatment may not be affected by whether or not I sign this form. I may not be allowed to participate in the research if I do not sign the form.

This authorization will expire on the date that the research study ends. (Other options for expiration include an actual date of expiration, occurrence of a particular event, or "none" if the authorization will have no expiration date.)

Expiration date:

I will be given a copy of this authorization form.

Signature of subject or subject's legal representative Date
(Form MUST be completed before signing)

Printed name of subject's legal representative
Relationship to the subject Initials
Parent
Medical power of attorney/representative
Legal guardian
Health care surrogate

Table C3. Subject Demographics

Code:______________________________
Age:__________________
Gender: Male/Female
Year in School: Freshman/Sophomore/Junior/Senior/Graduate Student

Injury History

1. Have you had a lower extremity injury within the past six months? Yes/No
If yes, please explain:____

2. Have you had an upper extremity injury within the past six months? Yes/No
If yes, please explain:____

3. Have you had a head injury within the past six months? Yes/No
If yes, please explain:____

4. Have you had any neurological disorders within the past six months? Yes/No
If yes, please explain:____

5. Have you had any vestibular disorders within the past six months? Yes/No
If yes, please explain:____

6. Have you had visual disorders within the past months? Yes/No
If yes, please explain:____

7. Are you currently involved in any of the following physical activities?
Weight Training/Cardiovascular Training/Pilates/Yoga/Other
If yes, please explain what physical activity you are involved in and how often
you are involved in each activity:__________________________________

8. Are you taking any medications that affect balance? Yes/No
If yes please explain:____

9. Do you have a history of chronic ankle instability? Yes/No
If yes please explain:____

10. Are you currently in a training program for balance? Yes/No
If yes please explain:____

Table C4. Proprioception Training Program

Week 1	Week 2	Week 3	Week 4	Week 5	Week 6
Fixed surface, eyes open (FEO)	Same as week 1	FEO	FEC	FEC	FEC
Fixed surface, eyes closed (FEC)		FEC	FPO	FPO	FPO
Fixed surface, picking up objects (FPO)		FPO	TEO2 X2	TEO2	TEO2
Tilt board, DF/PF, eyes open (TEO1)		TEO2	TEC2 X2	TEC2	TEC2
Tilt board, DF/PF, eyes closed (TEC1)		TEC2	WEO X2	WEO X2	WEO
Tilt board, INV/EV, eyes open (TEO2)		TEO3	WEC X2	WEC X2	WEC
Tilt board, INV/EV, eyes closed (TEO3)		TEC3		Functional hop, eyes open (FHO) X2	FHO X2
Tilt board, diagonal placement, eyes open (TEO3)		WEO X2			Functional hop, eyes closed (FHC)
Tilt board, diagonal placement, eyes closed (TEC3)	Wobble board, eyes open (WEO) X2	Wobble board eyes closed (WEC)			

Key: Week 1: 15 seconds each, 45 seconds of rest between exercises, Week 2: 20 seconds each, 40 seconds of rest between exercises, Week 3: 25 seconds each, 35 seconds of rest between exercises, Week 4: 30 seconds each, 30 seconds of rest between exercises, Week 5: 30 seconds each, 30 seconds of rest between exercises, Week 6: 30 seconds each, 30 seconds of rest between exercises

Table C5. Gluteus Medius Strength Training Program

Weeks 1 & 2	Weeks 3 & 4	Weeks 5 & 6
Side-lying hip abduction (SLAB), blue T-Band, 3x10	SLAB, blue, 3x15	SLAB, blue, 3x20
Walking w/ weight opposite hand (WW), 3 min, 5% BW	WW, 10% BW	WW, 15% BW
Gorilla walking (GW), blue T-Band, 3x20s	GW, blue, 3x30s	GW, blue, 3x40s
Multi-hip abduction (MHAB), 50% test value, 3x10	MHAB, 60%, 3x10	MHAB, 70%, 3x10
Single-leg squat (SLS), 2x5	SLS, 3x5	SLS, 4x5
Lateral step-downs (LSD), 2x5	LSD, 3x5	LSD, 4x5

Table C6. Star Excursion Balance Test Instructions (Pre- and Post-Test)

1. Subjects had their leg length measured in inches and recorded to normalize their excursions to their height.

2. They underwent a warm-up session of five minutes on a stationary bicycle at 120 revolutions per minute.

3. The subjects took a five minute break.

4. Subjects selected an index card to randomly determine in which direction they will start.

5. Subjects were instructed to stand in the center of the star grid and maintain a single-leg stance while reaching with the opposite leg to touch as far as possible along the randomly chosen reach direction.

6. Subjects were instructed to touch the farthest point possible as light as possible along a chosen reach direction with the most distal part of their reach foot.

7. Subjects whose reaching leg is the right went around the star grid in a counterclockwise fashion while subjects whose reaching leg is the left went around the star grid in a clockwise fashion.

8. Subjects were instructed to perform six practice trials in each of the eight excursions with a 15-second rest between each excursion.

9. After a five minute rest following the last practice trial, testing began.

10. Three trials were performed in each of the eight excursions with a 15-second rest between each reach.

11. Trials were discarded and repeated if the reach foot was used to provide considerable support when touching the ground, if the subjects' stance foot was lifted from the center of the star grid, or if the subjects were not able to maintain their balance at any point in the trial.

12. The average excursions for each reach direction were calculated and recorded.

13. The average excursions for each reach direction were divided by leg length and multiplied by 100 to determine each subject's dynamic balance score in each of the eight reach directions.

Table C7. Pre-Test Data Collection Sheet for the Star Excursion Balance Test

Pre-Test Data Collection Sheet for the Star Excursion Balance Test

Subject Number:______________________________
Age:____
Gender: Male/Female
Height:______________________________________
Weight:______________________________________
Right Leg Length:_____________________________
Left Leg Length:______________________________
Dominant Lower Extremity: Right/Left

Excursion	Trial 1	Trial 2	Trial 3	Average
Anterior				
Anteromedial				
Medial				
Posteromedial				
Posterior				
Posterolateral				
Lateral				
Anterolateral				

Table C8. Post-Test Data Collection Sheet for the Star Excursion Balance Test

Post-Test Data Collection Sheet for the Star Excursion Balance Test

Subject Number:____________________
Age:__________________________
Gender: Male/Female
Height:________________________
Weight:________________________
Right Leg Length:__________________
Left Leg Length:___________________
Dominant Lower Extremity: Right/Left

Excursion	Trial 1	Trial 2	Trial 3	Average
Anterior				
Anteromedial				
Medial				
Posteromedial				
Posterior				
Posterolateral				
Lateral				
Anterolateral				

Table C9. Gluteus Medius Strength Testing Instructions (Pre- and Post-Test)

1. Subjects were weighed using a digital scale.

2. Subjects were positioned side-lying on a treatment table. The hip was at approximately 10 degrees of abduction prior to testing.

3. The force pad of the manual muscle testing system was placed just above the knee joint on the lateral femoral condyle.

4. The subjects took three practice trials and three trials to be recorded.

5. The dynamometer was zeroed, and then the subject was instructed to push the leg upward gradually building up force for two seconds and then a maximal effort for four seconds.

6. The value on the dynamometer was recorded and then the dynamometer was zeroed out again before the next trial.

7. The subjects had 15-seconds of rest between trials.

Table C10. Pre-Test Data Collection Sheet for Gluteus Medius Strength

Pre-Test Data Collection Sheet for Gluteus Medius Strength

Subject Number:______________________________
Age:____
Gender: Male/Female
Height:______________________________________
Weight:______________________________________
Dominant Lower Extremity: Right/Left

Trial 1	Trial 2	Trial 3	Average

Table C11. Post-Test Data Collection Sheet for Gluteus Medius Strength

Post-Test Data Collection Sheet for Gluteus Medius Strength

Subject Number:______________________________

Age:____

Gender: Male/Female

Height:______________________________________

Weight:______________________________________

Dominant Lower Extremity: Right/Left

Trial 1	Trial 2	Trial 3	Average

Figure C1. Subject Performing Fixed Surface Balancing

1. Subject unilaterally stands on dominant leg on a flat, fixed surface.

2. Subject maintains balance unilaterally on flat surface for specified period of time corresponding to week of training.

Figure C2. Subject Performing Tilt Board Balancing in the Dorsiflexion/Plantar Flexion Direction

1. Subject unilaterally stands on dominant leg on a tilt board that is set for dorsiflexion/plantar flexion.

2. Subject maintains balance unilaterally on tilt board for specified period of time corresponding to week of training.

Figure C3. Subject Performing Tilt Board Balancing in the Inversion/Eversion Direction

1. Subject unilaterally stands on dominant leg on a tilt board that is set for inversion/eversion.

2. Subject maintains balance unilaterally on tilt board for specified period of time corresponding to week of training.

Figure C4. Subject Performing Tilt Board Balancing with a Diagonal Placement

1. Subject unilaterally stands on dominant leg on a tilt board that is set on a diagonal.

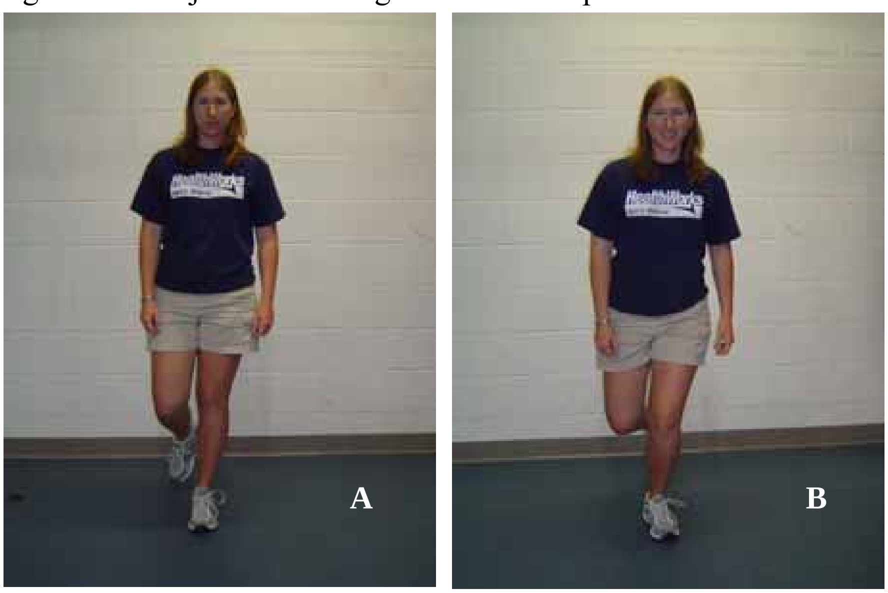
2. Subject maintains balance unilaterally on tilt board for specified period of time corresponding to week of training.

Figure C5. Subject Performing Wobble Board Balancing

1. Subject unilaterally stands on dominant leg on a wobble board.

2. Subject maintains balance unilaterally on wobble board for specified period of time corresponding to week of training.

Figure C6. Subject Performing Functional Hop Exercise



1. Subject unilaterally stands on dominant leg on a flat surface in box marked “Start.” (Figure A)

2. Subject performs a single-leg hop from “Start” box to box marked “1.”

3. Subject achieves balance in box “1.” (Figure B)

4. Subject repeats steps 2 and 3 along the functional hop pattern until box “6” is reached.

5. Subject begins once again at box marked “Start” until 30 seconds has passed.

Figure C7. Functional Hop Pattern

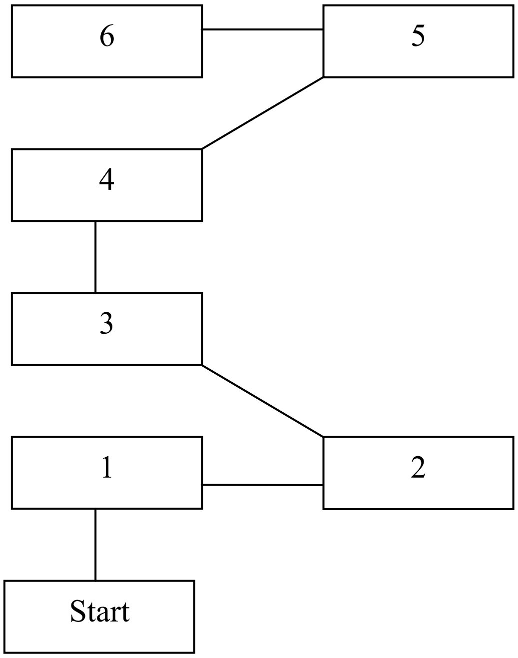


Figure C8. Subject Performing Side-Lying Hip Abduction with Elastic Resistance

1. Subject lies on his/her side on a table with dominant leg toward the ceiling.

2. He/she will start with hip in a neutral position. (Figure A)

3. Subject moves top dominant leg into abduction as high as possible. (Figure B)

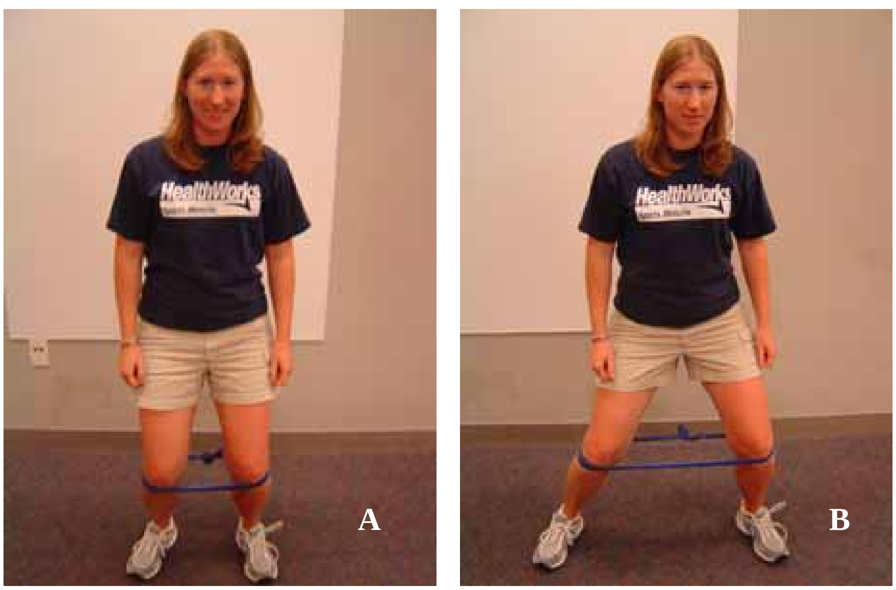
4. Subject then returns dominant leg to starting position and repeats steps 2 and 3 for number of repetitions that corresponds to week of training.

Figure C9. Subject Walking with Weight in Non-Dominant Hand

1. Subject carries a dumbbell in the hand on the opposite side of the body from the dominant leg.

2. Subject walks for three minutes while holding the dumbbell of a designated weight that corresponds to week of training.

Figure C10. Subject Performing Gorilla Walking with Elastic Resistance



1. Subject stands on both legs and has an elastic/rubber band around both legs (just above the knees) until snug. (Figure A)

2. Subject walks sideways with the dominant leg leading for the designated time that corresponds with the week of training. (Figure B)

Figure C11. Subject Performing Hip Abduction on Multi-Hip Machine

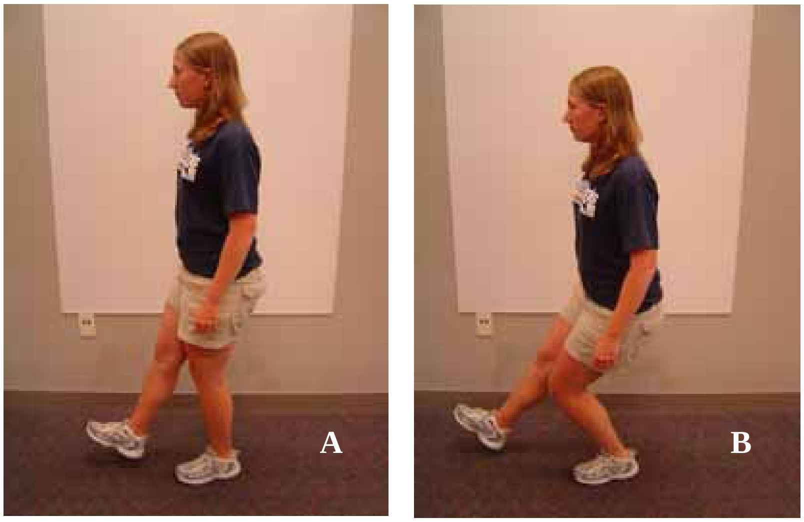
1. Subject stands on a multi-hip machine with non-dominant leg weight-bearing in neutral and dominant leg against the leg pad. (Figure A)

2. Subject selects weight according to pre-test values and week of training.

3. Subject then moves dominant leg away into abduction as far as possible and then returns to the starting position. (Figure B)

4. Subject repeats until three sets of ten are completed.

Figure C12. Subject Performing Single Leg Squat

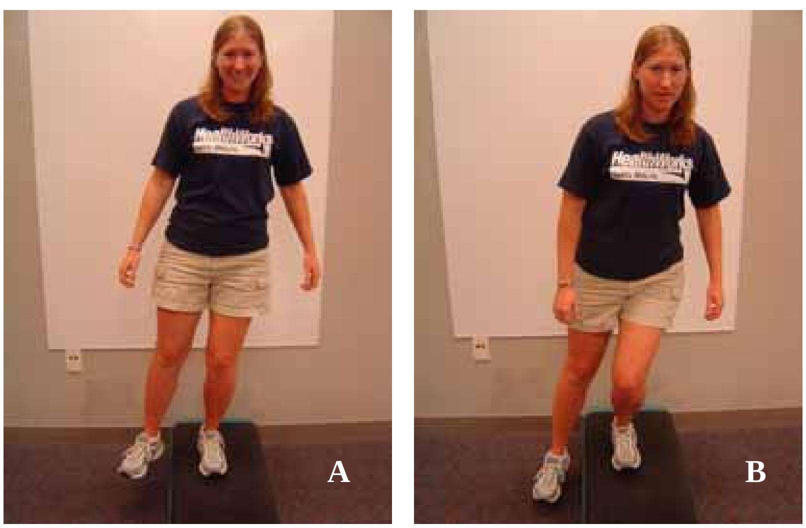


1. Subject stands on dominant leg and then squats down using only the dominant leg.

2. Subject squats until the knee is bent between 45 and 60 degrees and returns to the starting position.

3. Subject repeats squats corresponding to week of training.

Figure C13. Subject Performing Lateral Step-Downs

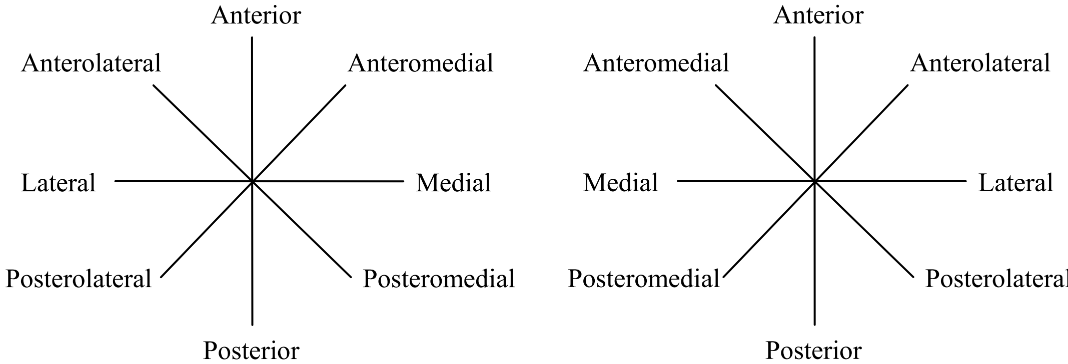


1. Subject stands on a 6” step on dominant leg with non-dominant leg off of step. (Figure A)

2. Subject bends knee on dominant leg until the foot on non-dominant leg touches ground next to the step. (Figure B)

3. Subject repeats step-downs corresponding to week of training.

FigureC14. Star Excursion Balance Test

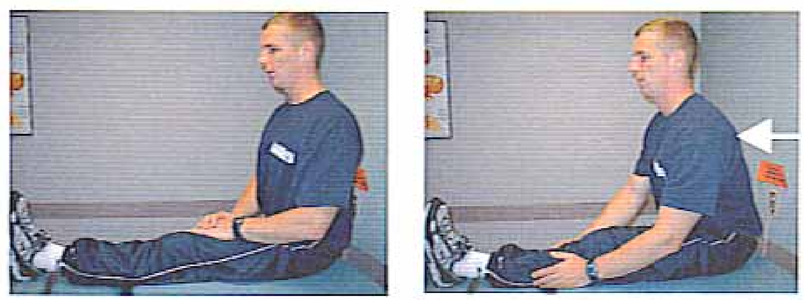


Left-Leg Stance Right-Leg Stance

Figure C15. Subject Performing Static Quadriceps Stretch

1. Subject stands unilaterally and grabs ankle that is non weight-bearing.
2. Subject pulls heel toward buttocks until a stretch is felt in the quadriceps (anterior thigh).
3. Subject holds stretch for 20 seconds and then performs stretch on opposite leg.
4. Subject repeats stretch two times on each leg.

Figure C16. Subject Performing Static Hamstrings Stretch



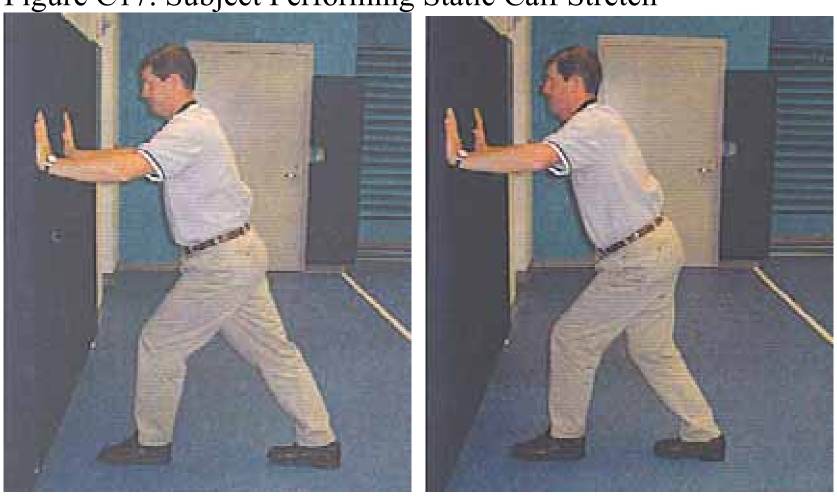
1. Subject sits with one leg on table and opposite foot on the floor.

2. Subject leans forward at waist while ensuring his or her back is straight until a stretch is felt in the hamstrings (posterior thigh).

3. Subject holds stretch for 20 seconds and then performs stretch on opposite leg.

4. Subject repeats stretch two times on each leg.

Figure C17. Subject Performing Static Calf Stretch



1. Subject stands facing wall with one leg back and one leg slightly in front.

2. Subject then places both hands on the wall.

3. Subject straightens knee on back leg and leans in toward wall until a stretch is felt in the calf (posterior lower leg).

4. Subject holds stretch for 20 seconds and then performs stretch on opposite leg.

5. Subject repeats stretch two times on each leg.

6. Subject then repeats stretch with back knee slightly bent twice on each leg.

Figure C18. Subject Performing Star Excursion Balance Test into Anterior Direction

Figure C19. Subject Performing Star Excursion Balance Test into Medial Direction

Figure C20. Subject Performing Star Excursion Balance Test into Posteromedial Direction

Figure C21. Subject Performing Gluteus Medius Strength Test

APPENDIX D

ADDITIONAL RESULTS

Table D1. Descriptive Statistics for Subject Demographics by Group, Gender, and Sport (N=48)

Group	Gender	Athletic Training	Rugby	Ice Hockey	Lacrosse	Intramurals	TOTAL
Combination	Male	1	1	1	1	0	12
	Female	4	3	0	0	1	
Gluteus Medius Strength Training	Male	1	1	2	2	1	13
	Female	3	2	0	0	1	
Proprioception Training	Male	1	1	4	1	1	12
	Female	2	2	0	0	0	
Control	Male	1	3	2	0	0	11
	Female	0	3	0	0	2	
TOTAL		13	16	9	4	6	48

Table D2. Descriptive Statistics of Subject Demographics by Age, Height, and Weight (N=48)

Group	n	Mean Age	Mean Height (cm)	Mean Weight (kg)
Combination	12	22.28 ± 2.02	169.81 ± 11.24	74.65 ± 16.33
Gluteus Medius Strength Training	13	22.10 ± 1.53	170.42 ± 9.73	72.04 ± 15.45
Proprioception Training	12	21.94 ± 1.74	176.21 ± 7.68	79.34 ± 14.30
Control	11	21.93 ± .99	171.10 ± 8.82	77.10 ± 18.14
TOTAL	48	22.06 ± 1.58	171.87 ± 9.52	75.72 ± 15.78

Table D3. Descriptive Statistics for Pre-Test Data for the Star Excursion Balance Test (N=48)

Reach Direction	Combination (n=12)	Gluteus Medius Strength (n=13)	Proprioception (n=12)	Control (n=11)
Anterior	90.11 ± 8.64	94.18 ± 4.85	93.97 ± 3.84	94.36 ± 5.98
Anteromedial	94.29 ± 10.42	96.71 ± 5.32	96.20 ± 5.01	97.00 ± 8.22
Medial	99.41 ± 12.19	102.96 ± 6.31	100.70 ± 7.26	100.26 ± 13.81
Posteromedial	105.43 ± 15.02	111.12 ± 6.46	107.32 ± 9.28	108.63 ± 14.25
Posterior	109.36 ± 17.04	117.28 ± 7.60	115.07 ± 10.63	111.42 ± 13.07
Posterolateral	100.22 ± 17.00	107.09 ± 12.85	105.43 ± 12.73	105.24 ± 11.62
Lateral	83.33 ± 10.16	89.45 ± 10.79	91.63 ± 6.11	88.31 ± 10.37
Anterolateral	81.78 ± 9.58	86.65 ± 8.25	85.39 ± 9.12	87.03 ± 8.27

Table D4. Descriptive Statistics for Post-Test Data for the Star Excursion Balance Test (N=48)

Reach Direction	Combination (n=12)	Gluteus Medius Strength (n=13)	Proprioception (n=12)	Control (n=11)
Anterior	95.59 ± 9.20	95.71 ± 4.43	97.06 ± 4.83	94.37 ± 5.90
Anteromedial	97.54 ± 11.48	98.39 ± 6.56	99.62 ± 6.19	97.54 ± 7.27
Medial	104.32 ± 11.04	104.53 ± 9.33	105.25 ± 6.46	102.52 ± 13.08
Posteromedial	111.18 ± 16.02	114.50 ± 6.97	112.45 ± 11.18	111.12 ± 14.89
Posterior	115.62 ± 18.24	122.05 ± 10.00	120.72 ± 12.02	114.66 ± 13.69
Posterolateral	106.36 ± 18.58	113.33 ± 15.76	110.89 ± 13.92	108.21 ± 12.00
Lateral	86.18 ± 12.28	97.07 ± 12.45	92.62 ± 7.85	90.00 ± 11.23
Anterolateral	86.15 ± 11.92	91.64 ± 8.51	87.89 ± 9.72	87.74 ± 8.94

Table D5. Mean Differences in SEBT Reach Distance Means from Pre-Test to Post-Test (N=48)

Reach Direction	Combination (n=12)	Gluteus Medius Strength (n=13)	Proprioception (n=12)	Control (n=11)
Anterior	5.48 ± 3.67	1.53 ± 2.14	3.09 ± 2.72	0.00 ± 0.79
Anteromedial	3.25 ± 4.09	1.68 ± 3.22	3.42 ± 3.13	0.54 ± 1.83
Medial	4.91 ± 2.65	1.57 ± 6.04	4.55 ± 3.42	2.26 ± 3.72
Posteromedial	5.75 ± 3.84	3.38 ± 3.00	5.13 ± 4.94	2.49 ± 2.36
Posterior	6.26 ± 3.19	4.77 ± 5.00	5.65 ± 3.91	3.24 ± 3.63
Posterolateral	6.14 ± 7.30	6.24 ± 5.66	5.46 ± 4.39	2.97 ± 5.33
Lateral	2.85 ± 6.22	7.62 ± 7.96	0.99 ± 2.19	1.69 ± 3.28
Anterolateral	4.37 ± 7.00	4.99 ± 3.65	2.5 ± 2.12	0.71 ± 1.40

Table D6. One-Way MANOVA of Pre-Test Data for the Star Excursion Balance Test (N=48)

Reach Direction	F	P	ES	ß
Anterior	1.341	0.273	0.084	0.332
Anteromedial	0.313	0.816	0.021	0.106
Medial	0.276	0.842	0.018	0.099
Posteromedial	0.527	0.666	0.035	0.149
Posterior	1.004	0.400	0.064	0.254
Posterolateral	0.572	0.637	0.038	0.158
Lateral	1.628	0.196	0.100	0.398
Anterolateral	0.880	0.459	0.057	0.226

Key: F = F value, P = significance, ES = Effect Size, ß = Power

Table D7. One-Way MANOVA of Post-Test Data for the Star Excursion Balance Test (N=48)

Reach Direction	F	P	ES	ß
Anterior	0.347	0.791	0.023	0.112
Anteromedial	0.171	0.915	0.012	0.079
Medial	0.148	0.930	0.010	0.075
Posteromedial	0.196	0.898	0.013	0.084
Posterior	0.854	0.472	0.055	0.221
Posterolateral	0.491	0.690	0.032	0.141
Lateral	2.103	0.113	0.125	0.501
Anterolateral	0.705	0.554	0.046	0.187

Key: F = F value, P = significance, ES = Effect Size, ß = Power

Table D8. Main Effects and Interactions Within and Between Subjects for the Star Excursion Balance Test (N=48)

	F	P	ES	ß
TEST	190.825	<0.001*	0.813	1.000
DIRECTION	141.825	<0.001*	0.763	1.000
GROUP	0.631	0.599	0.041	0.171
TEST X GROUP	6.145	0.001*	0.295	0.946
DIRECTION X GROUP	0.680	0.569	0.044	0.182
TEST X DIRECTION	3.303	0.076	0.070	0.428
TEST X DIRECTION X GROUP	1.571	0.210	0.097	0.385

Key: F = F value, P = significance, ES = Effect Size, ß = Power, * Significant at the $P \leq 0.05$ level

Table D9. Pairwise Comparisons for Reach Directions on the Star Excursion Balance Test (N=48)

Reach Direction	T	P
Pre- and Post-Test Anterior	-5.538	<0.001*
Pre- and Post-Test Anteromedial	-4.698	<0.001*
Pre- and Post-Test Medial	-5.287	<0.001*
Pre- and Post-Test Posteromedial	-7.690	<0.001*
Pre- and Post-Test Posterior	-8.579	<0.001*
Pre- and Post-Test Posterolateral	-6.363	<0.001*
Pre- and Post-Test Lateral	-3.947	<0.001*
Pre- and Post-Test Anterolateral	-5.116	<0.001*

Key: T = t value, P = Significance, * Significant at the P≤0.05 level

Table D10. Multiple Comparison Tukey Post Hoc Tests for Star Excursion Balance Test (N=48)

Group Comparisons	P
COMBINATION : GLUTEUS MEDIUS STRENGTH	0.559
COMBINATION : PROPRIOCEPTION	0.783
COMBINATION : CONTROL	0.953
GLUTEUS MEDIUS STRENGTH : PROPRIOCEPTION	0.984
GLUTEUS MEDIUS STRENGTH : CONTROL	0.876
PROPRIOCEPTION : CONTROL	0.979

Key: P = Significance

Table D11. Descriptive Statistics for Pre- and Post-Test Date for Gluteus Medius Strength (N=48)

Test	Combination (n=12)	Gluteus Medius Strength (n=13)	Proprioception (n=12)	Control (n=11)
Pre-Test	33.04 ± 5.13	33.24 ± 3.90	32.29 ± 4.99	31.24 ± 4.56
Post-Test	34.74 ± 5.35	35.28 ± 4.02	32.99 ± 4.79	31.69 ± 4.56
Pre-Test to Post-Test Difference	1.70 ± 1.55	2.05 ± 1.31	0.70 ± 0.71	0.45 ± 0.91

Table D12. One-Way ANOVA for Pre-Test and Post-Test Gluteus Medius Strength Data (N=48)

Test	F	P	ES	ß
Pre-Test	0.439	0.726	0.029	0.131
Post-Test	1.454	0.240	0.090	0.358

Key: F = F value, P = significance, ES = Effect Size, ß = Power

Table D13. Main Effects and Interactions Within Subjects for Gluteus Medius Strength Testing (N=48)

	F	P	ES	ß
TEST	51.782	<0.001*	0.541	1.000
GROUP	0.883	0.458	0.057	0.227
TEST X GROUP	5.172	0.004*	0.261	0.900

Key: F = F value, P = significance, ES = Effect Size, ß = Power, * Significant at the P≤0.05 level

Table D14. Multiple Comparison Tukey Post Hoc Tests for Gluteus Medius Strength (N=48)

Group Comparisons	P
COMBINATION : GLUTEUS MEDIUS STRENGTH	0.997
COMBINATION : PROPRIOCEPTION	0.911
COMBINATION : CONTROL	0.597
GLUTEUS MEDIUS STRENGTH : PROPRIOCEPTION	0.819
GLUTEUS MEDIUS STRENGTH : CONTROL	0.463
PROPRIOCEPTION : CONTROL	0.929

Key: P = Significance

Figure D1.Mean SEBT Reach Distances by Test for the Combination Group

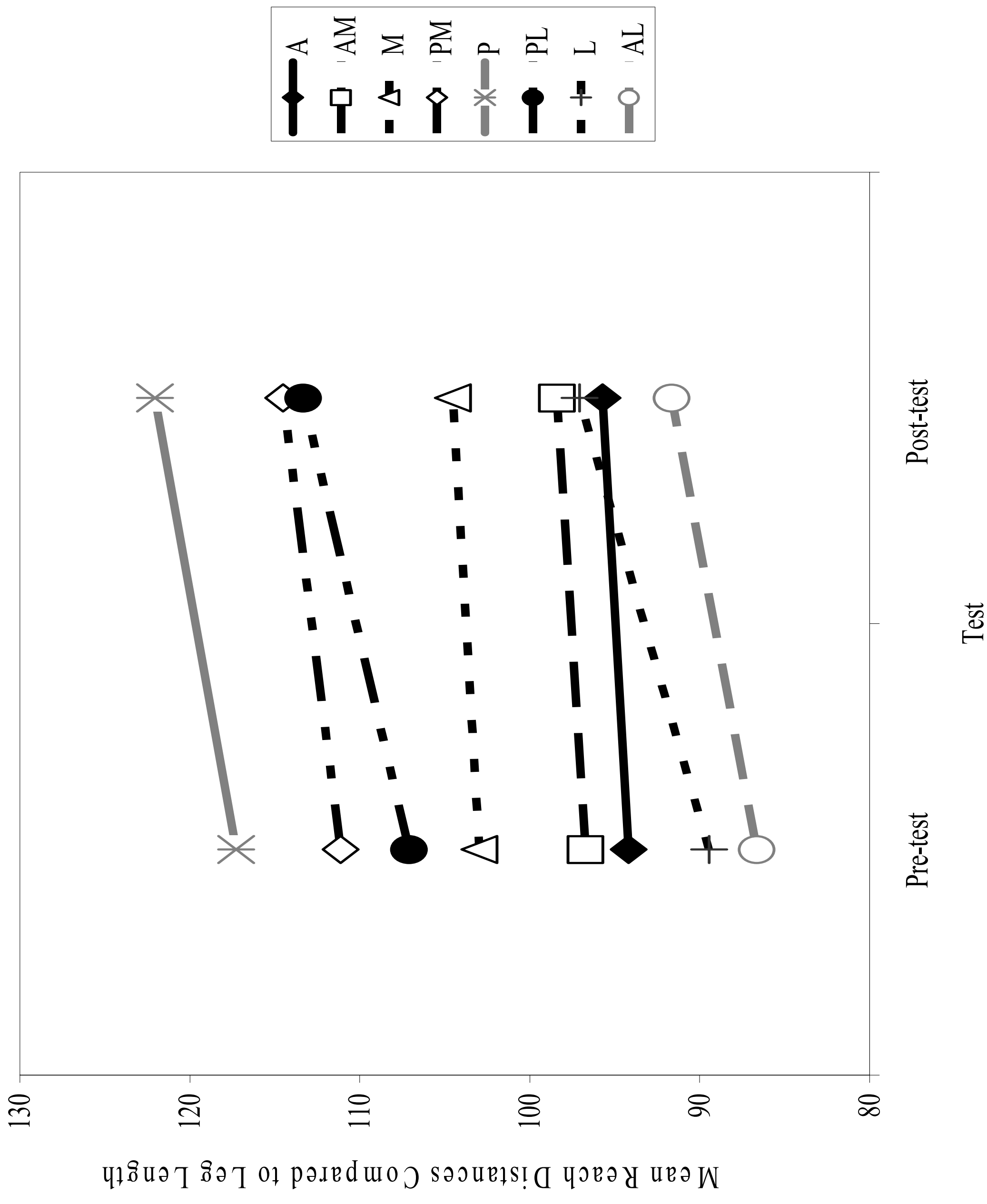


Figure D2. Mean SEBT Reach Distances by Test for the Gluteus Medius Strength Training Group

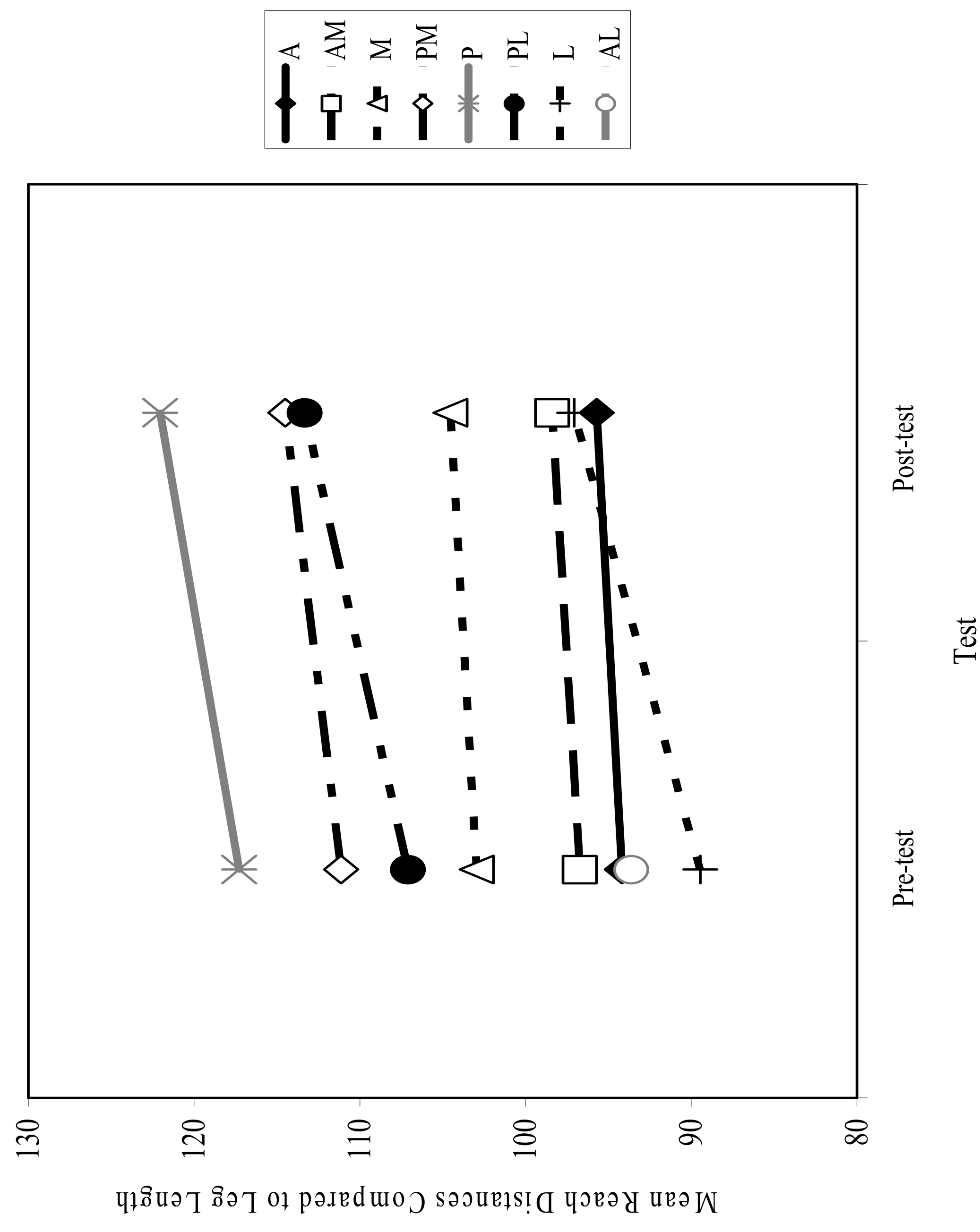


Figure D3. Mean SEBT Reach Distances by Test for the Proprioception Training Group

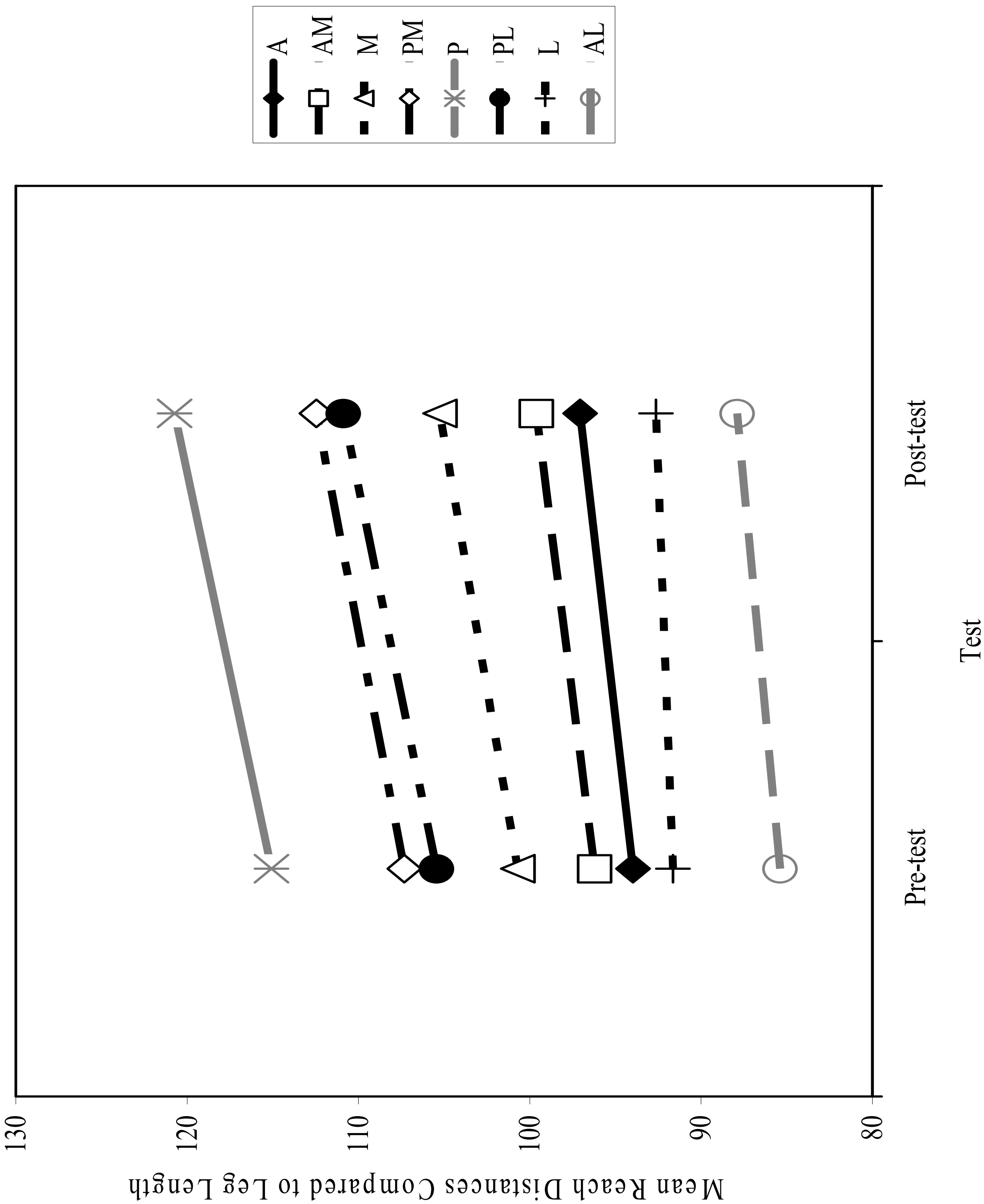


Figure D4. Mean SEBT Reach Distances by Test for the Control Group

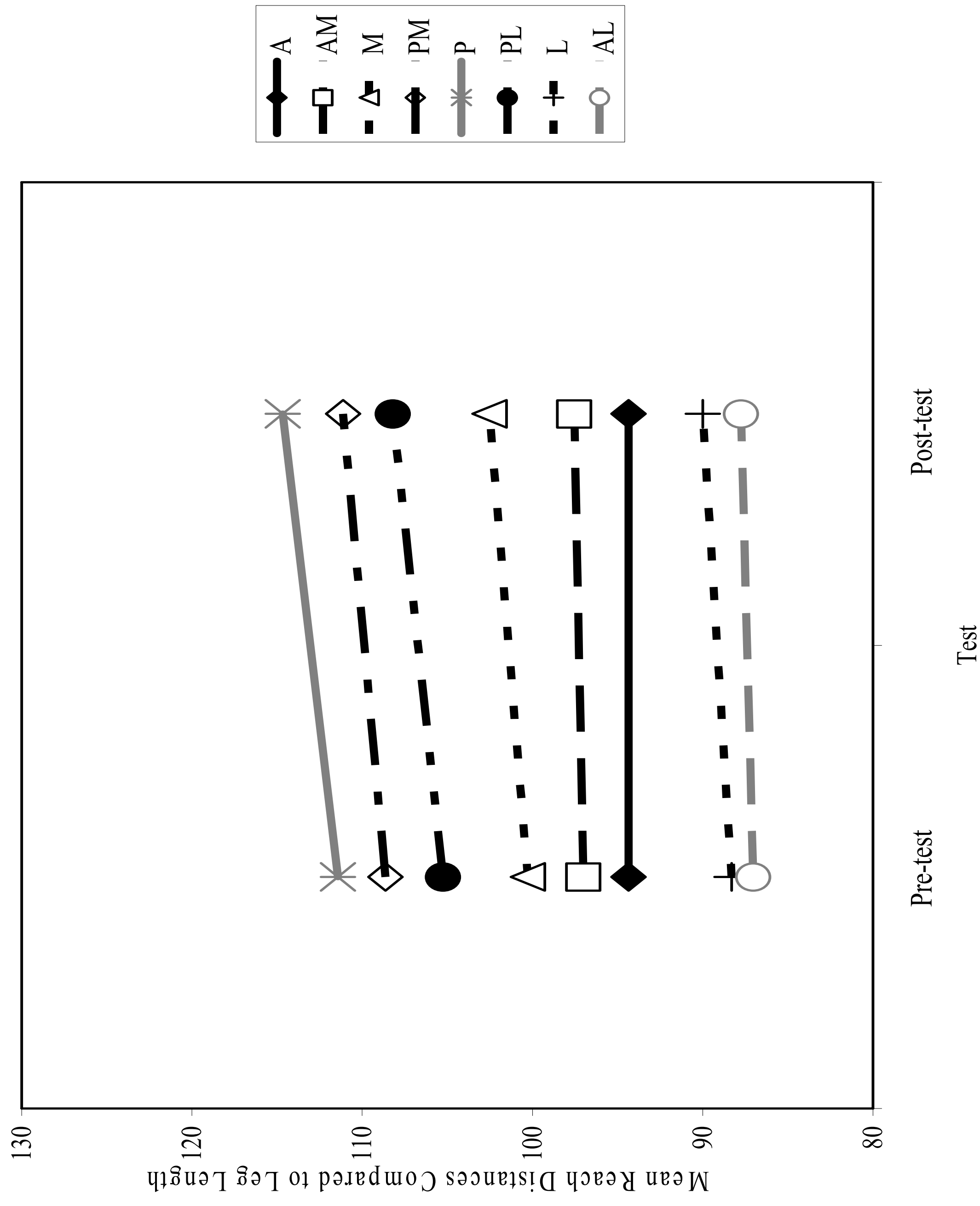


Figure D5. Mean SEBT Reach Distances by Test for All Subjects

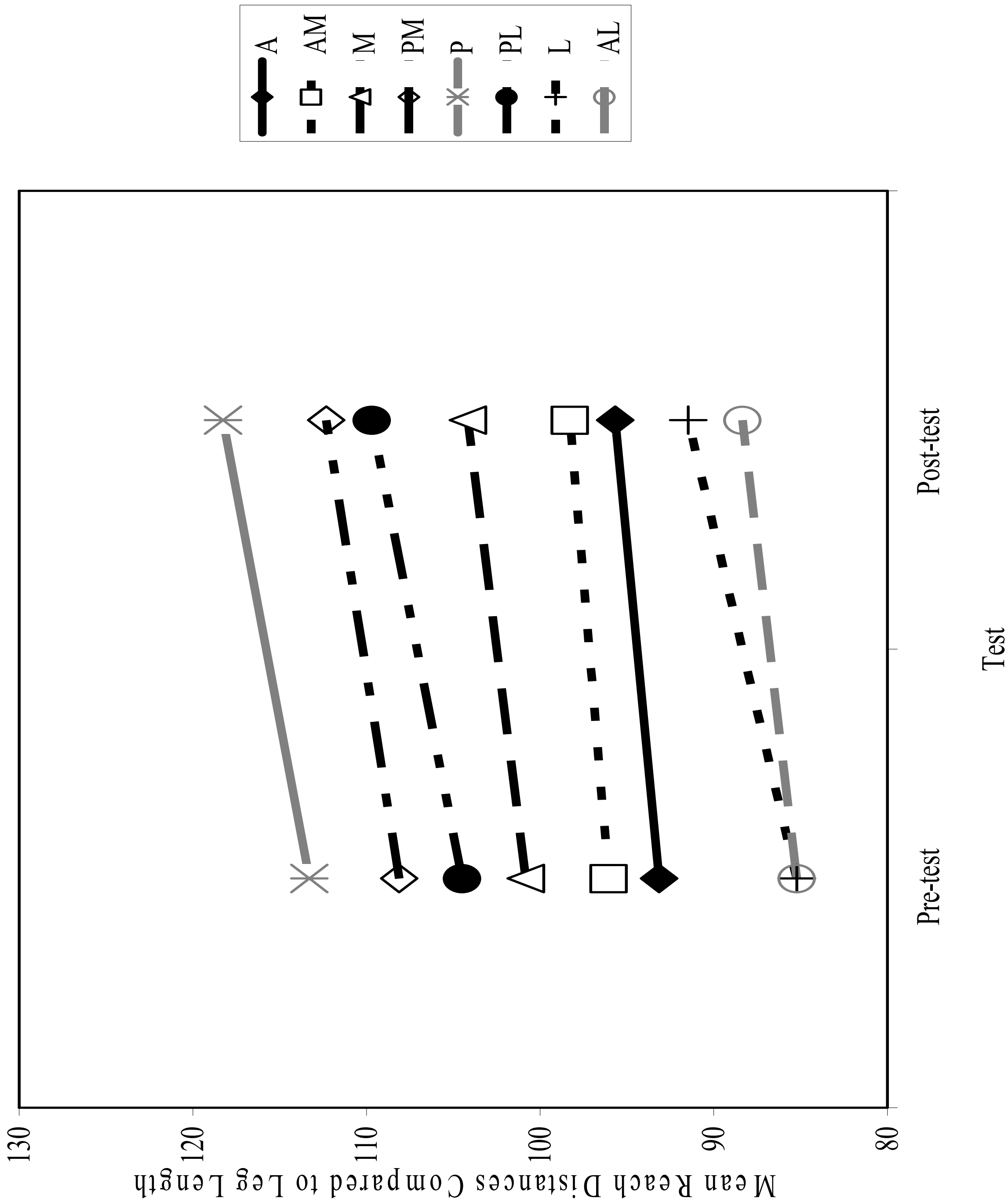


Figure D6. Mean SEBT Reach Distances by Test for All Groups

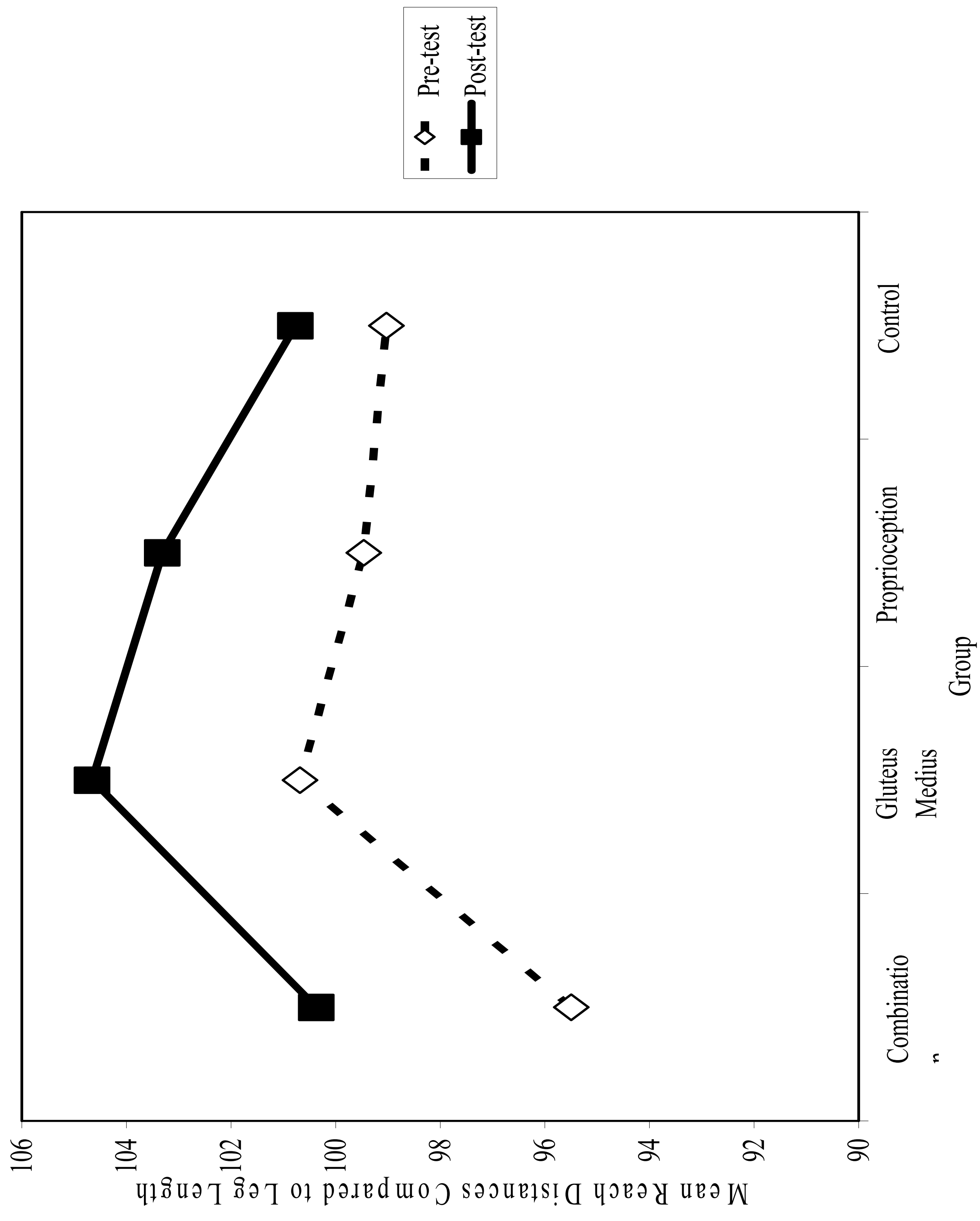


Figure D7. Mean SEBT Reach Distances by Group

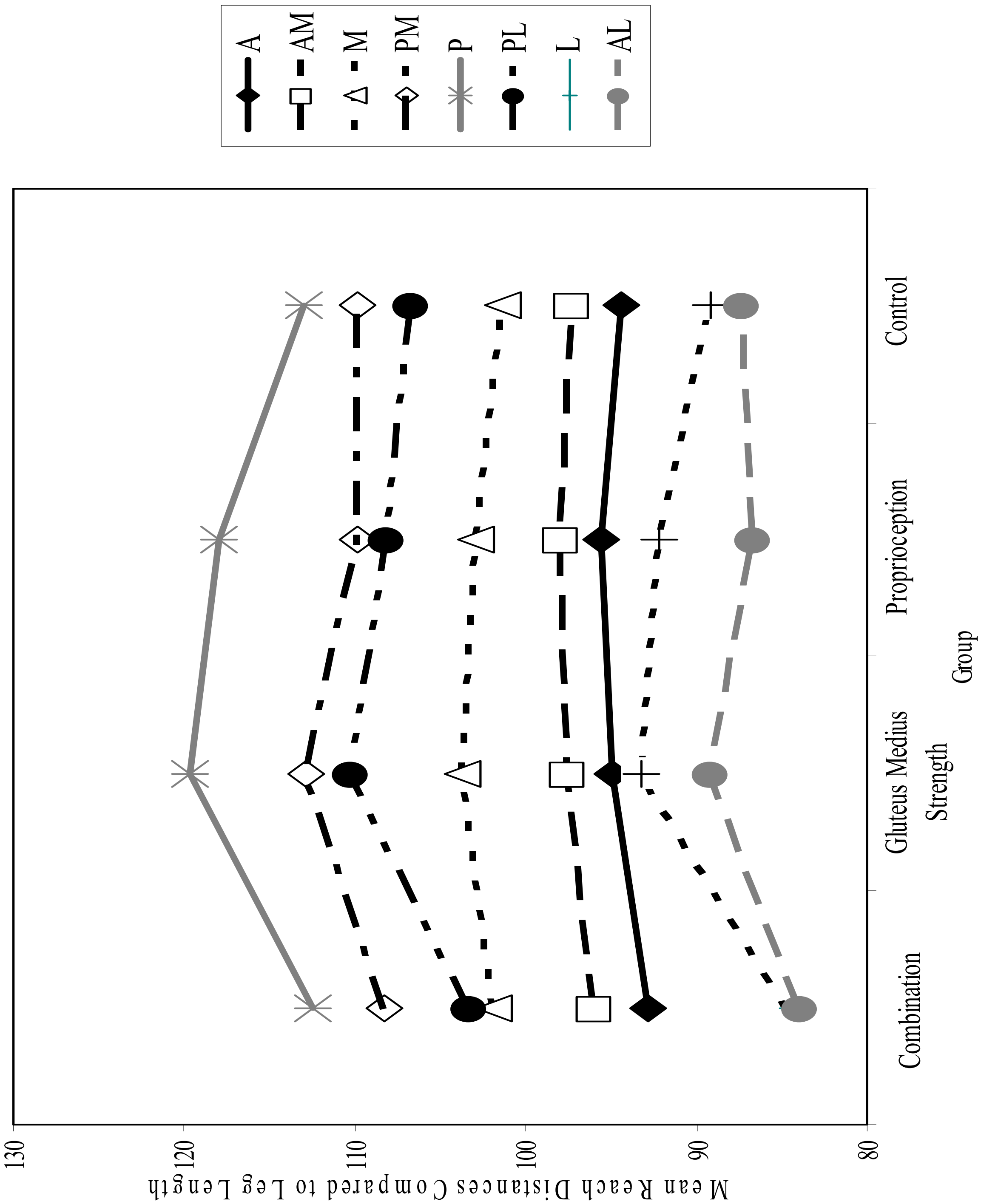


Figure D8. Mean SEBT Reach Distances by Direction for All Subjects

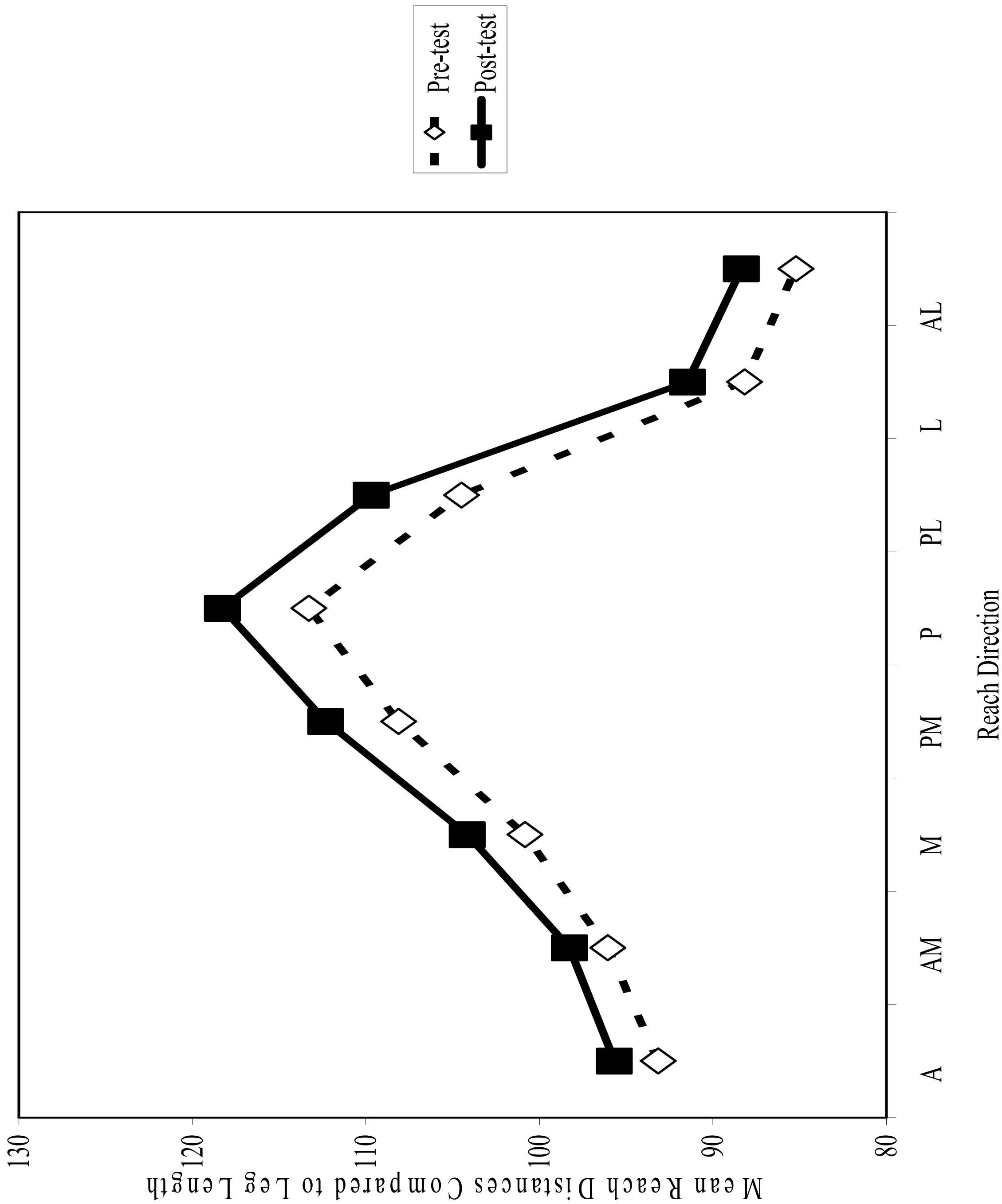


Figure D9. Mean Pre-Test SEBT Reach Distances by Direction for All Groups

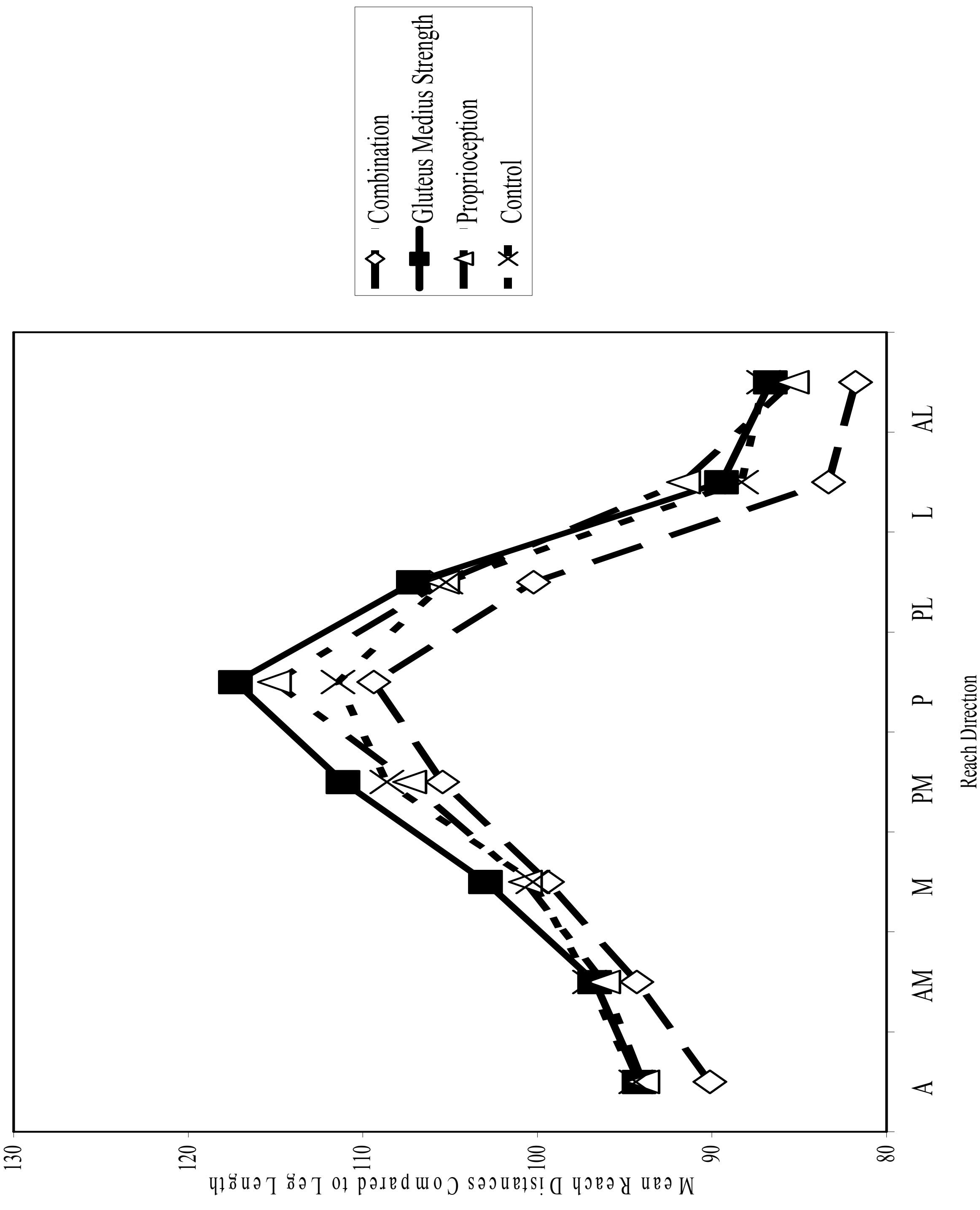


Figure D10. Mean Post-Test SEBT Reach Distances by Direction for All Groups

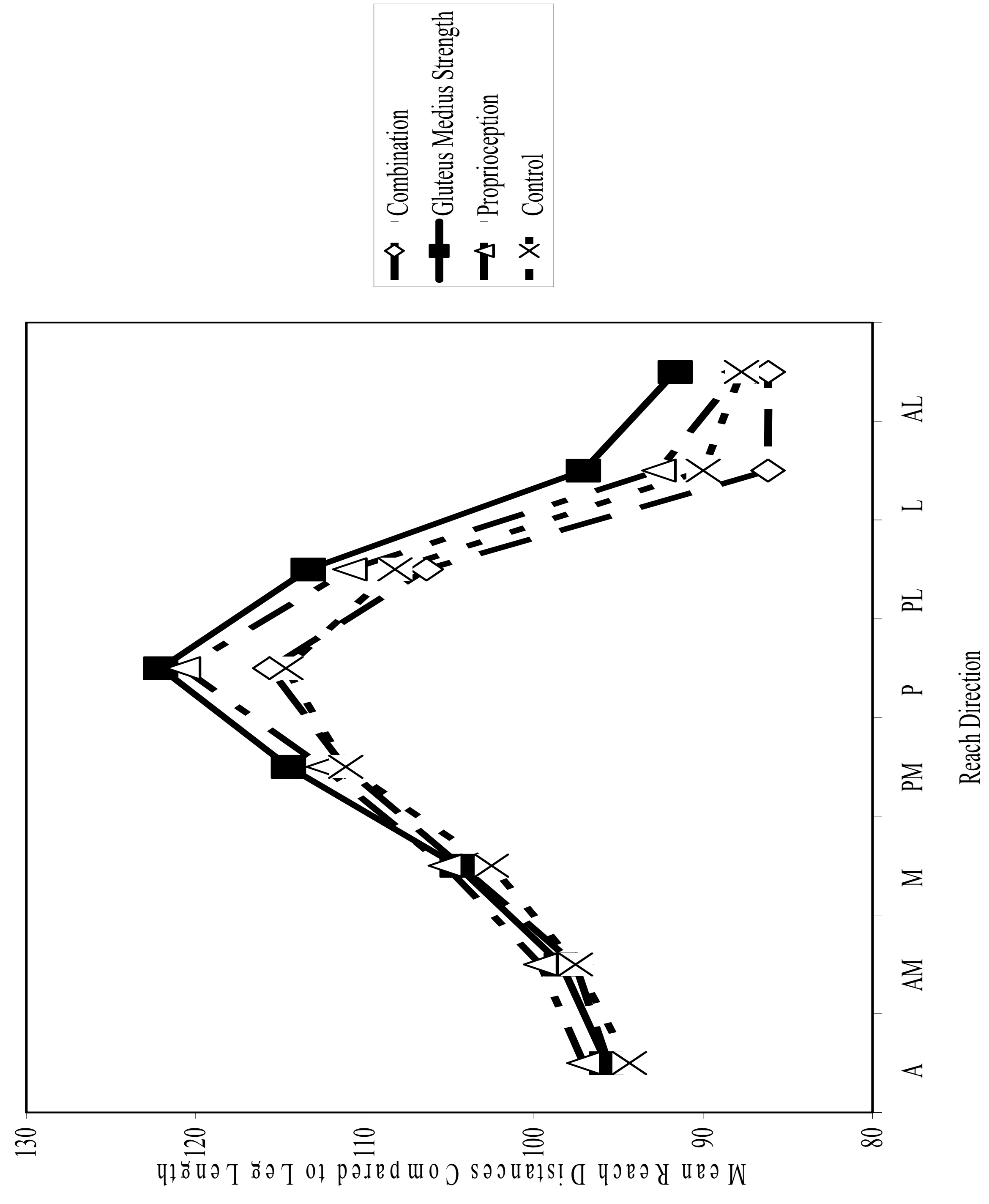


Figure D11. Mean Pre- and Post-Test Gluteus Medius Strength Recordings by Group

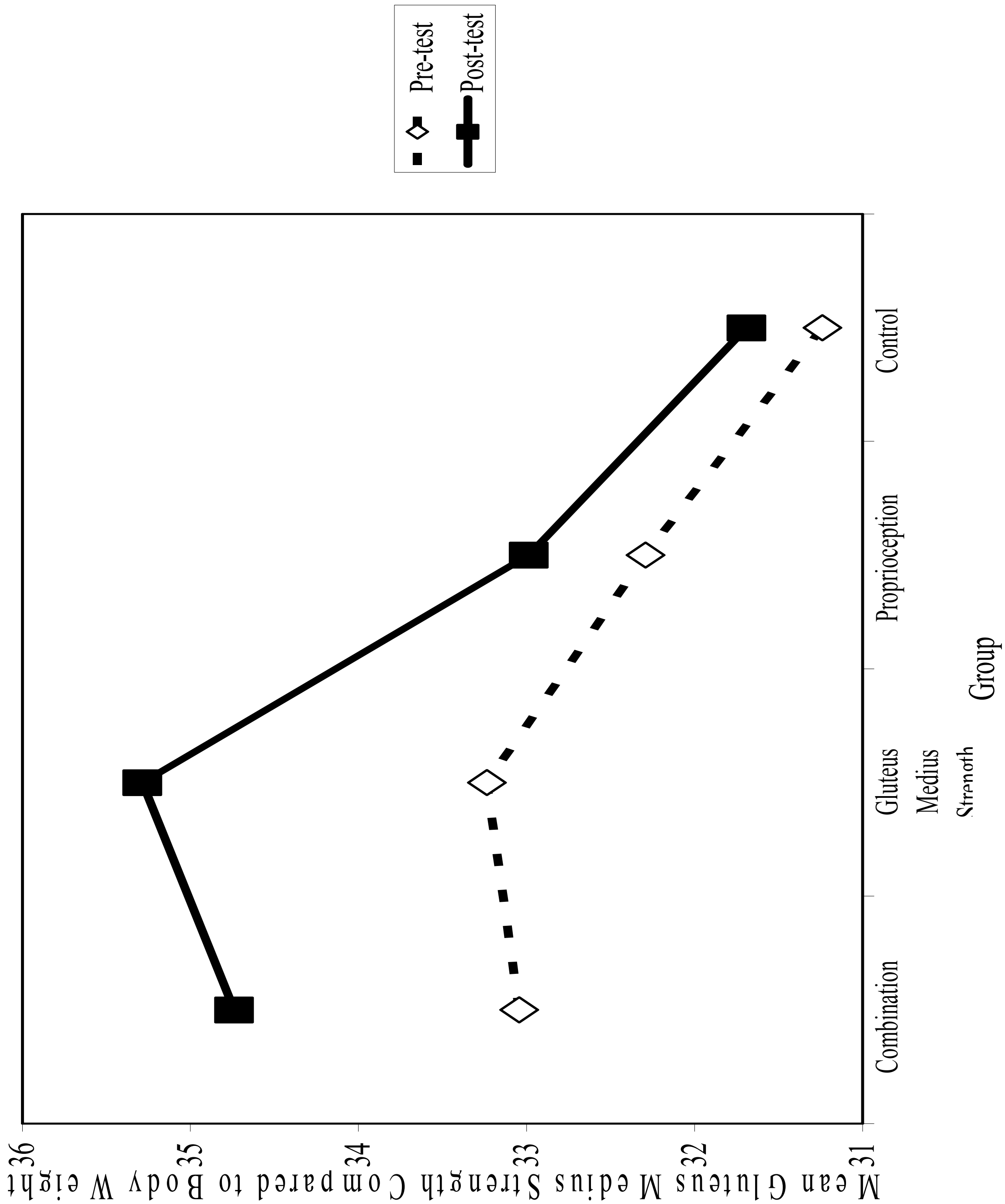
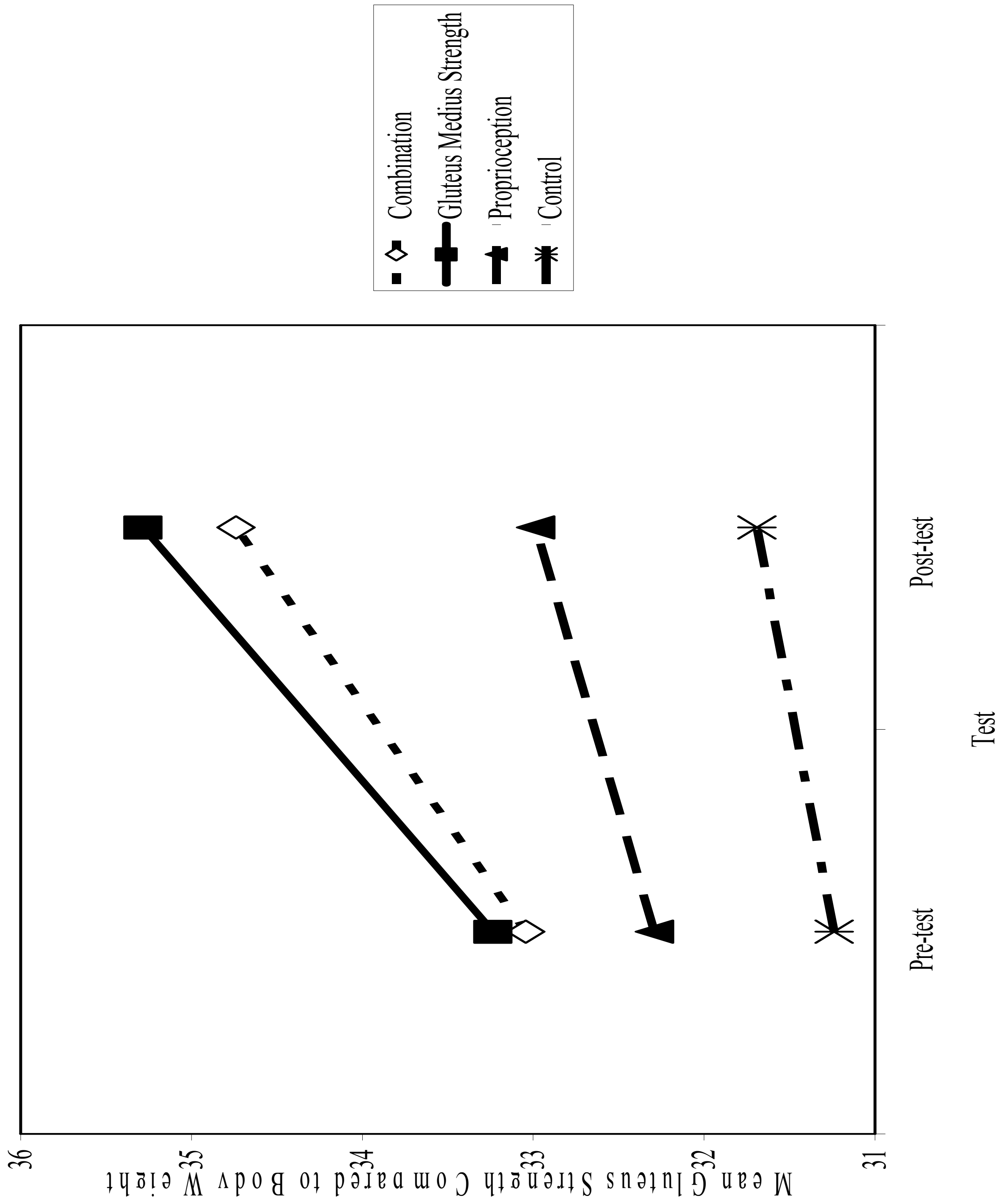


Figure D12. Mean Gluteus Medius Strength Recordings by Test for all Groups



APPENDIX E

RECOMMENDATIONS FOR FUTURE RESEARCH

1. Increase the length of the study from six weeks to ten weeks.
2. Increase the training sessions per week from three to four.
3. Conduct the study using injured subjects with acute lower extremity injuries.
4. Conduct the study using non-physically active subjects.
5. Conduct the study using subjects with chronic ankle instability.
6. Conduct the study using an older population who utilizes the hip strategy.
7. Conduct the study using intercollegiate athletes as opposed to club sports athletes, intramurals athletes, and athletic trainers.
8. Increase the number of subjects from between 11-13 to at least 20 subjects per group.
9. Conduct the study using more purely strengthening exercises (85 % of one repetition maximum, four to six sets of one to five repetitions, four times per week) for the gluteus medius strengthening and combination training groups.
10. Train the combination group for balance and gluteus medius strength on separate days to avoid fatigue.
11. Conduct a longitudinal study to examine the differences in pre- and post-training injury rates.
12. Conduct the study without allowing any compensatory arm movement during the SEBT.

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