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Research article

FIXED FOOT BALANCE TRAINING INCREASES RECTUS FEMORIS ACTIVATION DURING LANDING AND JUMP HEIGHT IN RECREATIONALLY ACTIVE WOMEN

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ABSTRACT
The objective of this study was to determine the effects of fixed foot and functionally directed balance training on static balance time, muscle activation during landing, vertical jump height and sprint time. Twenty-four recreationally active females were tested pre- and post-training (fixed foot balance training, n= 11, functionally directed balance training, n = 7 and control group, n = 6). Experimental subjects completed either fixed foot or functionally directed balance exercises 4 times/week for 6 weeks. Surface electromyography (EMG) was used to assess preparatory and reactive muscle activity of the rectus femoris (RF), biceps femoris (BF), and the soleus during one- and two-foot landings following a jump. Maximum vertical jump height, static balance and 20-meter sprint times were also examined. The fixed foot balance-training group showed a 33% improvement ($p < 0.05$) in static balance time and 9% improvement in jump height. Neither type of training improved sprint times. Further analysis revealed significant ($p < 0.05$) overall (data collapsed over groups and legs) increases in reactive RF activity when landing. Independently, the fixed foot balance group showed a 33% increase in reactive RF activity ($p < 0.01$). Overall, there was also significantly less reactive co-activation following training ($p < 0.05$). It appears that fixed foot balance training for recreationally active women may provide greater RF activity when landing and increased countermovement jump height.

KEY WORDS: Balance training, muscle activation, training specificity.

INTRODUCTION

Balance can be defined as the ability to maintain or make adjustments in order to keep the body's centre of gravity over the base of support (Irrange et al., 1994; Nashner, 1993). This adjustment occur through movements of the ankles, knees, and hips and may be disturbed when the center of gravity and base of support is disrupted or when corrective movements are not executed in a smooth and coordinated fashion (Bernier and Perrin, 1998; Diener and Dichgans, 1988).

The use of unstable platforms such as wobble boards, Swiss balls, and other equipment, which challenge balance, have been introduced as a part of rehabilitation and training programs. It has been shown that instability can contribute to less force production (Anderson and Behm, 2004; 2005; Kornecki et al., 2001) and greater fatigue (Hoffman et al., 1997; Mattsson and Brostrom, 1990). Studies have shown that implementing balance training resulted in improved strength and reduction in muscle imbalances (Balogun et al., 1992; Heitkamp et al. 2001). Anderson and Behm (2004) reported that the maintenance of muscle activation levels concomitant with a decrease in force was due to the increased stabilizing responsibilities of the prime movers. Improvements in balance could decrease the proportion of prime mover muscles allocated to stabilization and allow them to contribute more to the propulsion of the body when jumping or running. Furthermore, an individual with an unstable base may not direct all their propulsive forces in the optimal direction. Based on this previous research, wobble board training and jump-landing training may be an important part of athletic training especially when considering activities that often lead to injuries (jump landings) and require strength and power.

In sports such as volleyball and basketball, jumping is important for successful performance of both defensive and offensive skills. Making the transition from a jump to another skill is also important for successful performance, thus landings need to occur in a balanced position and with correct technique. However, teaching proper landing technique in many sports is still often neglected. It is therefore important to teach these athletes how to land in a balanced position as a possible factor in performance enhancement and the prevention of lower extremity injuries.

Decreased stability or poor balance can increase injury rates (Emery et al., 2005; McGuine et al., 2000; Troop et al. 1984). In a study comparing jump landing and wobble board training, it was found that athletes were better able to discriminate between ankle movements following the wobble board training (Waddington et al., 2000). Having greater proprioception enables the athletes to land more accurately and prepare for impact thus possibly aiding in injury prevention. Knee stability is provided by both preparatory (feed-forward) and reactive (feedback) muscle activity (Solomonow and Krogsgaard, 2001). The increased muscle activity can offer greater protection from the forces and loads experienced, by lower-extremity joints during landing. The ability of fixed foot balance training programs to improve preparatory or reactive muscle activity has not been thoroughly examined.

The concept of training specificity is commonly applied during the development of any athletic training program. For optimal performance, the training routine must mimic the athletic event.

The purpose of this study was to examine the effects of fixed foot and functionally directed balance training (wobble board training and jump-landing training respectively) on muscle activation and co-activation (with EMG) during jump landings of varying stability (one-foot and two-foot). Secondly, to determine the effects of fixed foot and functionally directed balance training on measures of jump height, sprint time and static balance.

METHODS

Experimental design

The purpose of this study was to compare the effect of fixed foot (wobble board) and functionally directed (landing from a jump) balance training on jump height, sprint time as well as static and functionally directed balance. Functionally directed balance changes were assessed by examining muscle activity patterns for the rectus femoris (RF), biceps femoris (BF) and soleus when landing from a jump onto a stable (2-foot) and less stable (1-foot) base of support. Subjects were randomly assigned to a control group, or to participate in a 6-week training program, which involved completing five balance jump-landing exercises or wobble board exercises four times per week with each session lasting approximately 20 minutes.

Prior to and following training, subjects completed three trials of the following measures: 1) landing on one foot after jumping over an obstacle, 2) landing on two feet after jumping over an obstacle, 3) countermovement vertical jumps, 4) wobble board balance test and 5) 20 meter sprint.

Subjects

For this study, 34 female volunteer subjects were randomly assigned to participate in 6-weeks of wobble board (fixed foot balance) or jump landing (functionally directed balance) training, or a control group. All females were chosen as a sample of convenience. Ten participants did not complete the program. The reasons for incompletion were time commitment issues (5), injuries sustained during other physical activity (2) or illness (3).

Based on the 24 subjects who completed the study the descriptive information is summarized in Table 1. Criteria for participation in this study

Table 1. Descriptive information of subjects. Data are means (±SD).

Group	n	Age (years)	Height (m)	Weight (kg)
Fixed-Foot	11	25.2 (5.7)	1.68 (.06)	67.1 (10.4)
Functionally Directed	7	23.7 (1.8)	1.66 (.08)	65.4 (9.3)
Control	6	22.8 (2.1)	1.66 (.04)	67.3 (12.0)
TOTAL	24	24.2 (4.1)	1.67 (.06)	66.7 (10.1)

Table 2. Summary of the training programs.

Exercise	Repetitions	Sets
Fixed Foot		
Anterior/Posterior Tilt	1 minute	3
Medial/Lateral Tilt	1 minute	3
One Foot Balance	1 minute, per leg	3
Knee Flexion	10 repetitions	3
One Hand Ball Toss	10 repetitions per hand (20 total)	2
Functionally Directed		
Simulated Running Strides	10 per leg (20 total)	3
Zig-Zag Bound and Stick	10 per leg (20 total)	3
Single Leg, Soft Mat	10 per leg (20 total)	3
Single Leg Box jumps	5 per leg (10 total)	3
Medial/Lateral Single Leg Box Jumps	6 per leg (3 medial, 3 lateral) (total of 12 reps)	3

included 1) recreational athletes (approximately 1-2 hours of activity, 3 times per week) 2) no musculoskeletal injuries and 3) no significant involvement in balance training activities. Each subject completed an informed consent form as well as a Physical Activity Readiness Questionnaire (PAR-Q) (Canadian Society of Exercise Physiology, 2003). Once subjects were cleared to participate they were randomly assigned to one of the three groups (control, functionally directed, or fixed foot). Ethics were granted from Memorial University of Newfoundland Human Investigation Committee.

Intervention

The study intervention included 6-weeks of wobble board (fixed foot balance) or jump-landing (functionally directed balance) training (see Table 2). The term “functionally directed balance” was derived from an article by Punakallio (2005) where this type of training was typical of dynamic training that measured a person’s ability to maintain balance as she or he walks or performs tasks as fast as possible. The wobble board exercises are commonly used in rehabilitation programs while the jump-landing exercises are commonly used exercises to teach jumping technique and were modified to focus on correct landing technique. Subjects in the two training groups completed one of the programs 4 times per week with each session lasting approximately 20 minutes, while the control group was instructed to continue with their normal activity. Each subject had a training log where the investigator recorded the date of each training session and the completion of each exercise.

Exercises for the jump-landing program were:

1) *Simulated straight running strides:* Subjects performed a running stride and on each landing they held the 1-foot landing position for 3 seconds. Completed 3 sets of 20 strides (10 per leg).

2) *Zigzag bound and stick:* Subjects jumped (1-legged) with a forward lateral push-off, again held the landing position for 3 seconds. Completed 3 sets of 20 jumps (10 per leg)

3) *Jump and land single-leg landing on soft mat:* Subjects jumped down from a 30 cm platform and landed 1-footed onto a soft cushion (mat). Repeated 10 times per leg for 3 sets.

4) *Single-leg box jumps:*Subjects jumped from the floor onto a box, 20 cm high, landing again on 1-foot with 3 sets of 5 jumps per leg.

5) *Medial/Lateral single-leg box jumps:* Subjects jumped from the floor laterally onto a box, 20 cm high again landing on 1-foot. They completed 3 sets of 6 jumps (3 medial and 3 lateral) per leg.

For each of the exercises, subjects were instructed to concentrate on the landing technique. They were instructed to ensure the hip, knee and foot were aligned facing directly in front of the body with minimal rotation at any joint. Each jump was also to be landed with knee and hip flexion, to help dissipate the ground reaction forces. The subjects were monitored for proper jumping and landing technique as well as appropriate pace during the first week of training and given feedback on the exercises. During the following five weeks of training the progress of subjects was monitored by one of the investigators (CK) and additional feedback was given. The investigator administering the programme was a certified Professional Fitness and Lifestyle Consultant who was very familiar with the proper training regimen. The training room also contained a full wall of mirrors so subjects were able to visually monitor their own landings.

For the wobble board training, the subjects completed the following tasks on a 40 cm diameter wooden wobble board with a vinyl covering:

1) *Anterior/posterior tilt*: Subjects placed feet shoulder-width apart on the board. They then

slowly and deliberately touched or 'tapped' the anterior and posterior edges of the board to the ground (front/back) for 1 minute. This was repeated three times.

2) *Medial/lateral tilt:* Subjects again placed feet shoulder-width apart on the board. They then slowly and deliberately touched the left edge of the balance board to the floor then the right edge for 1 minute, repeating the 1-minute exercise three times.

3) *Balance on one leg:* Standing with one foot in the center of the board, subjects attempted to keep all edges of the board off the ground for 1 minute. The subjects then switched to the opposite leg and repeated the exercise three times per leg.

4) *Squats:* With feet shoulder-width apart, subjects performed a squat while attempting to keep all edges of the board off the ground. Subjects completed 3 sets of 10 reps.

5) *One hand ball toss*: Standing on the board with feet shoulder-width apart, subject tossed a volleyball back and forth to a partner. The subjects had to balance the board before the partner would toss the ball to them and prior to them tossing the ball back to the partner. They completed 10 repetitions per hand with two sets.

Dependent variables

Maximum Voluntary Contractions (MVC) – Force production and muscle activity

Electromyography (EMG) and strain gauge data were collected during maximum voluntary contractions (MVC) of the quadriceps, hamstrings and plantar flexors of the dominant leg. The dominant leg was defined as the leg used to kick a soccer ball. EMG activity was sampled at 2000 Hz (Biopac System MEC 100 amplifier, Santa Barbara, CA), with a Blackman -61 dB band-pass filter between 10-500 Hz, amplified (bi-polar differential amplifier, input impedance = 2M, common mode rejection ratio $\geq$ 110 dB min (50/60 Hz), gain x 1000, noise $\geq$ 5 μV), and analog-to-digitally (Biopac MP 100) converted (12 bit) and stored on a personal computer (Sona; St. John's NL) for further analysis. Surface EMG electrodes (Kendall ® Medi-trace 133 series, Ag/AgCl, Chikopee, MA) were placed superficially on the midpoint of the muscle belly for the rectus femoris (RF), bicep femoris (BF) and on the mid-belly of the soleus directly below the intersection of gastrocnemius and the soleus. Light shaving, of the electrode placements area, followed by removal of dead epithelial cells with abrasive (sand) paper and cleaning of the area with an isopropyl alcohol was performed to prepare the skin.

Once the subjects were prepared for the EMG they performed two isometric MVCs for each muscle group (knee extension, hip extension and plantar flexion). A Wheatstone bridge configuration strain gauge (Omega Engineering Inc. LCCA 250, Don Mills, Ontario) attached to a high-tension wire was connected to the ankle to measure the force generated by the quadriceps and hamstrings during the MVCs. To measure the force of the plantar flexors, a piezo-electric wire strain gauge was used. All forces were detected by the strain gauge, amplified (Biopac Systems Inc. DA 100 and analog to digital converter MP100WSW; Hilliston, MA) and monitored on a computer (Sona; St. John's NL). Data were sampled at 2000 Hz, A/D converted and stored on a computer for further analysis on the AcqKnowledge software (AcqKnowledge III, Biopac Systems Inc., Holliston, MA).

For knee extension, subjects sat on a table with the knee flexed at 90^0 with their upper leg, hips, and upper body supported by two straps and a backrest. The foot was then inserted into a padded cuff, which was attached to the high-tension wire and strain gauge. For the hamstrings' MVC, subjects stood facing the table and with the foot slightly off the ground with the knee extended, and performed a hip extension movement. The foot was again inserted into the padded cuff and attached to a high-tension wire and strain gauge. For the plantar flexors, the subject was seated with the leg secured in a modified boot apparatus (Belanger and McComas, 1981) with the knee and ankle joints flexed at a 90^0 angle.

Muscle activity during functionally directed test

During the stable (2-foot) and less stable (1-foot) landings, EMG data were collected for the RF, BF and soleus of the subject's dominant leg. Subjects were instructed to take three strides (beginning with non-dominant leg) and jump from one tape marker to the next (1.5 meters). They were also instructed that upon landing to hold their position for approximately 2 seconds. A barrier (20cm high) was located midway between the 1.5 meter markers. This protocol was similar to that of Steele and Brown (1999), Cowling and Steele (2001) and Cowling et al. (2003), who had subjects take three strides, jump and land on a force platform, however it was modified to standardize the jump height and distances of subjects. To familiarize the subjects with the jump and landing protocol, subjects were given three practice trials of each protocol. A marker was used to indicate take-off and landing of the jumps in the collected EMG computer files. For each jump landing condition, subjects completed 3 landings.

Maximum vertical jump height

For the following measurements (jump height, static balance and sprint time), the Kinematic Measurement System (KMS) (Innervations, Muncie, IN, USA) and associated computer program were used to collect all relevant data.

For the jumping test, the KMS program recorded jump height based on flight time. With hands on hips, subjects stood on a contact mat connected to the computer. They then performed the countermovement jumps. An adjustable step was placed behind the subjects to standardize the degree of knee flexion (90^0) between pre- to post-testing sessions. Subjects descended in a controlled manner and as soon as the subjects touched the adjustable step with their buttocks, without pausing, they jumped as high as possible. The subjects repeated this test three times with 1-minute rest between trials. The best performance (highest jump height) was recorded.

Static balance

Using the KMS system, subjects performed a 30 second wobble board balance test. The wobble board had a diameter of 49cm and a height of 5cm. Once the subject was situated on the board, with comfortable foot placement, they were instructed to balance the board off the ground for 30 seconds. This measure was repeated 3 times with 1-minute rest between trials. The best performance (lowest number of contacts) was recorded.

Sprint performance

For the 20-meter sprint, time to completion was recorded. A contact mat was set up for the start of the 20 meters and a light gate marked the finish. Once the subject stepped on the contact mat (first sprint stride) from a standing start, the KMS program was triggered to start recording time and it stopped when the subject passed through the gate. The subjects performed three trials with 1-minute rest between trials. The best performance (lowest time to complete) was recorded.

Data analysis

Maximum voluntary contraction force and EMG

Using the AcqKnowledge software (AcqKnowledge III, Biopac Systems Inc., Holliston, MA), the maximum (baseline to peak) force during the MVCs' was analyzed.

The EMG signal for the tested muscle was smoothed (averaged over every 10 samples) and the average of the Root Mean Square (RMS) amplitude for 100ms during the MVC (taken 50 ms before and following the point of greatest force) was then analyzed. This was repeated for the quadriceps, hamstring and plantar flexors MVCs.

Muscle activity during jump landings

Using the AcqKnowledge software, the EMG signal for each muscle was smoothed (10 samples) and the average of a 100ms segment of the RMS amplitude was analysed prior to and following landing for each muscle. The 100ms prior to (preparatory EMG activity) and following landing (reactive EMG activity) were determined based on a marker placement in each EMG computer file. The marker was activated upon the landing of the participant's foot. These values were then normalized to the values obtained from the respective MVCs to calculate a percentage of the MVC EMG and a ratio of co-contraction of the hamstrings (BF) to quadriceps (RF).

Statistical analysis

Whereas, the three groups all exhibited a normal distribution (Shapiro-Wilk test of normality; Maximum critical value = 0.892 for $p < 0.05$; values ranged from 0.907 to 0.945) a repeated measures ANOVA (2x2) could be used. To investigate significant differences in the activity of each muscle, a three-way analysis of variance (ANOVA) (3 training groups x 2 testing times x 2 landings) was used to examine the EMG activity during the preparatory and reactive phases of the landing. A three-way ANOVA (group x time x landing) was also completed for hamstrings: quadriceps co-activation ratio in both the preparatory and reactive phases. Two-way ANOVA's (group x time) were completed to determine significant differences for the dependent variables of jump height, sprint time and static balance. Bonferroni post-hoc tests were used to discriminate between individual significant differences. All data were analyzed using GB-Stat (version 7.0 Dynamic Microsystems, Inc., Silver Spring, MD) for Microsoft Windows. The alpha level was set at $p \leq 0.05$ for statistical significance. Effect sizes (ES = mean change / standard deviation of the sample scores) were also calculated and reported (Cohen, 1988). Cohen applied qualitative descriptors for the effect sizes with ratios of 0.2, 0.5 and 0.8 indicating small, moderate and large changes respectively. Descriptive statistics and figures include means ± standard deviation (SD).

RESULTS

Maximum Voluntary Contraction – Force

Whether the groups were examined separately (group x time interaction) or with data collapsed over training groups (main effect of time), there was no significant difference in MVC force following balance training for the quadriceps, hamstrings or the plantar flexors.

Electromyography Activity (EMG)

Functionally directed balance test: Pre-landing activity: Whether the groups were examined separately (group x time interaction) or with data collapsed over training groups and landing (main effect of time), there were no significant differences in preparatory landing mean RMS amplitude for the RF, BF or soleus following training.

With data collapsed over training groups and time, there was significantly ($p < 0.01$; ES = 0.90) less preparatory soleus activity during the two-foot landing compared to the one-foot landing (57% ± 43.3 vs. 96% ± 64.2 of MVC).

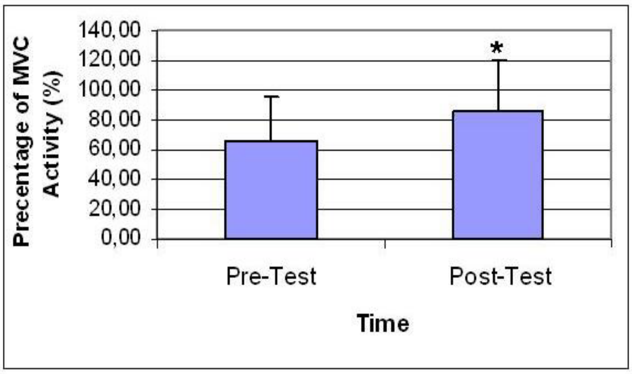

Figure 1. Reactive rectus femoris activity. * $p < 0.05$.

Functionally directed balance test: Post-landing activity: There was a significant ($p<0.01$; ES = 1.1) main effect (with data collapsed over training groups and landing) for training, with a 19% increase in reactive RF activity following training (Figure 1). There was also a trend ($p = 0.08$) for reactive soleus activity to increase (14%) following training. There was a significant interaction ($p<0.01$; ES = 1.6) increase of approximately 33% in the reactive RF activity with the fixed foot-training group from pre- to post-test (Figure 2).

With data collapsed over training groups and time (main effect for type of landing), there was significantly ($p < 0.01$; ES = 0.67) less reactive BF activity from the one-foot to the two-foot landings (30% ± 13.3 vs. 21% ± 11.6 of MVC). There was also significantly ($p < 0.01$; ES = 1.1) less reactive soleus activity for the two-foot compared to the one-foot landing (55% ± 43.3 vs. 101% ± 62.9 of MVC).

Co-activation of hamstrings and quadriceps: With data collapsed over training groups and time (main effect for type of landing), there was approximately 36% less co-activation ($p < 0.05$; ES = 0.63) with the two-foot versus the one foot landing (Figure 3). With data collapsed over training groups and landing (main effect for training), there was a significant ($p < 0.05$; ES = 0.41) decrease (approximately 20%) in the reactive co-activation ratio following training (Figure 4).

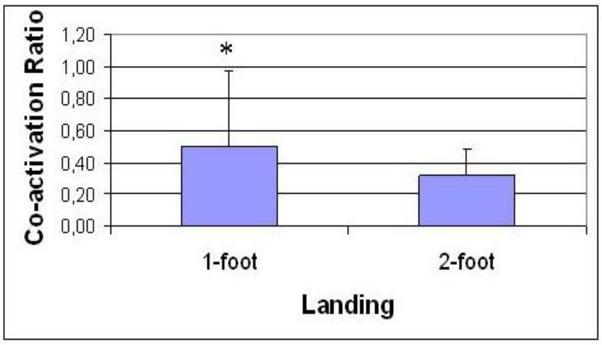

Figure 3. Reactive co-activation ratios. * $p < 0.05$.

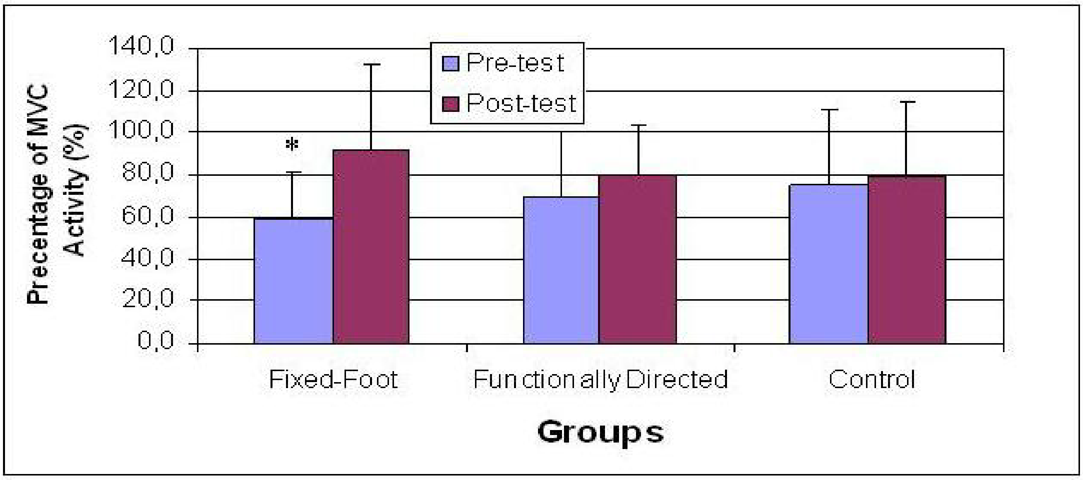

Figure 2. Reactive rectus femoris activity. * $p < 0.05$.

Performance Measures

Jump height and sprint time

With data collapsed over training groups (main effect for time), there was a significant ($p<0.05$; ES = 0.38) overall increase (5.3%) in jump height following training (pre-test: 0.223 m ± 0.031 vs. post-test: 0.235 m ± 0.033). A post-hoc test revealed a significant group by time interaction ($p<0.05$; ES = 0.57) with a greater difference in jump height (9.5%) between the fixed foot training group pre- (0.209 m ± 0.035) and post-test (0.229 m ± 0.041) as compared to the functionally directed and control groups. There were no significant differences in sprint performance.

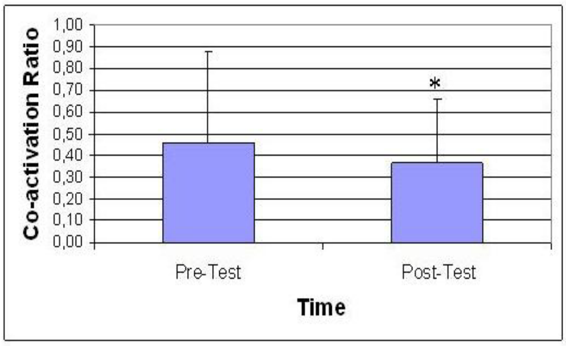

Figure 4. Reactive co-activation ratios.

Static Balance

For static balance performance there was a significant ($p<0.01$; ES = 0.8) group by time interaction with an improvement of 33% following training in the fixed foot balance-training group (Figure 5).

DISCUSSION

The most unique finding of this study was that balance training for recreationally active female subjects led to increased activity of the RF upon landing. Fixed foot balance training led to performance improvements in a dynamic task such as countermovement jump height. Conversely, neither fixed foot nor functionally directed balance training improved sprint time.

Functionally directed balance

Stability of the knee is provided through both preparatory and reactive muscle activity involving both feed-forward and feedback processing (Solomonow and Krogsgaard, 2001). Increased muscle activity can offer greater protection from the forces and loads experienced by lower-extremity joints during landing. It has been reported that the knee accounts for 23% to 41% of all athletic injuries (Kujala et al., 1986) and in basketball for instance, more severe knee injuries occur with women than men (Moore and Wade, 1989). Based on the current study, it appears that balance training for recreationally active women may be beneficial by increasing RF activation (and the tendency for preparatory RF activity and reactive soleus activity to increase) resulting in an increased muscle contractile response to reaction forces upon landing.

How much activity and stiffness is necessary to protect the joint and prevent injury however is still unclear (Kellis, 1998). Co-activation of the quadriceps and hamstrings increase joint stiffness and maintain stability but optimal amounts of co-activation are unknown (Solomonow and Krogsgaard, 2001). Co-activity in the present study decreased approximately 20% with balance training. Less co-activation does not necessarily equate with increased chance of injury. Grabiner et al. (1989) suggested that for healthy individuals the hamstrings are not utilized to reduce anterior cruciate ligament (ACL) loading. Furthermore, hamstring activity was demonstrated to be higher in ACL patients than with healthy individuals (McNair and Marshall, 1994). Kellis (1998) in a review of the literature reported a

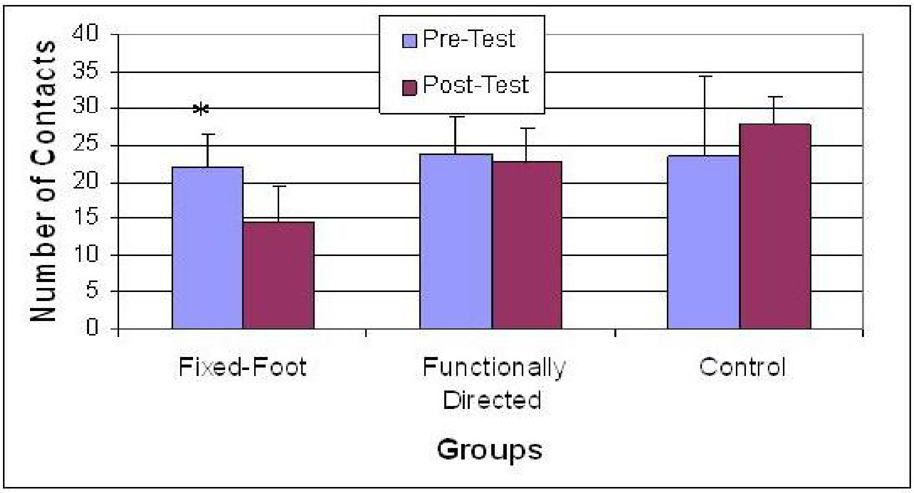

Figure 5. Static balance performance. * $p < 0.05$.

range of hamstring EMG activity from 9-50% of the quadriceps activation when performing activities such as walking, stair climbing, side stepping and isotonic contractions (similar to the values in the present study). Following an 8-week strength-training program, hamstring coactivity decreased approximately 20% (Carolan and Cafarelli, 1992). The authors indicated that these neural adaptations would enhance force-producing capabilities by providing less opposing force to the contracting quadriceps. Similarly, in the present study, the balance-training program did not generate greater coactivity. The decreased coactivity may have provided a modification of muscle co-ordination that would augment the increased RF activation during the eccentric portion of the landing.

The lack of training adaptations with functionally directed balance training might have been due to a lack of training intensity. Many of the studies that have examined jump landing patterns, had subjects complete fixed foot jumps of maximum height or drop jumps from various heights. The current study tested subjects with a functionally directed landing task by having subjects take three steps, jump from their non-dominant leg and land on their dominant leg over a pre-determined relatively low (20cm) obstacle. This was similar to a task implemented by Steel and Brown (1999), Cowling and Steele (2001) and Cowling et al. (2003). For these studies the landing was selected as a deceleration task and was thought to be similar to a typical non-contact mechanism for ACL injuries. In the present study, either the landing test was not sufficiently challenging or the functionally directed training program may not have been adequate to induce training-specific adaptations. On the other hand, the fixed foot training increases in reactive RF EMG activity during the landing task indicates that the fixed foot training program in this study was sufficiently challenging to the system in order to induce more diffuse or crossover training effects (non-training specific fixed foot to dynamic adaptations) to induce greater muscle activation. Augmented RF activation during landing may provide greater protection from external and reaction forces, contributing to injury prevention. Alternatively, a more highly activated muscle component may provide a stiffer spring-like mechanism decreasing the amortization period in the stretch-shortening cycle contributing to improved performances with eccentric-concentric coupled actions.

The decision to study one- and two-foot landings during the testing was due to the varying degrees of stability in the two tasks and both actions are present in various athletic activities. The two-foot landing was considered a more stable task due to the larger base of support (2 versus 1 point of contact). The findings of the present study support this idea, as the two-foot landings were found to have significantly less muscle activation and reactive co-activation than the one-foot landings.

Studies have found that simple instructions such as asking subjects to increase knee flexion during landing resulted in an appropriate (increased knee flexion) response from subjects. Subjects, however, were not able to respond to more complex instructions (asking them to activate selected muscles) (Cowling et al., 2003). The instructions for the functionally directed training group, in the current study, involved information regarding joint positioning rather than muscle activation strategies. Although it may be possible that the instructions could have affected the assessment outcome, based on the study of Cowling and colleagues (2003), it is more likely that the six weeks of balance training had a more significant impact.

Training specificity

It could be argued that one aspect of the present study contradicts the concepts of movement and velocity specificity (Sale, 1988) with fixed foot balance training improving performance in an explosive dynamic action involving countermovement jump height. This finding is similar to Bruhn et al. (2001) who noted a trend ($p = 0.17$) for jump height to improve following sensorimotor training. In the present study, the countermovement jump, which involved a controlled bilateral eccentric component to a 90^0 knee angle, mimicked some aspects of the fixed foot balance training (performing squats on a wobble board). Furthermore, Anderson and Behm (2004) demonstrated that force output decreases with decreasing stability. An improvement in stability with training should have increased the amount of force available for motive (jumping) rather than stabilizing functions. Finally, a more stable center of gravity should ensure that jump-related forces were directed in a more optimal (vertical) direction rather than suffering from slight deviations from vertical with a less stable individual.

Since the functionally directed balance tasks in the present study did not demand powerful contractions and emphasized slower controlled unilateral landings, there was no training crossover effect on the powerful bilateral contractions of the countermovement jump or the powerful rapid stretch-shortening type contractions involved with sprinting.

Force production

There have been equivocal findings on changes in force production/strength following balance training with some studies noting increases (Balogun et al., 1992; Heitkamp et al., 2001) and others showing no change (Bruhn et al., 2004; Holm et al., 2004). Studies using sedentary individuals (Balogun et al., 1992; Heitkamp et al., 2001) found increases whereas studies with trained subjects (Holm et al., 2004) found no increases. This matches the findings of the current study in which recreationally active female subjects participated. Furthermore, all of the previously cited studies used male participants, which could also have contributed to differences with the present study. Improvements in force with the aforementioned studies are more likely due to changes in coordination (Rutherford and Jones, 1986). For sedentary individuals the balance training may have been sufficient to improve coordination and positively affect strength. This may not occur in recreational athletes who may already have sufficient coordination to perform maximally or near maximally on the strength measurements.

Static balance

Similar to the findings of a number of wobble board (Emery et al., 2005) and sensorimotor (Bruhn et al., 2001; 2004; Heitkamp et al., 2001) training studies there were improvements in static balance following fixed foot balance training. Following the concept of training specificity (Sale, 1988), there were no crossover effects of functionally directed balance training on static balance measures. However, a more complete evaluation of training specific and crossover effects of the balance training programs should have included a wider array of static and dynamic balance tests.

CONCLUSIONS

Some of the findings in the present study illustrated the training specificity of balance training. Fixed foot balance training improved static balance measures but not force output or performance with sprinting. The squat activity during the fixed foot training may have provided a task or movement specific balance adaptation, which contributed to the increase in jump height. There was some crossover or non-specific training effects with the fixed foot balance training as reactive RF activity increased and co-activation ratios decreased with the functionally directed balance task. Functionally directed balance training did not independently improve any dependent variable and thus may not have been sufficiently taxing to the neuromuscular or vestibular systems. In conclusion, fixed foot balance training would be recommended for recreationally and less active individuals who by improving their fixed foot balance could increase their countermovement jump height and possibly provide increased knee protection from reaction forces with increased RF activity upon landing from jumping, striding or bounding type activities.

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KEY POINTS

- Balance training increased rectus femoris EMG activity upon landing from a stride.
- Fixed foot balance training improved countermovement jump height
- Neither fixed foot nor functionally directed balance training elicited changes in sprint times.

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