COMPARISON OF STATIC AND DYNAMIC BALANCE TRAINING ON MUSCLE ACTIVATION, STATIC BALANCE, JUMPING AND SPRINT PERFORMANCE

CRYSTAL OLIVE KEAN

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By

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A thesis submitted to
the School of Graduate Studies
in partial fulfillment of the
requirements for the degree of
Master of Science (Kinesiology)

School of Human Kinetics and Recreation
Memorial University of Newfoundland

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CO-AUTHORSHIP STATEMENT

The following statements clearly identify my role in the development, execution and preparation of this thesis:

1) **Design and identification of the research proposal:** The research proposal was developed from a previous work by Dr. David Behm. To expand on original studies Dr. Behm and I discussed and developed the methodology utilized. Dr. Behm provided the general overview of the studies and identified the variables to be measured and I developed the precise procedures and training programs.

2) **Practical aspects of research:** Raw data was collected by myself.

3) **Data analysis:** Under the supervision of Dr. Behm I performed all data analysis procedures.

4) **Manuscript preparation:** Under the supervision of Dr. Behm I prepared the manuscript.

THESIS STRUCTURE

This thesis was prepared in a non-traditional format. It has been written as two manuscripts, which are formatted for publication.

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THE ROLE OF BALANCE AND BALANCE TRAINING IN ATHLETIC PERFORMANCE

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Abstract

Balance has long been recognized as an important factor in a number of sports (such as gymnastics, and figure skating) and more recently has been regarded as important in other sports as well. Lack of balance has been shown to be detrimental to optimal performance through decreases in strength and force production, increased fatigue as well as predisposition to injury. Much of the research regarding balance training focuses on injury rehabilitation and prevention with little focus on examining the effects of short and long term balance training on athletic performance. The purpose of this paper is therefore to provide a comprehensive review of literature regarding balance, short and long term effects of balance training and its possible beneficial effects on athletic performance.

Introduction

There are a number of factors that affect athletic performance such as speed, strength, co-ordination, anthropometrics and endurance. Each of these factors plays a different role in a given sport with some being more important than others. For example, in football, characteristics of strength and power would be more important than aerobic endurance where as in distance running, aerobic endurance and speed would be more important than strength. The role of balance in athletic performance has become of increasing interest in all sports rather than just those that it has been traditionally deemed an important performance characteristic (such as figure skating, gymnastics). Poor balance has been associated with a number of negative effects such as decreases in force, increased muscle activation (which can be negative with submaximal or prolonged activity), fatigue and decreased confidence.

Due to the negative effects of poor balance on performance, it is important to incorporate balance into the athletes' training programs. It is, however, unclear what method is most appropriate to incorporate balance training since research into the effects of balance training and its specificity are limited. Does dynamic balance training transfer to only dynamic situations or can it also transfer to static balance and vice versa? It has been well documented that various types of training are specific in their adaptations. For example, when muscles are trained in a limited range of motion, the greatest strength improvements occur when evaluated in that specific range of motion (1). Because of this specificity, optiamal training must mimic the demands of the activity. While considering the factors important to the athlete's performance, one must also consider the effect concurrent training has on each factor. Concurrent strength and endurance training can have an adverse effect on strength (2-4), but the effects of concurrently training balance and other factors, such as strength and endurance, are unknown. For this reason, periodization is important for ensuring that the requirements of each factor are met and the interference with other factors is limited.

Most training adaptations are shown to be specific; transferring to situations that most simulates training conditions. Single sessions of balance training have been shown to improve performance in subsequent activities (5, 6). The effects of chronic balance training on injury rate in soccer, handball and volleyball studies have shown some promising results (7-13). The effect of balance training, however, on balance, proprioception and strength have shown mixed results (8, 14-20), and even fewer studies have examined the effects of this training on specific athletic performance (15, 21, 22). The objective of this paper is to review the literature regarding the role of balance and balance training in athletic performance.

How Balance Relates to Athletic Performance

For an athlete to perform at the best of their ability, they must have all training variables optimized. Stability is important to performance because in most sport situations you are constantly changing body position, accelerating and decelerating as well as dealing with unexpected perturbations (for example contact with another player or uneven field conditions). It has been found that pitchers who demonstrated greater stability had lower levels of pitching errors (23). Based on these findings, improving balance of athletes may be beneficial to improving athletic performance. Behm et al. (24) found a high correlation between hockey skating performance and static balance in hockey players under the age of 19. This relationship was not seen in older adults, thus stability maybe more important for speed performance in less experienced than experienced players.

Poor balance has been associated with a number of health care problems such as chronic knee and ankle pain or instability (25, 26), osteoarthritis of the knee (27, 28), and acute ankle sprains (29). For an athlete, these injuries can limit training time and lead to decreases in performance. Low back pain can also result from instability which can lead to a number of other problems for instance, inflexibility, altered muscle firing patterns and muscle imbalances (30-32). In addition to these health problems, poor balance can also adversely affect athletic performance (23, 33-35).

Fatigue

Instability has been shown to lead to a decrease in energy efficiency which can be detrimental to performance by leading to early fatigue. Mattsson and Brostorm (36) found an increase in the oxygen cost of walking with an unstable ankle (10%) and immobilized knee (23%). Increased energy expenditure during walking was also found in subjects with bilateral above-the-knee amputation. This increased expenditure was not only due to the walking movement but also due to increased energy necessary to maintain balance when walking (37).

Fatigue has been shown to affect proprioception and kinaesthetic properties of joints (38, 39) thus impairing balance and postural control (40, 41). It can also lead to decreased force production (42), coordination (43), and jumping performance (44). In subjects with joint instability the decreased dynamic postural control was also amplified in the presence of fatigue (40). Thus, a negative cycle is formed and there are increased risk of injury and decreases in performance.

Strength, Power and Muscle Activation

Instability has also been shown to decrease force output, velocity and power. For example, Kornecki (35) showed that the increased muscle contraction required for stability resulted in an average decrease of 30% in force, velocity and power. Behm et al. (45) examined the effects of muscle force and activation under stable and unstable leg extensions and plantar flexions. It was found that maximal force production decreased by 70.5% for the leg extension and 20.2 % for plantar flexion. The lower decrease in the plantar flexors force was due to the unstable condition still being more stable than the leg extension unstable condition (3 contact points vs 2 contact points). It was also found that during unstable leg extension, quadriceps activation averaged 44.3% less than the stable condition.

Anderson and Behm (34) examined muscle activation during a common resistance training exercises (chest press) under stable and unstable conditions. Subjects performed a maximum contraction chest press and it was once again shown that force production decreased. For the chest press, force output under the unstable condition decreased 59.6%, however there was no significant change in muscle activation between the stable and unstable conditions. Although force output decreased, the similar degree of activation illustrated that the synergistic and stabilizing muscles were stressed to a greater extent under the unstable condition and the muscles were recruited for a stabilizing rather than mobilizing role.

Another study by Anderson and Behm (33) examined muscle activity of trunk stabilizers and other postural muscles (soleus) during stable and unstable squats of three varying contraction intensities (no external resistance, with 29.5 kg of resistance and with 60% of body mass as resistance). There was an increased activity in these muscles during unstable conditions. If the unstable activity was repeated, the increased muscle activity could lead to increased fatigue and as was mentioned previously this could further affect performance.

When considering various sports, one can see that an athlete is rarely in a stable environment. Based on the findings of the above mentioned studies, if an athlete is unable to prepare for the instability, their performance is obviously going to decrease. For example, if a hockey player is unable to balance him or herself while taking a shot, the amount of force they can generate behind their shot may decrease. The muscle activity is directed to maintaining balance rather than producing the desired force to make a successful shot. In addition to the decrease in force production, if the athletes have increased muscle activation and postural muscles to maintain stability, there is an increased demand on the body's energy system which in turn can increase the rate of fatigue which may decrease performance.

Injury

Poor balance has been shown to be a predictor of injury and it has also been shown to be impaired in those with injuries, specifically ankle injuries. McGuine et al. (29) examined balance as a predictor of ankle injury rates in high school basketball players found an increase risk of injury in those with poor balance. Balance was assessed by measuring the postural sway which was defined as the average degree of sway per second (compilation (COMP) score). It was found those who sustained ankle sprains had a higher preseason COMP score than those who did not sustain an injury, with those demonstrating poor balance having almost seven times as many ankle sprains as those with good balance (29). It has also be shown that those with functional instability, as measured by performance on a stabilometer, had higher risk of sustaining an ankle injury than those with a more stable performance on the stabilometer (46).

Another study examined static and dynamic postural stability in individuals with functionally stable and unstable ankles (25). Subjects performed single-leg stance and single-leg jump landings to measure anterior/posterior and medial/lateral mean sway and time to stabilization for static and dynamic postural stability, respectfully. The mean sway was not significantly different between the groups, however, anterior/posterior time to stabilization was considerably long for those with functional instability. Lateral and anterior peak forces also occur earlier during jump landings in subjects with ankle instability (47) as well as greater ankle dorsiflexion and knee flexion. These altered patterns of activation and time to stabilize could put an athlete at a greater risk of injury.

Based on these findings, it appears that instability of a joint can lead to a decrease in performance. Although the instabilities in some of the aforementioned studies were induced through external environments, one would think that instability within the system, including problems with neuromuscular system or muscle systems, would lead to similar decreases in performance. The key when training, however, is to ensure the training program is specific to the desired gains.

Training Specificity

Training adaptations have been shown to be very task-specific (48). For example, the angle, type, velocity of a contraction is very specific and training at a specific angle, velocity or type of contraction can lead to minimal increases in performance at other angles, velocities or with other types of contractions. In addition to these strength training factors, metabolic adaptations are also specific to the type of training (aerobic versus anaerobic). It was first shown that resistance training was specific to movement by Rasch and Morehouse in the 1950's. They found larger increases in strength when subjects were tested in a position that mimicked the strength training exercise protocol (49). Research has shown the specificity of training is seen in a number of factors (48, 49, 50, 51) however, specificity of balance training has not been well established.

Guidelines for resistance training often focus on slow, controlled movements however applying the principle of specificity, greater gains could be seen if training velocities mimicked the velocities of the sports skill. For example training at faster velocities may be more appropriate when a sport skill requires greater power and velocities greater than 200 degrees/second (50). Behm (51) trained 31 male subjects using either isotonic equipment, hydraulic equipment, or surgical tubing to perform a shoulder press at 180 degree/second. Following the training they found significant gains in one repetition maximum for all groups at and below the training velocities, however there were no gains at velocities above the training velocity (51).

Rutherford and Jones' (52) were able to demonstrate that the improvements in strength training were largely due to the ability to lift the weights in a more coordinated manner rather than increases in peripheral factors such as amount of muscle activation or intrinsic strength factors of muscle size and fiber arrangement. It was found that large increases in quadriceps strength were not reflected in increases in intrinsic strength of muscles. Improvements in isometric strength were also shown to only account for a small amount of the improvements in weight lifted. Based on these results, it may be possible that the coordination of the abdominal and trunk muscles to stabilize the body may assist in the ability of the quadriceps to generate force. Although these findings support the role of coordination and learning in strength training, the patterns of activation of the abdominals and trunk during leg extension exercise may vary from those in athletic events such as jumping and sprinting. Therefore, it is important to ensure the training task is specific to the athletic event rather than focusing on specific strength exercises for selected muscles.

Similarly to the finding of dynamic strength training and the lack of transfer to static adaptations, it has been documented that there is little transfer between different balance skills. Static measures of balance did not transfer to dynamic measures (53) suggesting little transfer between skills requiring dynamic balance and those requiring static. It has also been found that various measures of walking balance (dynamic) do not correlate with measures of standing balance (static) (54).

Improvements in balance following balance training programs also seem to be specific to the type of balance involved in the training programs. Most studies have found dynamic balance improves following programs that involve dynamic balance exercises (14, 55) whereas static balance has improved following, static balance training (20). There has however been some transfer between dynamic balance training and static balance performance and vice versa (16, 55).

For athletes, skills are typically not performed in stable situations (for example when completing skills such as a golf swing, a hockey shot or a soccer kick the body is an unstable system) therefore based on the concept of training specificity it is important that the training simulates the demands of the task. Thus when training one must create an environment that provides sufficient chaos similar to the situations an athlete may encounter during competition. This chaotic environment can possibly be created through training on unstable surfaces.

Classic stability training focuses on movements with slow, isolated single plane movement, but for athletes the training program must be concerned with balance, stability, mobility and flexibility (56). The problem with incorporating these components in stability training is the counter-productivity of developing phasic strength without tonic stabilization.

Training on a stability ball, enables the whole-body to be activated to maintain balance rather than individually training each segment in a balanced situation thus the athletes is better able to coordinate his/her body efficiently as well as increasing skill, speed and power (56). Like with strength and endurance training, specificity of training is important with stability training as well. Thus, as suggested from the research by Behm et al. (24) performing unilateral exercises or exercises in an unstable environment may simulate the sport action. Abdominal crunches and other exercises on a stable surface would also tend not to transfer well to sports situations due to the dynamics of the activity (56). Thus performing crunches and other abdominal/back strengthening exercises on an unstable surface such as a stability ball may provide the added challenges an athlete needs to maximize his/her core stability for performance. However the question remains regarding the specificity of performing unstable static exercises while prone or supine to performance improvements in unstable upright or erect activities.

Since training is task specific, it is important that each characteristic of performance be accounted for in the athletes training performance. When structuring an athlete's training program, it is therefore important to consider the negative effects concurrent training of physical abilities (strength and endurance) can have on each other. Training studies have found mixed results on the effects of concurrent training on strength, aerobic fitness and power. The most consistent finding is that concurrent training hinders improvements in strength and power (2-4). Other studies, however, have shown no difference in strength and power following concurrent training (57-60). Many differences in the studies results are due to differences in training modes, testing measures, and the volume and intensities of the training programs.

Due to the fact that the various forms of training may impair the training effects of another program, one must select which factor is important to train at various times during the season and when it is appropriate to vary the intensities and volume of each factor. This is done through creating a periodization program of training which breaks the season into macrocycles and mesocycles which enables the trainer to manipulate the training intensities and volumes of each factor. How balance training affects other performance factors (such as strength, aerobic fitness) has been examined to a limited extent (8,14-16, 20) (more details later) and the effects of concurrently training balance and strength, power, or aerobic fitness has not been researched.

Effect of Acute Balance Training

Single sessions of balance training have been shown to have an effect on the H-reflex and also anticipatory postural adjustments (APA) which are important for maintaining balance. The effects of acute balance training on athletic performance, however, are unknown. The central nervous system (CNS) takes into account the biomechanical characteristics of a movement as well as the initial and final position to minimize balance perturbations (61-64). Based on the CNS interpretation of the movement, it initiates APA's to preserve whole body balance by activating various muscles necessary to minimize the postural disturbances of the movement.

The maintenance of postural stability is partly due to the response of spinal-stretch reflexes to involuntary stretch of postural muscles (65). With age the spinal-stretch reflex system has been shown to degrade, however Myhark and Koeja (5) were able to demonstrate that single sessions of balance training could retrain and rehabilitate the ability to modulate reflex output. Mynark and Koceja (5) found that following one session of balance perturbation, there was significant down training of the soleus H-reflex in both young and elderly subjects (20.4% and 18.7%, respectively). Following a second session of balance perturbation, there was additional down-training of the soleus H-reflex from the initial to the final test block (24.6% in young subjects and 21.0% for elderly). In addition to reducing the H-reflex, there was a significant improvement in static balance in the elderly subjects from pre-test to post-test.

Once exposed to an unstable condition, postural adjustments to maintain balance are quickly modulated to the previous condition. With repeated exposure to slipping, feedforward adjustments from sit-to-stand performance were made to reduce the likelihood of backward balance loss. Following only 2 trials of slipping, subjects significantly decreased the anterior position and forward velocity of center of mass to prevent backward balance loss (66). With repeated nonslipping conditions, subjects made adjustments to reduce the likelihood of falling forward. The CNS, thus made feedforward adjustments based on the last condition experienced and over the training session made longer-term adjustment to reduce loss of balance in both forward and backward directions.

In a similar study by Pai et al. (67) feedforward adjustments in elderly subjects were found following repeated slip exposure. The elderly subjects were able to reduce their incidence of falls and backward balance loss, and with repeated exposure to slip and nonslip conditions, the subjects began to adapt a general strategy to avoid balance loss under both conditions (67). Like Pavol and Pai (66), the results from Pai et al. (67) indicate that adaptations began immediately and reached a steady state within two trials.

Recovery response following an initial slip trial has also been found to be significantly different than the recovery response on subsequent slip trials (6). During the first slip there was rapid onset of flexor synergy, large arm elevation and modified swing limb trajectory, these responses were reduced on subsequent slips (6), thus it was demonstrated again that the CNS can quickly adjust to the condition based on previous experience.

Although it has been shown that feedforward adjustments to muscle and reflex activity can be modulated following a single session of balance perturbation to improve balance and stability, it is unclear if simple balance activities can improve stability and balance in subsequent athletic performance. For example, can non-specific static and dynamic balance training activities improve performance on unstable tasks such as agility tests, or unstable power? Although research into the effects of acute balance training are limited to APA's and reflexive activity, long term balance training has been examined for injury prevention and rehabilitation and some athletic performance measures.

Effects of Chronic Balance Training

There are a number of terms used to describe balance training. For the purpose of this review, studies which have examined the effects of exercises that challenge dynamic and static balance will be regarded as balance training programs. Other terms used by these studies for balance training include (but are not limited to): neuromuscular training, proprioceptive training, ankle disc training, wobble board training and jump-landing training. These programs all use a variety of equipment such as exercise mats, wobble or balance boards, Pedalo stepper, mini-trampolines, Swiss balls as well as instruction on proper techniques to aid in the maintenance of balance. Balance training is often used as part of an injury rehabilitation program; however there is little scientific research to support its use. There is, for example, anecdotal evidence for the use of wobble boards to increase the range of motion of the ankle joint, reduce the incidence of chronic ankle injuries and also strengthen muscles of the lower extremities (68, 69). In more recent years research has been conducted to support these claims; however there are still a number of areas to be examined. Research in the use of balance training to improve athletic performance and its transferability to various sport skills is even more limited.

Much of the research regarding balance training has examined its use in injury prevention and rehabilitation, postural control, proprioception, and some athletic performance factors. Research in these areas has been conducted in sedentary populations, athletes as well as older adults. Most of the findings support the use of balance training; however there are some conflicting results and the protocols for balance training are quite different.

Injury Prevention

Balance exercises and training programs are often used both to prevent sports injuries and as an integral part of rehabilitation of these injuries, particularly ankle sprains and anterior cruciate ligament (ACL) injuries. The programs are designed to address risk factors for injury, such as awareness of body positions (in particular the knee and ankle), and restore muscle strength and proprioception after injury. Through the use of external devices such as wobble boards and exercise mats, challenges are provided to the neuromuscular system. It is therefore believed that the unstable surfaces could improve proprioception, coordination and overall balance as well as challenge the core muscles of the body.

The studies of injury prevention have focused on sports such as soccer, handball and volleyball with much of the research examining female athletes. With regards to knee injuries, females are 4 to 6 times more susceptible to knee injuries than males participating in the same sports which involve jumping and cutting. Knee ligament injuries and meniscal tears are the most common female soccer player injury (70) and ankle sprains are most common in adolescent and adult (both male and female) soccer players (9). In handball, ACL injuries are five times higher in females and the difference is greater at the elite level (8). While in volleyball ankle inversion sprains are the most common acute injury (71).

Soderman et al. (9) examined the use of wobble board training in the prevention of traumatic injuries in female soccer players. The wobble board group athletes performed a 10-15 minute wobble board program daily for 30 days and then 3 times a week for the remainder of the season. This study found no significant difference between the control and trained groups with respect to the incidence of traumatic injuries, number of injured players, number and type of injury, or the time of first injury. The trained group did, however, have a higher incidence of major injuries. One positive finding of Soderman et al. (9) was that out of players who had been injured within three months of the study, more of these players in the control group sustained a new injury as compared to the intervention group. This however maybe due to lingering effects of the injury (for example inadequate fitness level) even though the symptoms/signs of the injury were not present. There findings are contradictory to those of Caraffa et al. (13) who found a reduction in the number of ACL injuries in semiprofessional/amateur soccer players. The players completed a 5-phase progressive training program on a wobble board for 20 minutes a day which is a greater volume than Soderman et al. (9).

Wedderkopp et al. (11) used a training program involving ankle disk exercises and two or more functional activities for the major muscle groups. They examined the injury rate among female handball players who followed this program and similar to the aforementioned studies found significantly fewer injuries during games and practices than in the control group of female handball players was found (11). It was unclear, however, if the ankle disc training or the functional activities in the warm-up were responsible for the differences in injuries.

Following Wedderkopp et al. (11), another study was conducted to distinguish between the ankle disc (wobble board) training and the functional strength training components of the Wedderkopp et al. study (11). The wobble board training resulted in significantly fewer traumatic injuries (a fourfold reduction in the odds of a traumatic injury); however there was no difference in the number of overuse injuries. The wobble board group had only minor injuries while the function strength training group had ten minor, five moderate and one major injury (7).

Petersen et al. (72) found similar results following a proprioceptive program that incorporated information on injury mechanisms, proprioceptive training and jump training. Compared to the previous season, those in the training group did not have any severe injuries to the ankle or knee and the incidence of mild and moderate injuries was significantly lower in the prevention group (72). The difference between seasons was not significant due to the low number of subjects. It is possible that the wobble board training could improve proprioception, coordination, and overall balance which would enable the athletes to avoid collisions and unprovoked falls thus preventing injuries (7).

Myklebust et al. (8) specifically examined prevention of ACL injuries in female handball players over three seasons. They designed a neuromuscular training program, using floor, mat and wobble board exercises, to improve awareness and knee control during athletic maneuvers that often lead to injury specifically cutting, jumping and landing. In the elite division, those who completed the training program had a decrease risk of injury. There was also a reduction in the total number of non-contact injuries from the control season, the second training season (eighteen versus seven) and a trend toward a reduction in the number of ACL injuries during the three seasons ($p = .15$ for all divisions and .06 for the elite division only).

There have been three studies examining balance training and injury prevention in volleyball. Similar to the results of the handball studies (11, 7) and the Caraffa et al. soccer study (13), the use of balance boards, in some cases, is effective in preventing injuries. Verhagen et al. (73) found significantly fewer ankle sprains in the balance board training group with the risk of an ankle sprain, after the training, being reduced for those who had a history of ankle sprains. The incidence of overuse knee injuries in those with a history of knee injuries was, however, significantly higher in the intervention group than the control. The effect of balance training on reducing injuries in those with a history of ankle sprains is similar to the findings of Barh et al. (12) and Tropp et al. (74). Using the proprioceptive and technique programs outlined by Barh et al. (12), Stansinopoulos (71) also showed that the programs were effective in preventing ankle sprains in volleyball players who had suffered four or more ankle injuries. Although the incidence of overuse knee injuries increased in those following the balance program, the amount of balance training (four times per week, less than five minute sessions) does not seem sufficient to account for the injuries. It is however possible that by preventing injuries in the ankle, the knee has now become the weaker link and thus more susceptible to injury.

Hewett et al. (10) conducted a study to investigate the effects of neuromuscular training on the incidence of knee injuries in females. The researchers monitored two groups of female athletes, one that was trained prior to participating in sports and the other was not, as well as a group of untrained males. The training program consisted of flexibility, plyometrics and weight training which were used to increase muscular strength and decrease landing force. There was also a jump training program which over six weeks, the participants were taught proper jumping techniques, built a base for strength, power and agility and also how to achieve maximum vertical jump. The results of this study revealed that the female untrained group incurred higher incidences of injury than the male untrained group and there was no significant difference between the female trained group and the male untrained group. The injury rate for the untrained females was 3.6 higher than trained females and 4.8 higher than males. The trained females only showed a rate 1.3 times higher than males.

Another study examined the effects of a home-based balance training program in healthy adolescents (75). High schools students, who completed the training program, reported fewer injuries than the control students. The training program was also more effective in preventing injuries among students who had reported injuries in the previous year. Although there is significant clinical importance in the different injury rates between the intervention and control, this study used self-reporting of injuries. Due to possible difference in interpretations of injuries by the subjects the self-reporting could lead to errors in data. Other studies had set criteria of injury levels, such as any injury occurring during a game or practice that caused the athletes to miss the next game or practice or to participate with discomfort (76, 11) and had physical therapist and coaches report the injuries (8, 9, 71, 73).

The use of balance training in an athletic population has been shown to be beneficial in the prevention of injuries. These studies have done little to speculate on why this type of training has decreased the number of injuries as they have just examined injury rates and not physiological factors (such as muscle activity patterns), proprioception, balance, or other mechanisms which may underline the adaptations that occur with balance training. Most will say the training improves proprioception and balance, based on other research which will be discussed shortly, but these studies have did not directly measured balance and proprioception with their training programs.

Strength Gains

Holm et al. (14) attempted to understand some of the underlying mechanisms of neuromuscular training and why it is effective in reducing injuries in the lower extermeties by examing the program implemented by Myklebust et al. (8). Holm et al.

(14) took the same program and examined its effects on strength and functional ability as well as balance and proprioception. Isokinetic strength was measured, using a Cybex, and functional ability was measured using three functional knee tests including 1-leg hop, triple jump or stair hop test. There were no significant differences over the study period in muscle strength, with quadriceps and hamstring strength as well as the ratio of hamstring to quadriceps strength remaining constant throughout the study. There were imbalances found between dominant and non-dominant leg hamstring muscles at 240°/sec at pre-training and 1 year following training test. There was also no significant difference in the functional knee test. Based on the idea of training specificity it is not surprising that strength and functional ability did not improve as the training program was not designed to improve these areas.

Like Holm et al. (14), Bruhn et al. (15) did not find any significant changes in muscle strength, however there was a tendency, within the balance training group, for maximal voluntary contraction (MVC) during one legged isometric contractions ($p = 0.057$) to increase by approximately 5%. The balance training group performed various balancing task on a wobble board for one hour, twice a week for four weeks. There was approximately a 4% improvement in squat jump heights following sensorimotor training, but again it did not reach significance ($p = .117$). The muscle activity of the shank muscles (gastrocnemius medials, peroneus longus and tibialis anterior) during a 40 second one-legged balance test was slightly improved after the sensorimotor training but failed to reach significance. For the strength training group however, the muscle activity of the shank muscles was significantly reduced following training. The sensorimotor group also had more preparatory muscle activity during early ground contact of the drop jumps. The improved muscle activation for the sensorimotor group may contribute to the stiffness regulation of relevant muscles when completing athletic tasks such as jumping (15).

Although the study by Holm et al. (14) did not find significant changes in muscle strength, a study by Heitkamp et al. (16) did find strength gains and improvements in muscular balance following balance training. Heitkamp et al. (16) questioned whether the gains in strength at the beginning of a resistance program could also be seen by coordination training without the actual resistance training. The balance training program stressed the hamstrings and quadriceps through use of mini trampolines, rolling boards, and Swiss balls. The strength of the flexors (hamstrings) and extensors (quadriceps) increased in both the resistance training and balance training groups, with the gains being slightly higher following resistance training (22% vs 12%). The percentage difference between right and left extensors decreased in both groups with subjects in the balance training reaching similar strength values in both right and left. There were four cases in the strength training group of increased muscle imbalance in the flexors, however in the balance training group all subjects showed a decrease in muscle imbalances (16).

Balogun et al. (20) also found increased knee extensor and flexor muscle's isometric force as well as in ankle dorsiflexors and plantar flexors. These increases were greater than those of Heitkamp et al. (16) with knee extensors and flexor isometric force increases by 56.3% and 58.6 %, respectively and ankle dorsiflexors and plantar flexors increasing by 133.1 % and 97.3 %, respectively. These studies used different methods to measure the isometric strength. Heitkamp et al. (16) used the Cybex, an isokinetic device, and Balogun et al. (20) used a cable tensiometer. The training programs also differed as Balogun et al. (20) had subjects train on a wobble board only by rocking back and forth for 10-25 minutes, 3 times a week for 6 weeks with the time increasing as weeks progressed. The gains by Balogun et al.'s (20) subjects were reported to be comparable to that of isometric and isotonic weight training programs.

Although the gains in strength were quite high, the authors were not surprised with their finding because the muscles of the lower extremities during wobble board exercises can be stressed with sufficient intensity to elicit strength gains. For example the tibialis anterior, while on a wobble board, can be stressed up to 80% of the MVC (77). Since the exercises of the training programs vary considerably and so do the results regarding strength gains in the lower extremities, it may be that the exercises in the studies that showed no gains, did not provide sufficient stress to see adaptations. It is interesting to note that the studies that found strength gains were conducted on sedentary individuals and those that did not find strength gains were conducted on elite athletes. Thus, the stress may have been sufficient for sedentary individuals but not for athletes who have high training levels and require higher overload to elicit training adaptations. Therefore as with other training, the principle of overload must be applied to the balance training to see gains in strength.

The improvements in muscular balance are very important when examining injury prevention as imbalances greater than 10% have been linked to higher injury rates (78). Another study found that hamstring imbalance between dominant and non-dominant legs greater than 15% correlated with higher incidences of lower extremity injuries in female athletes (79).

Balance and Proprioception

Balance and proprioception adaptations are the two common dependent variables examined with balance training. Much of the research examines the benefits of the training to improve balance and proprioception in healthy individuals and those with ankle instability. Both static and dynamic balance have been studied with varying difficulty while proprioception has been studied through kinaethesia (threshold to detection of passive movement, TDPM) and joint position sensibility.

Based on the principle of training specificity, it is not surprising to find balance and proprioception often improve following neuromuscular and proprioceptive balance training programs. Following a 4 week neuromuscular training program for postural control, Kovacs et al. (55) found significant improvements in balance during more challenging test (such as landing with eyes closed) and only small changes in basic test (such as single limb standing with eyes open). The program was specifically designed for figure skaters and thus the subjects may have already had sufficient postural control to perform the basic test. Balogun et al. (20) in their 6-week study of wobble board training in sedentary men, however found large improvements in static balance during single limb stance test with eyes open (201.2%) and eyes closed (58.8%).

Holm et al. (14) also found improvements in dynamic balance following a neuromuscular training program; however there was no significant change in static balance. Once again, following the principle of training specificity, it was not surprising that dynamic balance improved and not static because the program involved mainly dynamic balance exercises. Heitkamp et al. (16) found that static balance (one-leg standing) increased 146% in their balance training group while only 34% in the strength training group. The improvements in dynamic balance however were seen to have individual variation in the balance training group but no significant changes in the strength training group. The increases in static balance were proposed to be due to the effects of the training on reflex control as the strength group exercises involved closed chain kinetic exercises (16).

Improvements in postural sway have also been illustrated following balance training. Kollmitzer (18) found improvements when subjects had full sensory feedback from their feet. Strength training of the back extensors however resulted in an increased body sway. In subjects with ankle instability, both medial/lateral and anterior/posterior postural sway were improved during a stable eyes closed and dynamic eyes open balance test following balance training (80). Postural sway has been shown to be increased in those with functional ankle instability (80). Postural sway was again shown to improve following ankle disc training and a multi-station proprioceptive training program (80, 81). Both Gauffin et al. (82) and Rozzi et al. (83) found improvements in the balance of untrained limb following 8-weeks of ankle disc training and 4-weeks of static and dynamic balance training, respectively. Gauffin et al. (82) found that when standing on the non-symptomatic untrained foot there was a decrease in postural sway. Rozzi et al. (83) examined balance performance on a platform of varying stability and found that on a less stable platform the unstable- ankle balance-training group had improvements in the trained (injured limb) where as the nonimpaired training group had improvements in both the trained and untrained limb. On the more stable platform, however, the opposite results were found with the unstable ankle group having improvements in the balance of both the trained and untrained limb where as the nonimpaired group only had improvements in the trained limb (83). The findings of these studies suggest a central neuromuscular control mechanism for balance and posture and illustrate cross education between the limbs.

Ankle and knee proprioception have also been examined following balance training programs. The results of these studies have shown to be mixed, with either improvements or no change being noticed. The results seem to depend on the training state of the subjects, the program guidelines and initial ankle stability. The TDPM remained unchanged following neuromuscular training of female handball players (14). The TDPM was lower than that of normal values in a study by Beynnon et al. (84) and similar to the findings of that of Lephart et al. (85) who found the TDPM was significant lower in intercollegiate gymnast in an age-matched control group. It is therefore possible that the training did not provide enough stress to lead to adaptations in elite athletes.

Unlike Holm et al. (14), Waddington et al. (19) found improvements in movement discrimination for both right and left ankles in first-grade rugby players following 5 weeks of wobble board training. These results were replicated in another study by Waddington et al. (17). Wobble board training resulted in improvements of ankle discrimination where as jump landing training resulted in no improvements. Knee flexion discrimination was also found to improve from pre-test and post-test, however these results were also found in the control group and therefore viewed as a result of the normal training program of the rugby players.

Joint position sense, measured through passive and active movements, has been shown to improve following balance training in subjects with ankle instability (83). There were more pronounced improvements found at 15 and 30 degrees of plantar flexion. Bernier and Perrin (80) also found improvements from pre-test to post-test (p=.024) and with the mean of active position sense greater than passive position sense ($p<.001$). The improvements noticed, however, were postulated to be a learning effect rather than the training as there was no main effect or interactions involving groups (80).

Improvements in joint position sense, in particular plantar flexion, may be important for athletes to prevent recurrent injuries (81). Based on these studies, balance training does tend to illustrate the principle of specificity. For the training to be effective the task needs to replicate the desired activities and challenge motor control. Being able to discriminate ankle movements may enable athletes to detect the extent of inversion which may be dangerous to the lateral ligaments of the ankle and therefore initiate eversion to prevent injury. Discriminating movements may also allow for more accurate foot preparation when landing which can again aid in the prevention of injuries (17).

Balance Training with Older Adults

As we age there is a significant lost of functional balance and this loss is more pronounced in those who are physically frail. The loss of balance is due to deteriorations in function of both the neural and musculoskeletal systems (86). The loss of functional balance can lead to falls and injuries which can further lead to loss of independence. Various forms of exercise have been shown to improve balance (87-89). Tai Chi, functional balance exercises, community based balance programs and wobble board training programs have been implemented in older adult studies to examine the effect on balance, prevention of falls, and strength.

Tai Chi as a mode of balance training has been found to improve control on function balance tests (Berg Balance Scale, Dynamic Gait Index and Functional Reach Test), however had no effect on strength (measured by grip strength) (90). In the same study, following the 6 month Tai Chi program there was a decrease the number of falls, the risk for falling, and the fear of falling in elderly populations over 70 years of age (90).

Nitz and Choy (91) implemented a workstation balance program that mimicked daily activities and found functional ability to improve as well as functional balance. As with the younger subjects of Waddington et al. (17, 19), the elderly subjects also had significantly greater mean ankle discrimination change following wobble board training (92). Nordt et al. (93) also found single-axis wobble board training to improve balance and confidence in their elderly subjects. Improvements in balance were found to be significantly related to reducing the likelihood of falling and increase the confidence of the elderly adults by decreasing their fear of falling (93).

Neuromuscular Function of Lower Limbs for Stability

During movement, stability is provided through the lower limbs and trunk musculature. It has long be recognized that when a limb is moved, the body configuration is altered and therefore a reaction force of the same magnitude but opposite direction of the movement force must occur in order to maintain stability. When the CNS activates muscles of the trunk to prepare for movement, it also activates the muscles of the lower limbs. Two kinematic strategies have been noticed in subjects when trying to maintain postural stability. The first is the 'hip strategy' during which equilibrium is maintained by moving the body around the hip joint, with the second strategy, 'ankle strategy', involving movement around the ankle joint as a way to maintain stability (94). The soleus is one of the most important muscles of the lower body in maintaining posture as its one of the first muscles activated around the ankle joint to help the body restore equilibrium (95).

When rapid arm movements are performed in unstable conditions there is a decrease in anticipatory activity of the tibial anterior, bicep femoris as well as the erector spinae and rectus abdominis, however the decrease in anticipatory activity were only significant for the bicep femoris (96). Unlike activation of the deep trunk muscles which are activated to maintain stability no matter which direction the movement is in, muscles in the lower body are activated based on direction. When an unstable platform was displaced backwards (body moves forward) the hamstrings and gastrocnemius were activated to maintain stability (97). It has also been shown that if the final posture is unstable, APA's are greater (98).

To stabilize the ankle and knee when jumping, landing, running and many other sporting activities, the neuromuscular system places a major role. When referring to joint stability, neuromuscular control is viewed as the "unconscious activation of dynamic restraints occurring in preparation for and in response to joint motion and loading for the purpose of maintaining and restoring functional joint stability." (99, p. 73). For joint stability information from the three sensory systems (somatosensory, visual and vestibular) are also necessary. These three systems provide proprioceptive information about the external environment (eg. uneven ground during walking or running) as well as plan and modify internal motor commands (99). When landing a jump, information regarding the landing surface, height from ground, ankle, knee and hip joint angles all come into play to safely land the jump and prevent injury. The motor control system therefore interprets the information to create the proper motor command of sufficient muscle activation and pattern. For example, the quadriceps eccentrically contract to control flexion and decelerate the landing and during dynamic landing task hamstrings activate before landing to counter tibial anterior translation (100).

The central nervous system may adopt a number of different strategies to counter the external loads experienced during many athletic tasks. Two general strategies that come into play during running, cutting and jumping are the selective activation of muscles to counter the loading and generalized co-activation of hamstrings and quadriceps without any selection of specific muscles (101). Muscle activation of the hamstrings and quadriceps was found to be significantly greater during cutting than running ($p<0.01$) which coincided with increase valgus/vargus and internal/external knee moments (101).

Coactivation of the quadriceps and hamstrings has been noted during a number of movements. It helps produce a smooth and accurate movement and maintain joint stability (102). Coactivation has also been found to increase the stiffness of the joint which again aid stability and prevention of disturbance to the intended movement (102). The antagonist has been shown to have a decreased level of activity at the initiation of movement to allow for acceleration and increased activity in the final phases of the movement to decelerate the limb and stop the movement at the desired position as well to prevent injury (102). Although coactivation has been shown to be beneficial to joint stability, too much can hinder performance. As one acquires the skill, the amount of coactivation can decrease to allow for joint efficiency. The lack of coactivation can allow for improved performance, however, in skilled athletes it can also have a negative effect; the absence of hamstring activity can leave the ACL to injury and the knee joint to instability. (102).

Co-contraction was found to be present in stabilizing the knee joint in vargus/valgus during preplanned cutting and sidestepping tasks (101). In another study examining the stiffness of the ankle and knee joint during various running speeds found that knee stiffness increased from 17 Nm/deg to 24 Nm/deg. The stiffness of the ankle joint did not change with running speed (103). There were also increases in the EMG preactivation value of the knee extensors which increase the stiffness of the joint to absorb the impact loads on ground contact (103). In addition to the increased EMG there was co-contraction between the knee flexors and extensors again contributing to the joint stiffness and preparation for ground contact.

Maintenance of postural stability and joint stability is provided through a number of neuromuscular strategies of the lower limb musculature. Anticipatory postural adjustments are used to maintain stability and depending on the instability of the task, the amount of APA's are adjusted accordingly (increasing with increased instability). During athletic maneuvers, muscles are activated in a particular pattern either individually or in a generalized coactivation to maintain joint stability and prevent injury. These strategies allow for optimal performance of the task and protect the athlete from harm. When these strategies are initiated or carried out incorrectly, injury can occur.

Male versus Female differences

Female athletes are 4 to 6 times more susceptible to knee injuries than males participating in the same sports which involve jumping and cutting (104). The majority of these injuries occur in non-contact incidents such as changing directions while running or during the landing of a jump (105). Neuromuscular, anatomical and hormonal differences in males and females lead to the higher incidences of injuries in females. In addition to this, joint stability, in particular the knee and ankle, is key to preventing these injuries. The sensorimotor system (proprioception) plays a major role on motor control and joint stability during athletic performance.

It has been found that females tend to be ligament-dominant, quadriceps-dominant and also dominant-leg dominant. Those who have ligament-dominance have an absence of muscle control of the mediolateral knee which can lead to high ground reaction forces and valgus torques of the knee. During many sporting activities requiring landing and cutting maneuvers, females tend to allow the ground reaction force to control the motion of the lower extremity joints and ligaments. When trying to stabilize the knee, females activate their knee extensor more than their knee flexors which lead to strength and recruitment imbalance. Lastly, they tend to have an imbalance in muscular strength between the dominant and non-dominant limb. The non-dominant leg often has weaker and less coordinated hamstrings (106). These dominance issues may predispose the female athlete to knee injuries.

Significant differences in the landing patterns of male and female soccer and basketball players during one-leg and forward hop landings have been found. During single-leg landing, females have greater internal rotation of the hip, less knee flexion and less internal rotation of the lower leg (107). There was also less time required to reach maximum knee flexion thus resulting in a more abrupt absorption of the forces that occur during landing (107). During the forward-hop landing, females had significantly more time to maximum angular displacement for internal rotation of the hip and lower time to maximum angular displacement for knee flexion. The lack of knee flexion and tibial rotation may result in injury to the ACL. There were also significant differences in strength of quadriceps and hamstrings of the male and female athletes. Females had significantly relatively weaker quadriceps and hamstring (107). When landing a jump the lack of quadriceps strength can contribute to a lack of control and deceleration of the movement, thus landing in a more extended knee position and increased ACL loading. Hewett et al. (108) found that females tend to land with greater medial motion of the knee and maximum lower-extremity valgus angle than males.

Unlike Lephart et al. (107), Croce et al. (109) did not find significant differences in muscular responses during landings. Croce et al. (109) found no significant gender differences in any of the dependent variables of the landing (pre-landing, post-landing EMG activity of the hamstrings, and quadriceps, co-contraction ratios and knee angle at initial contact). There were however significant developmental stage differences. The post-pubescent subjects displayed greater hamstring activity and coactiviation ratios in the pre-landing stage relative to the post-landing and the pre-pubesenct subjects had greater post-landing and initial-contact-to-maximum-knee-flexion ratios (109). Although Croce et al. (109) found no differences in genders (not even at the different developmental levels), Hewett et al. (108) did note some differences between the genders as well as developmental differences. Hewett et al. (108) found greater quadriceps peak torque with increasing maturation in males where as females did not show an increase.

There was also significant difference in females between maximum valgus angles of dominant and non-dominant lower extremities after maturation (lower values for the non-dominant side). It appears that following the "neuromuscular" growth spurt, males can regain their neuromuscular control whereas girls seem to lack the neuromuscular adaptations (108). This change following maturation may be due to decreases in neuromuscular control. Both studies found that as the participants matured (males only in the Hewett et al. (108) study) the level of coactivation prior to landing increased allowing for greater control of ground reaction forces and tibial displacement during landing. This increased coactivation, as previously mentioned, is necessary to prevent injuries to the knee joint.

With female athletes more prone to ACL injuries due to a number of anatomical, hormonal and neuromuscular factors, it is important to find ways to prevent these injuries. Changes to training programs maybe necessary to produce adaptations in the neuromuscular system and thus possibly prevent ACL injuries and other injuries. Since the sensorimotor system is essential to providing joint stability it may be possible that non-specific balance training for the sensorimotor system maybe sufficient to aid in these adaptations and prevent injuries.

Conclusion

As it has been shown, balance is important to daily activities as simple as moving from a seated position to standing and walking. Balance also plays an important role in athletic performance by allowing optimal performance of a skill or movement as well as preventing injuries. Through single sessions of balance disruptions, the CNS can alter its movement program for subsequent movements to compensate for the loss of balance and stability. The research of long-term balance training has mainly focused on injury prevention and rehabilitation; however some improvements of strength, dynamic and static balance may provide beneficial effects to athletic performance. Evidence has been provided for both specific and non-specific training adaptations, with gains seen in strength from simple balance training and static balance training transferring to improvements in dynamic balance and vise versa. The evidence has been contradictory as the training programs and dependent variables have shown large variations. Many of the programs however were designed to be specific to the sport of the athletes being tested but not all of the test measures were specific to the sport. Future research therefore should concentrate on the transferability of both short term and long term non-specific balance exercises to athletic performance.

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COMPARISON OF STATIC AND DYNAMIC BALANCE TRAINING ON MUSCLE ACTIVATION, STATIC BALANCE, JUMPING AND SPRINTING PERORMANCE

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Running Title: Static and Dynamic Balance Training and Performance

Abstract

The objective of this study was to determine the effects static balance and dynamic balance training on muscle activation strategies, static balance, jump and sprint performance. Twenty-four recreationally active females were tested pre- and post-training (static balance training, n= 11, dynamic balance training, n = 7 and control group, n = 6). Experimental subjects completed either static or dynamic balance exercises 4 times per 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. Maximum vertical jump, static balance and sprint times were also examined. A 3-way ANOVA revealed a significant ($p<.05$) increase in reactive rectus femoris activity, as well as a group by time interaction for the reactive rectus femoris activity. The static balance group showed a 33% increase in reactive rectus femoris activity ($p<.01$). There was also significantly less reactive hamstring to quadriceps coactivation following training ($p<.05$). The group by time interaction for the static balance and maximum vertical jump height performance ($p<.05$) were also significant. The static balance training group showed a 33% improvement in static balance and 9% improvement in jump height performances. Based on the finding from this study, it appears that balance training is specific to task and therefore training programs should be designed to mimic the demands of the sport or activity.

Key Words: balance training, muscle activation, training specificity

Introduction

Background of Study

Balance challenges for athletes can result in injury and impaired performance. Balance can be defined as the process whereby the body's state of equilibrium is controlled for a given purpose. Equilibrium can be static (body at rest) or dynamic (body is moving with unchanging speed and direction) (1). Posture is controlled by the coordinated activity of three balance systems: visual, vestibular, and somatosensory systems (2). In order to maintain balance, the body is continually making adjustments in order to keep the center of gravity over the base of support (3, 4). These adjustments occur through movements of the ankle, knee, and hip and may be disturbed when the center of gravity and base of support cannot be properly sensed or when corrective movements are not executed in a smooth and coordinated fashion (5, 6).

It has been shown that poor balance can contribute to increased injury rates (7, 8, 9), less force production (10, 11, 12), fatigue (13, 14), and numerous other factors that can hinder athletic performance. Considering how important balance is to performance and injury prevention, coaches and trainers must find ways to incorporate balance training into the regular training schedule. Although balance is necessary, research on the effects of static and dynamic balance training on athletic performance factors is limited. Most of the research focuses on injury prevention and rehabilitation, specifically for ankle and knee injuries, rather than on performance factors, such as speed and power.

In sports such as volleyball and basketball, jumping is important for successful performance of both defensive and offensive skills (for example, hitting or shooting and blocking or rebounding). 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. In these sports and a number of others, which involve jumping and landing, injuries to the lower extremities are very common. These injuries are often due to incorrect landings as a result of improper muscle activation, poor foot positioning and instability(15). Landing also plays a major role in non-jumping sports such as soccer where the proper landing of each running stride is important to prevent injury. As a result of the number of injuries, improving balance or stability through teaching correct jumping technique has become an important part of training for sports involving jumping, such as basketball and volleyball, however teaching proper landing technique in many sports is still often neglected. It is therefore important to teach these athletes how to land properly as a possible influence on the preventions of injuries.

The use of unstable platforms such as wobble boards (or ankle disc), Swiss balls, and numerous other piece of equipment which may challenge one's balance or stability have been introduced as a part of rehabilitation programs as well as prophylactic measures to prevent injuries. However, there is little research, which examines the effect of these devices on athletic performance. In a study comparing jump-landing training and wobble board training it was found that athletes were better able to discriminate between ankle movements following the wobble board training (16). Having greater proprioception enables the athletes to land more accurately and prepare for impact thus aiding in injury prevention and possibly improved performance. Other studies have shown that implementing balance training resulted in improved strength and reduction in muscle imbalances (17, 18). Based on this previous research, wobble board training and jump-landing training may be important part of athletic training especially when considering activities that that often lead to injuries (jump landings) and require strength and power.

Purpose of Study

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. Since balance and stability are important for athletic performance, it too must be incorporated into one's training program. A minimal amount of published research has examined the effects of balance training on athletic performance factors. However, the existing literature has primarily examined the effects of balance training on injury prevention and rehabilitation as well as on static and dynamic balance measurements.

The purpose of this study was to determine the effects of static and dynamic balance training, wobble board training and jump-landing training, respectively on athletic performance. In particular jumping and sprinting performance were examined. In addition to examining athletic performance the study also examined the effects of dynamic and static balance training on muscle co-activation and electromyographic (EMG) patterns during jump landings of varying stability (one-foot and two-foot).

Significance of Study

During daily activities, our bodies are continuously challenged to remain in a state of equilibrium. In athletic events these challenges are often exacerbated and thus in order for athletes to perform their best, they need to be able to adjust to the challenges. It is important to determine if static balance exercises can transfer to the dynamic activities of athletic performance or if similar to other training factors, balance is specific to training mode. Thus it is important to determine if non-specific dynamic or static balance exercises can provide improvements in performance.

Methodology

Experimental Design

The purpose of this study was to compare the effect of dynamic (landing) and static (wobble board) balance training on static balance, jump height and sprint speed as well as muscle activity patterns for the quadriceps, hamstrings and plantar flexors when landing from a jump onto a stable (2-foot) and less stable (1-foot) context. 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 lasted 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 jump-landing (dynamic balance) or wobble board (static balance) training, or a control group. Due to the length of the study, some participants did not complete the program. The drop out percentage was 30.9%, with 10 subjects not finishing the training. The reasons for incompletion were time commitment issues, injuries sustained during other physical activity or illness, which prevented the participants from continuing with training.

Based on the 24 subjects who completed the study the anthropometric information is summarized in Table 1.

Group (n)	**Age (years)** **(mean ± SD)**	**Height (m)** **(mean ± SD)**	**Weight (KG)** **(mean ± SD)**
Static (11)	25.18 ± 5.67	1.68 ± .06	67.14 ± 10.43
Dynamic (7)	23.71 ± 1.8	1.66 ± .08	65.41 ± 9.27
Control (6)	22.83 ± 2.14	1.66 ± .04	67.34 ± 11.95
TOTAL (24)	**24.17 ± 4.10**	**1.67 ± .06**	**66.71 ± 10.07**

Table 1 Demographic information of subjects

Criteria for participation in this study included 1) recreational athletes (approximately 1-2 hours 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) (19). Once subjects were cleared to participate they were randomly assigned to one of the three groups (control, dynamic, or static). Ethics was granted from Memorial University of Newfoundland Human Investigation Committee.

Intervention

The study intervention included 6-weeks of wobble board (static balance) jump-landing (dynamic balance) training. 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 were 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 completed a simulated running stride and on landing the stride 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-legged 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, 3 sets.
4) **Single-leg box jumps** – Subjects jumped from the floor onto a box 20 cm high, landing again on 1-foot. 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. Completed 3 sets of 6 jumps (3 medial and 3 lateral) per leg.

For each of the exercises subjects emphasized and concentrated on the landings. 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 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 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 place 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-with 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 ball (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 two sets.

Table 2 provides a summary of the training programs.

Exercise	Repetitions	Sets
Static Balance		
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
Dynamic Balance		
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

Table 2 Summary of the training programs.

Dependent Variables

Maximum Voluntary Contractions (MVC) – Force Production and Muscle Activity

Electromyography (EMG) and strain gauge data was 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. The EMG signal was collected at 2000Hz amplified 1000x (Biopac System MEC 100 amplifier, Santa Barbara, CA), monitored and directed through an analog-digital converter (Biopac MP 100) to be stored on the computer. 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 then 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. 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 degrees 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 and knee extended, 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 leg was secured in a modified boot apparatus (20) with the knee and ankle joints flexed at a 90 degree angle. Figures 1, 2 and 3 illustrate the MVC protocols for the quadriceps, hamstrings and plantar flexors, respectively.

Figure 1 Quadriceps MVC set-up

Figure 2 Hamstring MVC set-up

Figure 3 Plantar Flexor MVC set-up

Muscle Activity during Dynamic Test

During the stable (2-foot) and less stable (1-foot) landings, EMG data was collected for the RF, BF and Soleus of the subject's dominant leg. Subjects were instructed to take three strides (beginning with nondominant 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 et al. (21) and Cowling et al. (22, 23), 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. This allowed the subjects to become familiar with the distance and heights necessary to complete the jumps successfully as well as become familiar with the jump while attached to the EMG system. 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. See figure 4 for illustration of jump-landing protocol set up.

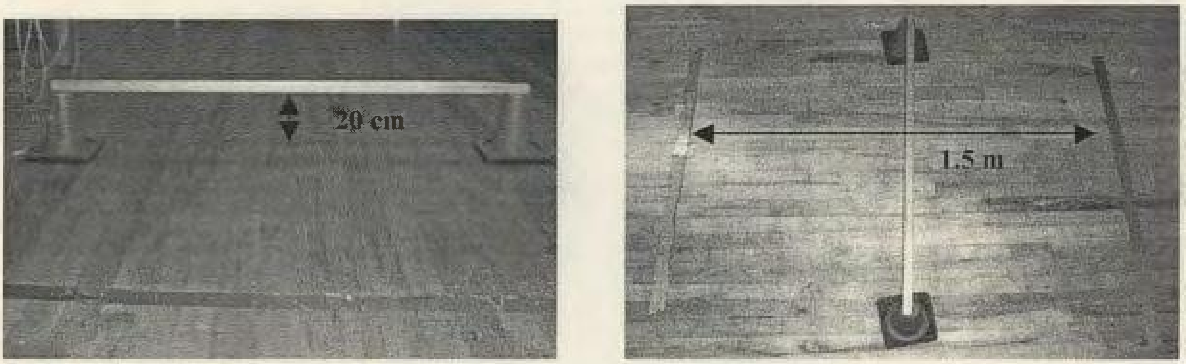

Figure 4 Jump-landing protocol

Maximum Vertical Jump

For the following athletic performance measurements, 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. With hands on hips, subjects stood on a contact mat connected to the computer and KMS program. They then performed the countermovement jumps. An adjustable step was placed behind the subjects to standardize the degree of knee flexion (90 degrees) between pre- to post-testing sessions. Subjects descended slowly 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. See Figure 5 for illustration of countermovement jump.

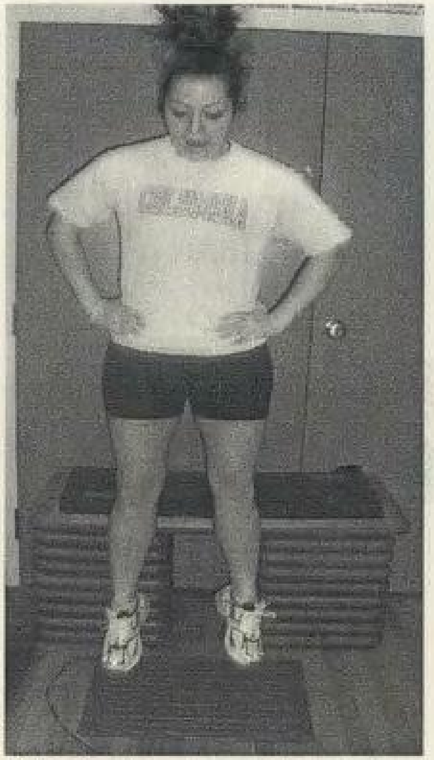

Figure 5 Countermovement Jump

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 footing, 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 number of contacts for the best trial was recorded. See Figure 6 for illustration of the static balance test.

Figure 6 Static Balance Test

Sprint Performance

For the 20 meter sprint, time to complete 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), 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 force during the MVCs' was computed. The EMG signal for the tested muscle was then filtered (10-500Hz) and smoothed (10 samples). The average of the Root Mean Square (RMS) amplitude for 100ms of the MVC (taken during the point of greatest force) was then computed. This was repeated for the quadriceps, hamstring and plantar flexor MVCs.

Muscle Activity during Jump Landings

Using the AcqKnowledge software, the EMG signal for each muscle was first filtered (10-500Hz) and smoothed (10 samples). The average of a 100ms segment of the RMS amplitude was analysed prior to and following landing for each muscle. A 100ms segment was selected for analysis because this would only allow time for reflex adjustments post-landing and not allow time for feedback modification. Thus the emphasis would be placed on feedforward or APA responses rather than feedback responses. The 100ms prior to (preparatory activity) and following landing (reactive activity) were determined based on the marker placement in each EMG computer file. 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

To investigate significant differences in the activity of each muscle, a three-way analysis of variance (ANOVA) (3 training groups x 2 times x 2 landings) was used to examine the amount of 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. 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. Descriptive statistics and figures include means ± standard deviation (SD).

Results

Maximum Voluntary Contraction – Force

With data collapsed over groups, there was no significant difference in MVC force following balance training for the quadriceps, hamstrings or the plantar flexors. See Table 3 for summary of MVC forces.

	Static Group		Dynamic Group		Control	
Variable	Pre-Test	Post-Test	Pre-Test	Post-Test	Pre-Test	Post-Test
Force (N)						
Quadriceps	352.32 ± 108.05	342.99 ± 77.85	445.61 ± 230.75	411.40 ± 173.11	404.22 ± 117.13	423.57 ± 72.32
Hamstrings	186.89 ± 52.10	182.42 ± 48.68	206.24 ± 96.70	238.89 ± 72.32	258.25 ± 76.04	244.02 ± 47.97
Plantar Flexors	72.98 ±17.10	75.76 ± 26.98	79.07 ± 32.87	90.69 ± 34.47	87.97 ± 18.28	92.01 ± 24.29

Table 3 Summary of Maximum Voluntary Contraction (MVC) Force and the Performance Conditions (Mean ± SD).

Electromyography Activity (EMG)

Pre-landing Activity

With data collapsed over groups and landing there were no significant differences in preparatory landing mean RMS amplitude for the RF, BF or soleus following training.

With data collapsed over group and time, there was significantly less preparatory soleus activity during the two-foot landing compared to the one-foot landing (57% vs 96% of MVC) ($p < .01$) (Figure 7).

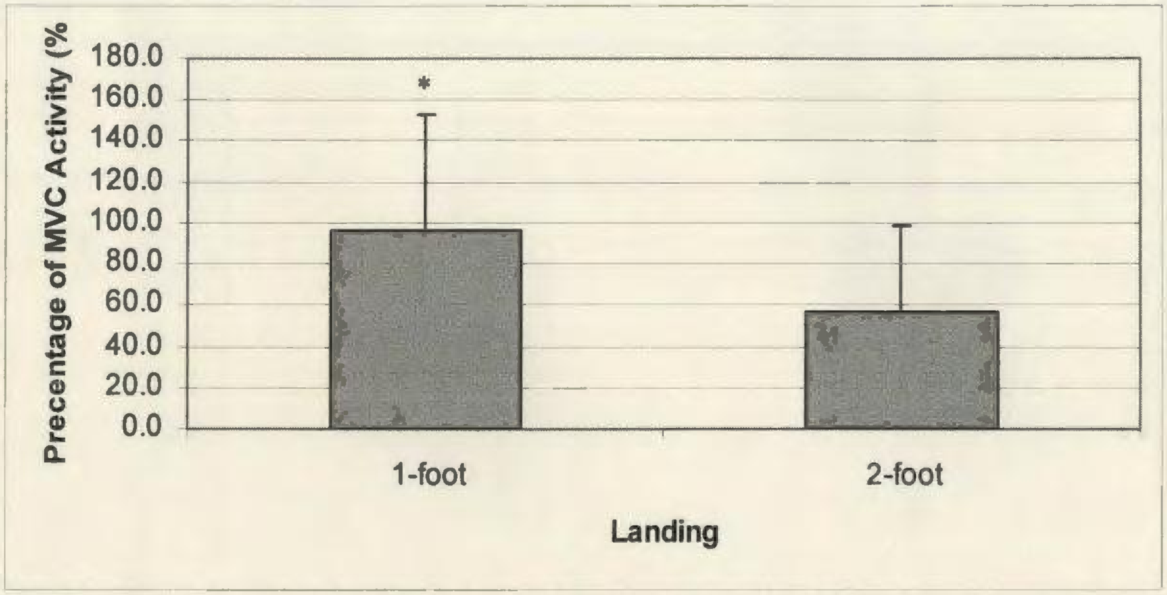

Figure 7 Preparatory soleus activity. There was significantly less preparatory soleus activity during the two-foot landing (57%) compared to the one-foot landing (96%) (p < .01)

Post-landing Activity

With data collapsed over groups and landing, there was a significant increase (19%) in reactive RF activity following training (p < .01) (Figure 8). There was also a trend for reactive soleus activity to increase (14%) following training (p = .08) (Figure 9).

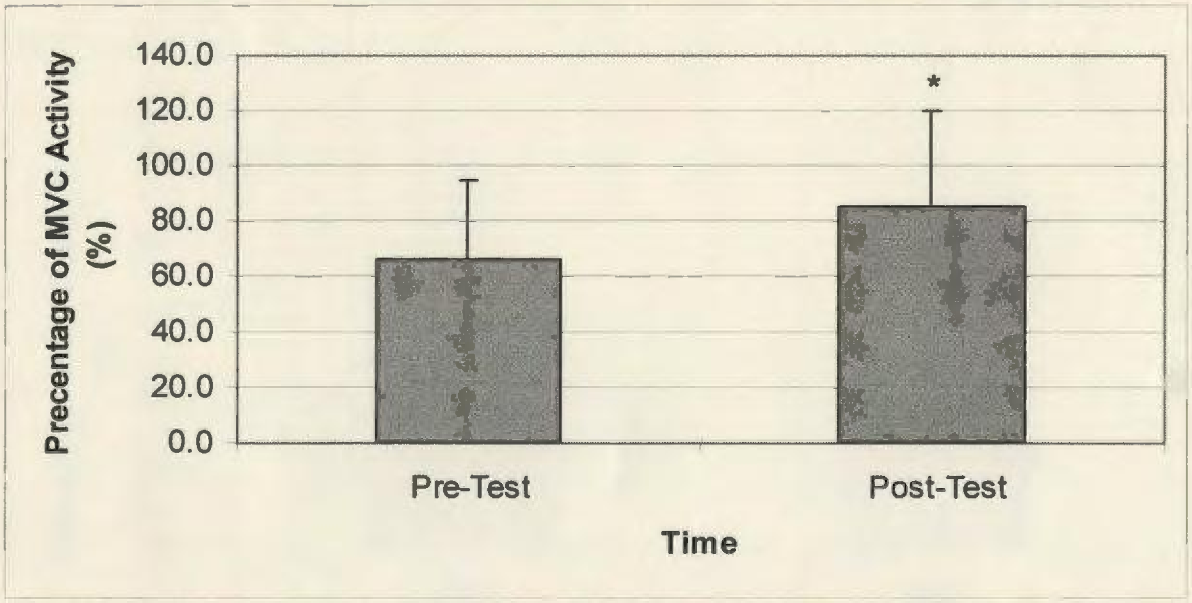

Figure 8 Reactive rectus femoris activity. With data collapsed over group and landing, there was an increase of approximately 19% in reactive quadriceps activity following training (p <.01)

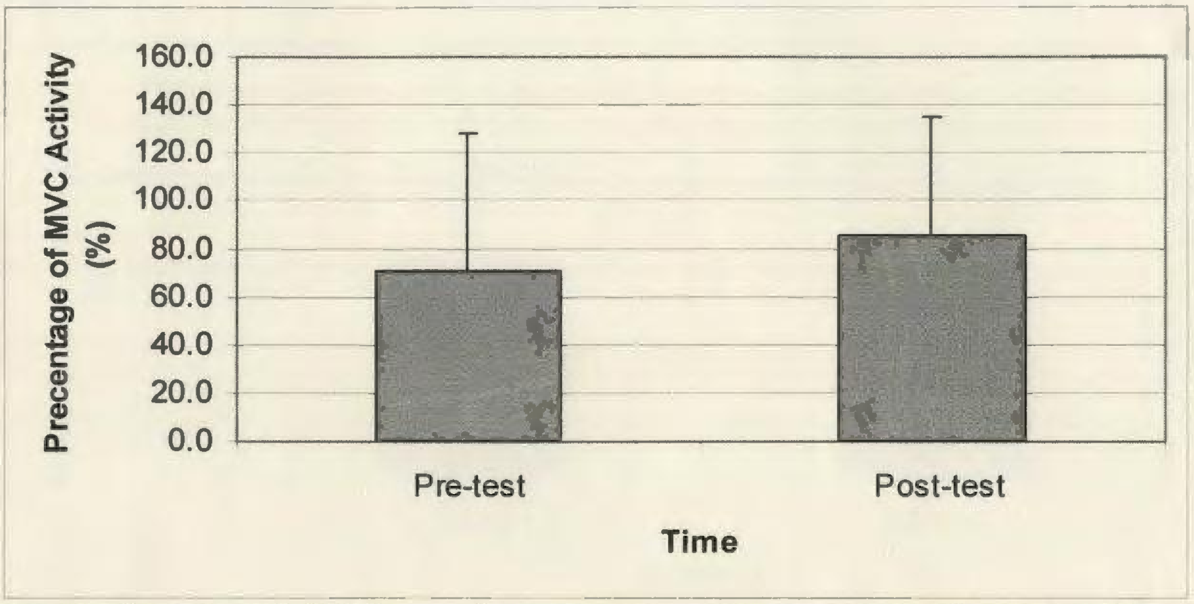

Figure 9 Reactive soleus activity. With data collapsed over group and landing, there was a trend for reactive soleus activity to increase from pre- to post-test (p = .08).

With data collapsed over groups and time, there was a significant decrease in the amount of reactive BF activity from the one-foot to the two-foot landings (30% vs 21%) (p < .01) (Figure 10). There was a significant decrease in reactive soleus activity for the two-foot landing compared to the one-foot landing (55% vs 101%) (p <.0001) (Figure 11).

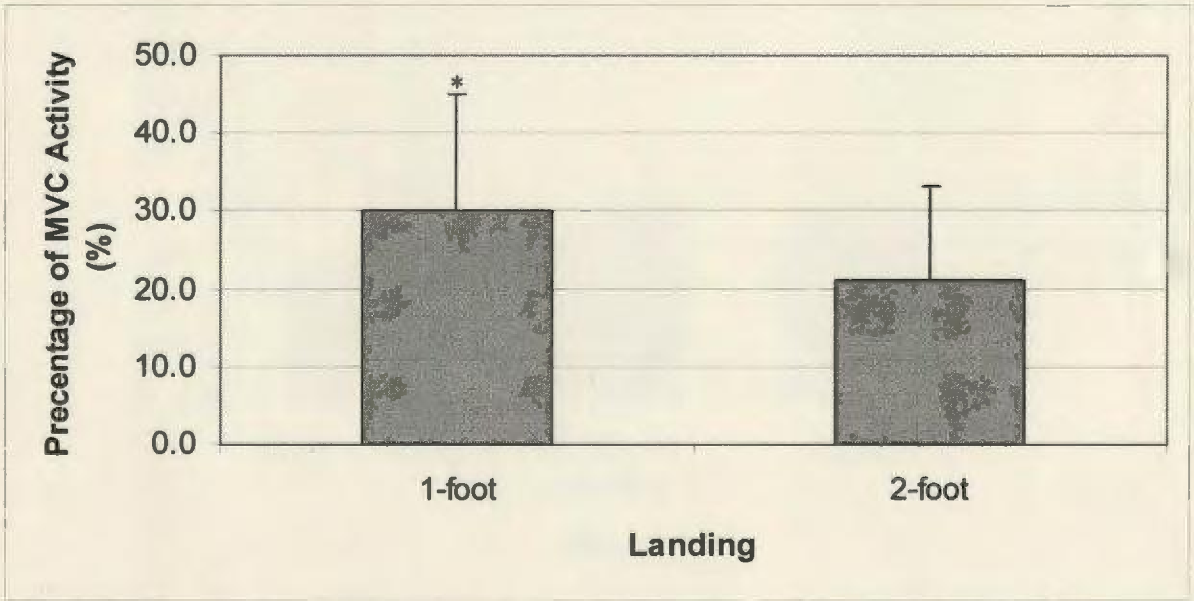

Figure 10 Reactive biceps femoris activity. With data collapsed over group and time, there was a significant difference in reactive biceps femoris activity for the one-foot and two-foot landings 30% vs 21% ((p < .01)

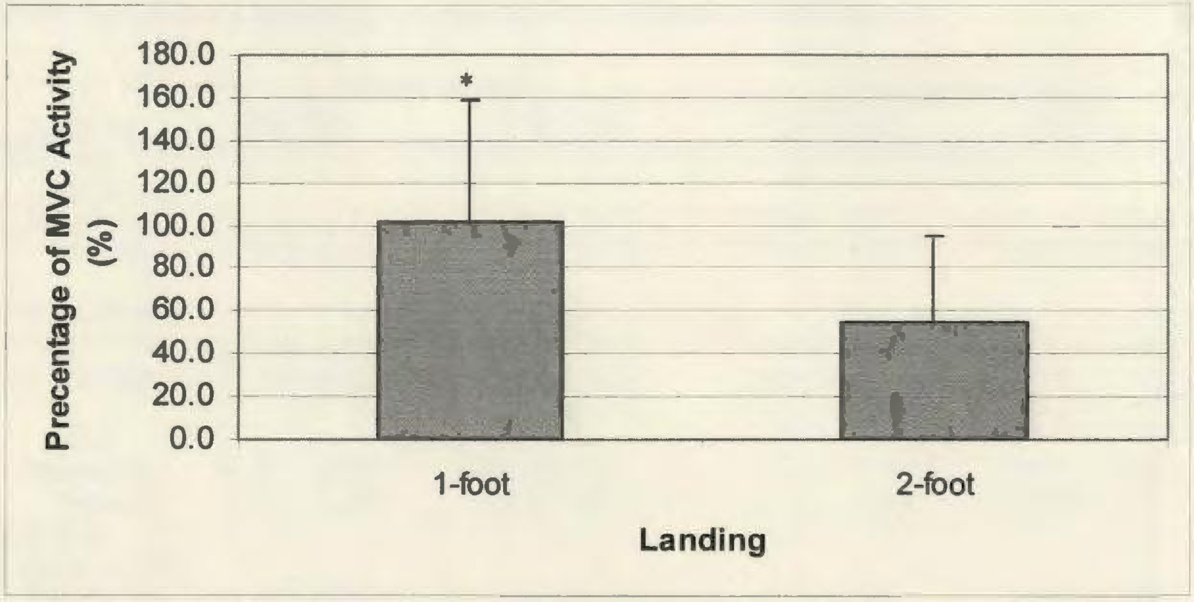

Figure 11 Reactive soleus activity. With data collapsed over group and time, there was a significant difference in reactive soleus activity for the one-foot and two-foot landings 101% vs 55% ((p <.0001)

With data collapsed over landing, there was a significant group by time interaction for reactive RF activity (p < .05). A t-test revealed there was a significant increase (approximately 33%) in the amount of reactive RF activity from static pre-test to static post-test (p<.01) (Figure 12).

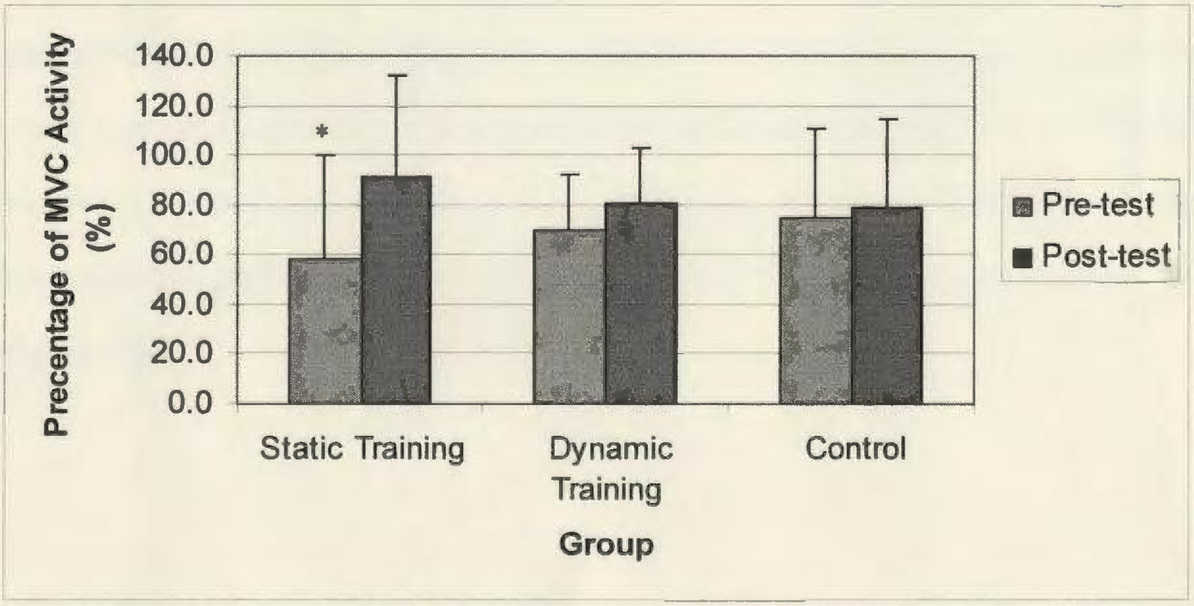

Figure 12 Reactive rectus femoris activity. With data collapsed over landing, there was a significant increase in reactive rectus femoris activity following static balance training (p <.01)

Table 4 provides a summary of preparatory and reactive EMG activity .

	Static Group		Dynamic Group	
Variable	Pre-Test	Post-Test	Pre-Test	Post-Test
One-Foot				
Rectus femoris				
Preparatory	58.93 ± 34.43	73.76 ± 36.92	48.54 ± 21.13	41.16 ± 22.51
Reactive	58.02 ± 28.01	96.30 ± 47.38	77.84 ± 31.52	80.80 ± 27.38
Biceps femoris				
Preparatory	32.48± 20.63	37.67 ± 17.04	21.08 ± 8.77	21.03 ± 13.90
Reactive	37.57 ± 20.43	34.16 ± 14.80	22.40 ± 9.77	27.80 ± 8.45
Soleus				
Preparatory	86.54 ± 66.36	108.59± 58.17	102.84 ± 79.67	80.26 ± 52.68
Reactive	74.66 ± 62.83	120.86 ± 69.70	112.58 ± 73.13	99.84 ± 46.32
Two-Foot				
Rectus femoris				
Preparatory	58.20 ± 27.04	72.12 ± 45.17	59.58 ± 30.28	57.69 ± 18.88
Reactive	58.85 ± 16.91	86.39 ± 35.67	61.36 ± 29.80	79.68 ± 20.03
Biceps femoris				
Preparatory	26.98 ± 14.03	33.01 ± 15.45	19.57 ± 12.32	28.41 ± 19.26
Reactive	25.01 ± 10.90	29.06 ± 15.31	16.63 ± 11.29	18.27 ± 9.05
Soleus				
Preparatory	62.37 ± 63.47	57.69 ± 49.42	66.74 ± 25.11	56.29 ± 35.23
Reactive	52.60 ± 60.95	64.33 ± 39.20	54.81 ± 44.51	55.36 ± 28.91

Table 4 Summary of EMG activity and the Performance Conditions (Mean ± SD).

Co-activation of Hamstrings and Quadriceps

With data collapsed over groups and time, there was a significant difference in reactive co-activation ratio for the one-foot and two-foot landings ($p < .05$). For the two-foot landing there was approximately 36% less co-activation than for the one-foot landing (Figure 13). With data collapsed over group and landing, there was a significant decrease (approximately 20%) in the reactive co-activation ratio following training ($p < .05$) (Figure 14).

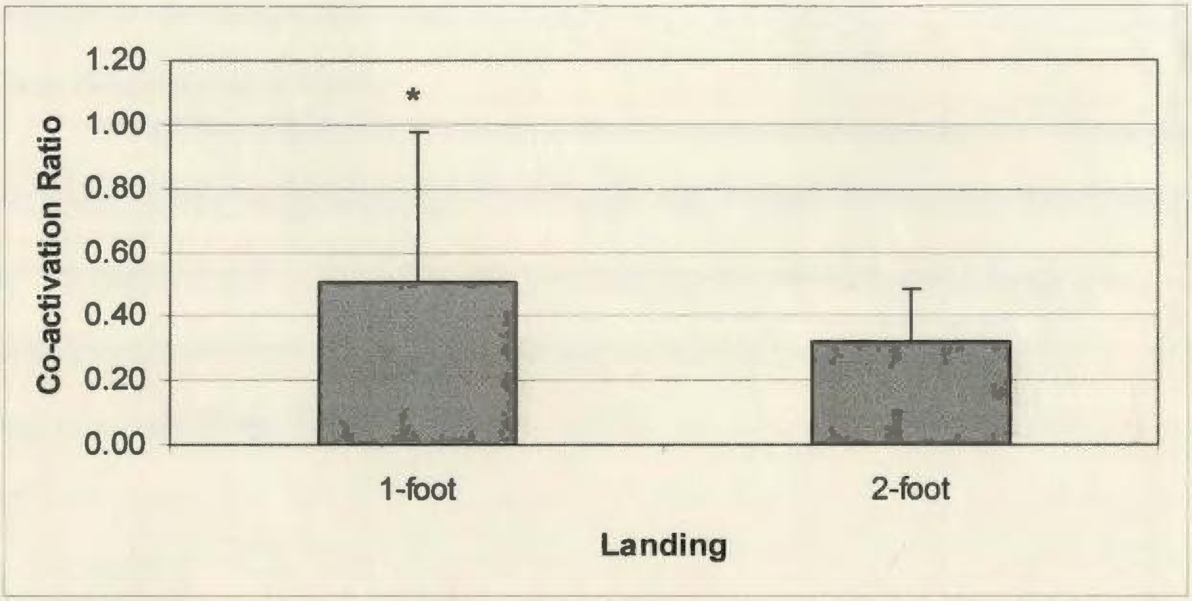

Figure 13 Reactive co-activation ratios. *There was significantly less co-activation for the two-foot landing compared to the one-foot landing (.50 vs .32) (p <.05)*

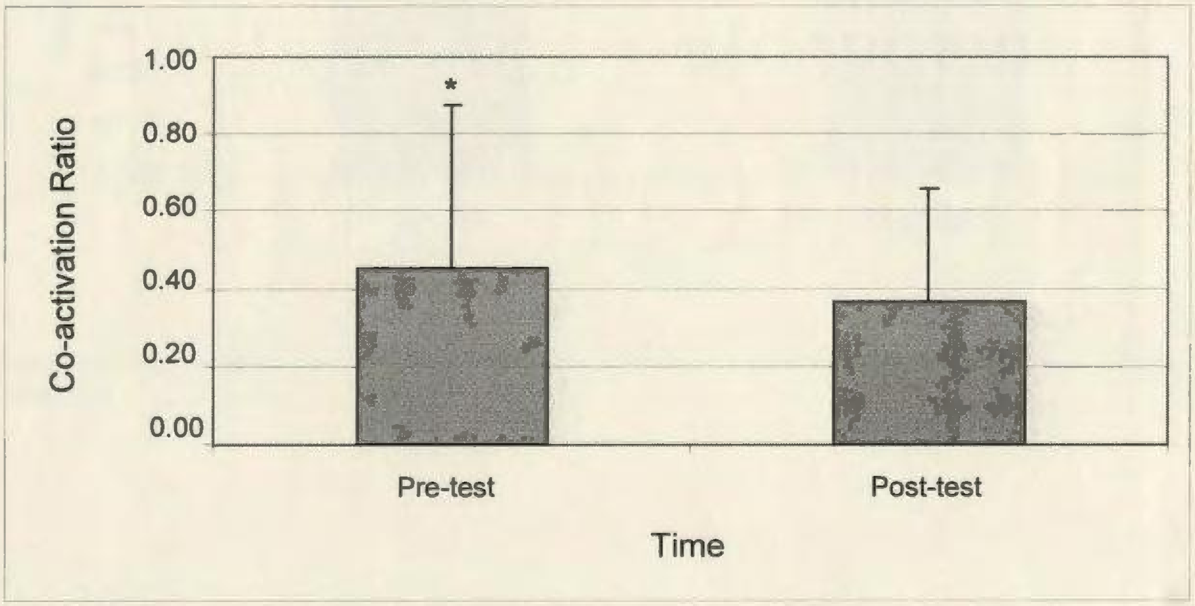

Figure 14 Reactive co-activation ratios. *There was significantly less reactive co-activation following training (p < .05)*

Athletic Performance Measures

Jump Height and Sprint Time

With data collapsed over groups, there was a significant increase (4%) in jumping performance following training ($p < .05$) (Figure 15). There was also a significant group by time interaction ($p < .01$). A Bonferonni post-hoc test revealed, a significant difference between the SBT pre- and post-test, with jump height increasing approximately 9% ($p < .05$) (Figure 16).

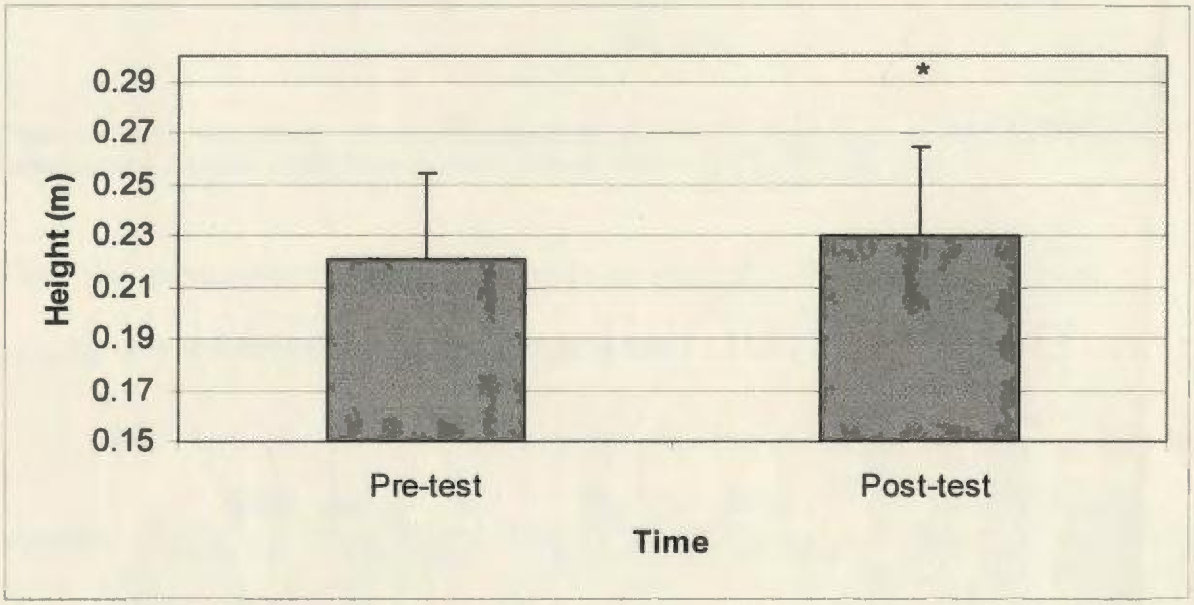

Figure 15 Jump performance. There was a significant increase (4%) in maximum jump height following training (p < .05)

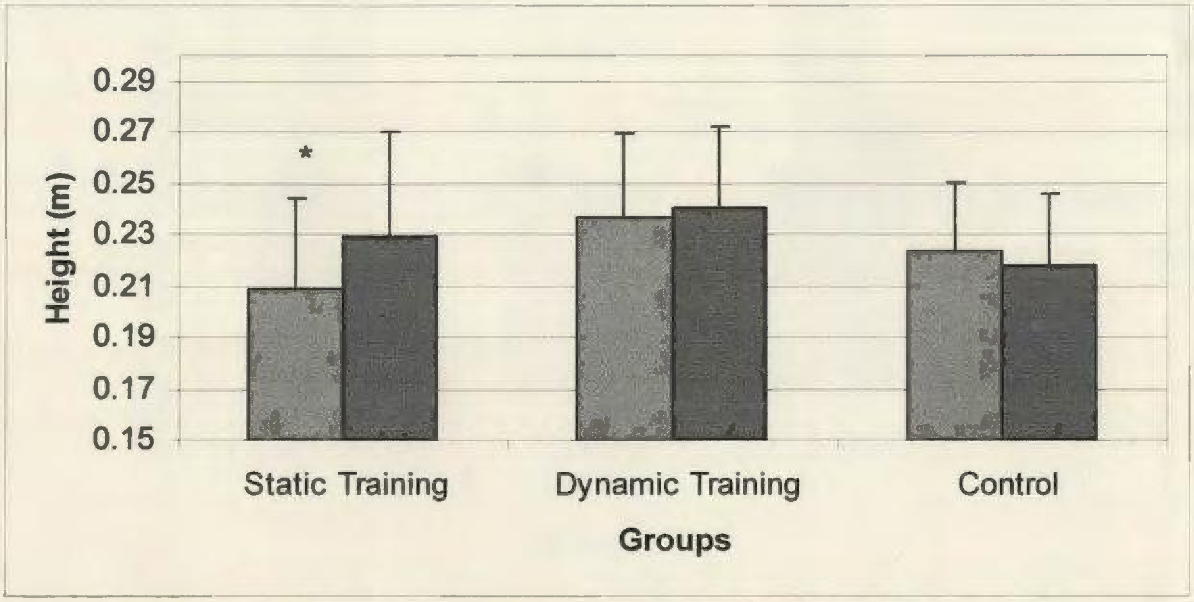

Figure 16 Jump performance. There was a significant group by time interaction (p < .01) with the static balance group showing a significant increase (9%) following training (p<.05).

There was no significant difference in sprint performance. Table 5 summaries the jumping and sprinting performance of each group.

Variable	Static Group		Dynamic Group		Control Group	
	Pre-Test	Post-Test	Pre-Test	Post-Test	Pre-Test	Post-Test
Jump Height (m)						
	0.209 ± 0.035	0.229 ± 0.041	0.237 ± 0.032	0.241 ± 0.031	0.224 ± 0.026	0.218 ± 0.028
Sprint Time (s)						
	3.79 ± 0.36	3.73 ± 0.35	3.70 ± 0.48	3.58 ± 0.19	3.90 ± 0.22	3.98 ± 0.22

Table 5 Summary of athletic performance measures and condition (Mean ± SD).

Static Balance

For static balance performance there was a significant group by time interaction (p = .01). A Bonferroni post-hoc revealed significant improvement (approximately 33%) following training in the SBT group (p <.05) (Figure 17).

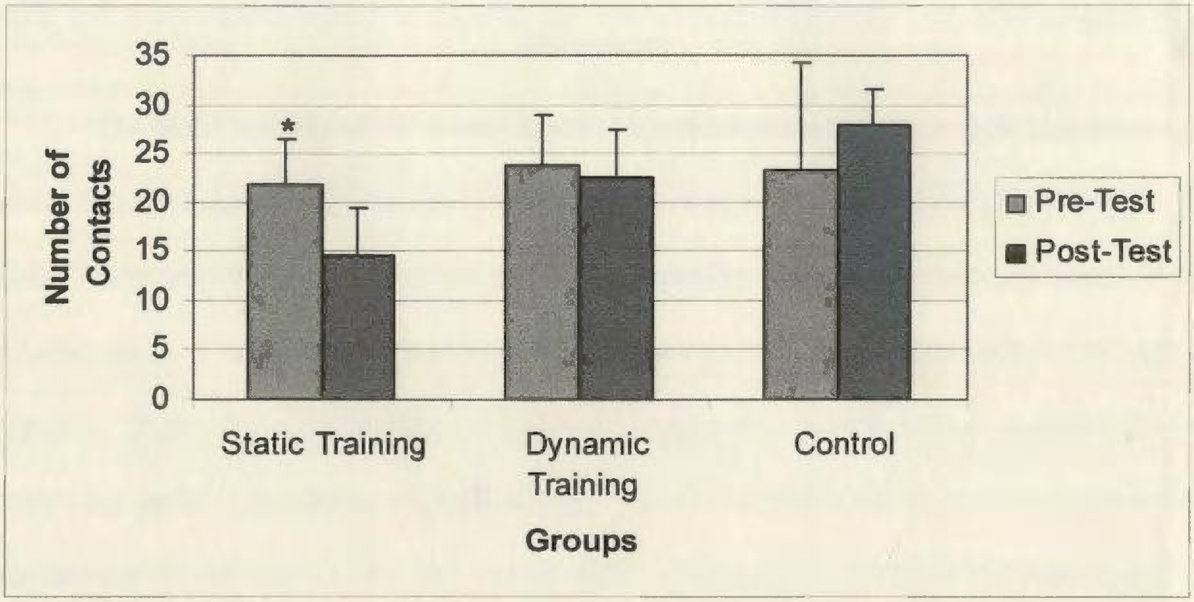

Figure 17 Static balance performance. There was interaction between group and time (p = .01) with the static training group showing a significant improvement following training (p <.05).

Discussion

The main finding of this study was that for recreationally active female subjects, static balance training did transfer and result in training adaptations during a dynamic task. There were improvements in static balance performance as well as maximum vertical jump. These adaptations however were not present following dynamic balance training. There were no significant changes in sprint performance or force production following static or dynamic balance training. Following training there was an increase in the amount of reactive RF activity, and a trend for increased preparatory RF activity and reactive soleus activity. When comparing the two-foot landing to the one-foot landing, there was significantly less preparatory soleus activity, reactive BF and reactive soleus activity as well as a trend for less reactive RF activity. There was also significantly less reactive co-activation following training as well as for the two-foot landing.

Training Specificity

Resistance training and endurance training have both been shown to be specific in muscle and performance adaptations. For example, resistance training results in muscle hypertrophy (24 25, 26), increases in muscle protein (26,27) and subsequently increases force production and strength while endurance training increases capillary density, mitochondrial density as well as oxidative enzymes (28, 29) and thus improvements in aerobic capacity. The type of resistance training and endurance training are also specific in their transferability to the task. Training at a specific angle or velocity, has been shown to result in greater increases at that angle or velocity more so than at other angles or velocities (30).

In the present study balance training also appears to have some specific training adaptations. There were no significant changes in force production or sprint performance following static or dynamic balance training. Static balance training did result in improvements in static balance performance, while dynamic training resulted in no changes. Although balance training does appear to be specific to the task, some improvements in jump performance (following static balance training only) as well as changes in muscle activation patterns during dynamic jump landings occurred.

Force Production

There has been mixed findings on changes in force production/strength following balance training with some studies noting increases and others showing no change. Bruhn et al. (31), following their 4-week sensorimotor wobble board training, found no significant increases in one-legged isometric MVC (leg press), however there was a trend for maximum isometric strength to increase ($p = .057$). Holm et al. (32) found no change in quadriceps or hamstrings isokinetic strength following their 6-week balance training program. Following 6-weeks of wobble board training, Balogun et al. (17) however found an increase in isometric strength during knee extension and flexion, and ankle dorsiflexion and plantar flexion. Following a 4-6 week balance training program (11 sessions), Heitkamp et al. (18), also found increases in isometric force during knee flexion and extension which were comparable to the increases found in their strength training group.

Studies using sedentary individuals (17, 18) found increases where as studies with trained subjects (32) found no increases. This matches the findings of the current study in which recreationally active females subjects participated. Improvements in force with the aforementioned studies are more likely due to changes in coordination (33) rather than muscle size since the duration of the programs were only 4-6 weeks which places a greater emphasis on neural adaptations (34). Thus for sedentary individuals the balance training may have been sufficient to improve coordination and thus 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. These improvements in strength and coordination may also impact jumping and sprinting performance.

Jumping and Sprinting Performance

The current study found no improvements in sprinting performance following either form of training, while there were improvements in jump performance following static training only. Few studies have examined the effects of balance training on athletic performance; with no studies to our knowledge having examined the effects of balance training on sprint performance.

Improvements in jump height were only present in the static balance training group. This finding is similar to Bruhn et al. (31) who noted a trend ($p = .17$) for jump height to improve following sensorimotor training. Since no improvements were noted in isometric force production, these improvements may be attributed to dynamic-specific force changes or muscle coordination. The possible increases in coordination may be related to the squats performed on the wobble board which is a similar action to the countermovement jump. There may have also been some increased coordination of the trunk musculature resulting in a greater vertical aspect and possible decrease of horizontal movement that may be present in a less coordinated individual.

Rutherford and Jones (33) noted strength gains were largely due to being able to lift a weight in a more coordinated manner. When coordination was not challenged, such as with an isometric open-kinetic chain exercise, no gains in strength were found. With the countermovement jump, coordination is important to obtain optimal performance. Anderson and Behm (11) noted a decrease in force production during unstable bench press, however the amount of muscle activity remained the same. Thus the muscles functioned more as a stabilizer rather than a mobilizer. In the current study, following the static balance training, the subjects may have had more muscle coordination and therefore the muscles could have emphasized greater mobilizer functions rather than stabilizer to produce a higher vertical jump performance.

Based on the findings of the current study, it appears that balance training (both dynamic and static) was not sufficient to produce changes in sprint performance. It is not surprising that there were no improvements, as improvements in force production of lower-extremity muscles were also not found. Thus adhering to the concept of training specificity, the counter movement jump, which commences from a stationary bilateral position similar to the static balance training, displayed improvements while the more dynamic unilateral sprinting movements may have been too divergent from the static training protocols.

The lack of improvements in jumping and sprinting performance following dynamic balance training may also be explained by the idea of training specificity. The dynamic program focused on small jump heights and slow controlled movements and the actions did not replicate the movements of the countermovement jump as with the static program. As for the sprinting, simulated running strides were performed in the dynamic program, however each stride was held for three seconds and therefore did not elicit the explosive bounding of one stride to the next that is essential to sprinting performance.

Static Balance

Similar to the findings of a number of balance training studies there were improvements in static balance following training. It is interesting to note however the improvements were only seen following the static balance training program and not following the dynamic program, once again illustrating the concept of training specificity. Holm et al (32) found improvements in dynamic balance on the KAT 2000 balance system, while no improvements found in static balance. No measures of dynamic balance were performed for the current study; however some evidence has been provided that static balance training transfers to improvements in dynamic balance performance. Following 6-weeks of wobble board training, improvements in static balance (time able to stand on one leg with eyes closed) and dynamic balance (time to stand on one leg with eyes closed on a balance pad) were found (7).

Other studies have noted improvements in balance, however, the training programs and measures of balance varied considerably from this study. Kollmitzer et al. (35) measured postural sway during four conditions (hard surfaces versus elastic surface, with eyes open versus eyes closed). Following their balance training program, improvements in body sway were found only when full sensory feedback was provided from the hard surface. This was unlike Emery et al. (7) who found improvements in both hard and soft surfaces. Heitkamp et al. (18) measured one leg standing balance similar to Emery et al. (7) and again found improvements following sensorimotor training. Heitkamp et al. (18) also used a stabliometer to measure static balance and also found improvements in performance following a 4-6 week sensorimotor program. This device is similar to the wobble board and recorded the number of contacts during 30 seconds.

Bruhn et al. (31,36) found improvements in postural stability following their sensorimotor training program, however improvements in control groups (36) were also noted thus improvement could be contributed to a learning effect rather than the training. In the current study there were no improvements in the control group. While Balogun et al. (17) found greater increases in the simple eyes open balance task, Kovacs et al. (37) found greater improvements in balance performance for the more complex balance task (landing a jump with eyes closed and single-limb stance with a skate on).

Muscle Activation during Landing

In the present study there were no significant changes in preparatory RF, BF or soleus activity following training. There was however a tendency for preparatory RF activity to increase. Overall, there was a significant increase in reactive RF activity and a tendency for reactive soleus activity to increase following training.

Stability of the knee is provided through both preparatory and reactive muscle activity involving both feed-forward and feed-back processing (38). Increased muscle activity leads to increased joint and muscle stiffness which can offer greater protection from the forces and loads experienced by lower-extremity joints during landing. Based on the current study, it appears that balance training may be beneficial to increasing joint stiffness and protection through the increase in reactive RF activity and tendency for preparatory RF activity and reactive soleus activity to increase. How much activity and stiffness is necessary to protect the joint and prevent injury however is still unclear. Co-activation of the quadriceps and hamstrings also increase joint stiffness and maintain stability but again optimal amounts of co-activation are unknown (38).

Chimera et al (39) examined muscle activation strategies following 6-weeks of plyometric training and found increases in preparatory adductor EMG activity. There was also an increase in preparatory adductor-to-abductor muscle co activation and a trend toward increased reactive quadriceps-to-hamstring co activation. While Chimera et al. (39) examined muscle activation during landing of drop jumps, the current study used a dynamic (3 step) jump protocol and one- and two-foot landings.

The programs also differed significantly as the plyometric program (39), although focused on correct landing technique also focused on improving jumping. Plyometric training by nature also focus on eccentrically loading the muscles followed by concentric contraction (40, 41). The present dynamic balance program however did not focus on explosive jumping (with maximum heights and little time between jumps) but rather smaller jumps with slow, controlled landings. Plyometric training has been found to be beneficial in altering the sensorimotor system to enhance dynamic restraint mechanisms (42, 43). Other studies examining landing patterns following jumps have mostly focused on the kinematics of the ankle and knee joints (44-48). A study by Hewett et al. (48) found that plyometric jump training resulted in decreased peak landing forces, as well as knee adduction and abduction moments. There was also an increase in hamstring muscle power.

Although the subjects of the current study were all recreationally active, the training background of the subjects was not controlled. Considering that landing patterns are related to training background, it is possible that no significant changes were seen following training due to the large variability in previous learned landing strategies. If the subjects had similar backgrounds (for example, if all subjects were basketball players) small changes in motor control following static and dynamic balance training may be present. The goal of the dynamic training program was to teach the subjects to land properly, however, a 6-week training program may not have been sufficient to undo years of previously learned landing strategies.

Many of the studies that have examined jump landing patterns, had subjects complete stationary jumps of maximum height or drop jumps from various heights. The current study had subjects perform a dynamic landing task by having subjects take 3 steps, jump from their non-dominant leg and land on their dominant leg. This was similar to task implemented by Steel et al. (21), Cowling et al. (22, 23). For these studies the dynamic landing was selected as a deceleration task and was thought to be similar to a typical noncontact mechanism for ACL injuries. They examined gender differences and the effects of upper-limb movement and ACL deficiency on muscle synchronization in the lower extremities. Thus the selection of jumping/landing task for this study may not have been suitable to notice changes in landing patterns.

The selection to study one- and two-foot landings during the testing was because of 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. Since muscle activation contributes to joint stiffness, if the subjects were in a stable situation (i.e. two-foot landings) less muscle activity would be necessary to maintain joint stability.

Studies have found that simple instructions such as asking subjects to increase knee flexion during landing resulted in accurate response from subjects. Subjects, however, were not able to respond to more complex instructions (asking them to activate selected muscles) (23). The instructions for the dynamic training group, in the current study, involved information regarding joint positioning rather than muscle activation strategies. Thus, the training program may have been effective in producing these changes however joint kinematics were not a variable in this study.

Conclusions

Although the study found few significant differences in muscle activation during one and two foot landings following training and no significant differences in sprinting performance, significant improvements were found in static balance and jump performance following the static balance training only. This study is limited by the variations in training backgrounds of the participants as well as the number of participants per training group. The use of balance training has been shown to be beneficial in elderly populations to increase confidence by improving balance and proprioception and decrease the risk of falls and instability. It has also been shown to be beneficial in subjects with ankle instability by improving balance and proprioception and decreasing further risk of injury. Finally balance training has also shown positive results in sedentary individuals through increasing strength as well as balance.

The use of balance training in a physically activity population has shown some improvements in various static and dynamic balance test and prevention of injuries, however determining the optimal program is still questionable. Based on the findings of the current study, it appears that balance training needs to be specific to the task and thus there may not be one optimal program but rather a variety of programs specifically developed for a given sport.

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