A Comparison of the Effectiveness of Balance Training Performed after Exertion versus before Exertion

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Abstract

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(Under the direction of Troy Blackburn)

Lower extremity injuries occur at a high rate in women's collegiate field hockey and lacrosse, and they occur more frequently in the later stages of practices and games. Poor balance ability is a predictor of injury risk. However, balance ability can be improved with training, and balance training reduces injury risk. Balance ability has also been shown to decrease with fatigue. In an effort to discover if balance training is more effective when performed after exertion, 45 collegiate women's lacrosse and field hockey players were randomly assigned to two training groups. One training group performed a six week balance training program immediately before their sport-specific practice sessions, and the other group performed the balance training immediately after practice. Eleven physically active colleged-aged students served as a control group. Balance was assessed via center of pressure elliptical sway area and sway speed, and the Balance Error Scoring System before and after the training intervention. We found that the effects of balance training did not differ when performed before versus following physical exertion, and that the BESS is not capable of detecting balance changes associated with training. Specifically, both training groups and the control group improved their balance ability from pre-test to post-test, and the BESS was not sensitive or specific to changes in balance following the six-week balance training protocol.

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CHAPTER I

INTRODUCTION

A 16 year longitudinal study of 15 NCAA Division I sports revealed that over 50% of injuries sustained by both male and female athletes were to the lower extremity (Hootman, Dick et al. 2007). This study projected that, across the 15 sports observed, an average of over 11,000 ankle sprains occur annually, accounting for almost 15% of all injuries (Hootman, Dick et al. 2007). Additionally, it has been shown in high school athletes that over 52% of all injuries are to the lower extremity, with ankle injuries accounting for 40% of total injuries (Fernandez, Yard et al. 2007). Among high school basketball players, almost 40% of all reported injuries are to the ankle or foot (Borowski, Yard et al. 2008), and in high school rugby players, ankle and foot injuries account for over 13% of all injuries (Collins, Micheli et al. 2008). Furthermore, ankle sprains constitute 17.7% of total injuries in women's collegiate lacrosse and 10% in field hockey (Hootman, Dick et al. 2007).

Poor balance ability has been demonstrated to be an indicator of ankle injury risk in high school basketball players (McGuine, Greene et al. 2000). Balance training is a common therapeutic exercise component used by athletic trainers in the rehabilitation and prevention of ankle injuries. Subjects with chronic or functional ankle instability have shown improvements in balance ability with balance training (Rozzi, Lephart et al. 1999;

Michell, Ross et al. 2006; Hale, Hertel et al. 2007; Kidgell, Horvath et al. 2007), as have individuals with stable ankles (Michell, Ross et al. 2006; Ross and Guskiewicz 2006; Yaggie and Campbell 2006). With respect to injury prevention, balance training has been demonstrated to decrease the risk of non-contact ankle sprains in high school football players by 77% (McHugh, Tyler et al. 2007), and to be more effective at reducing the risk of repeat ankle sprains in male soccer players when compared to strength training or orthoses (Mohammadi 2007). Additionally, a limited amount of evidence suggests that balance training is more effective when performed following, as opposed to before, physical activity (Gioftsidou, Malliou et al. 2006).

Fatigue has also been theorized to increase the occurrence of ankle injury (Gioftsidou, Malliou et al. 2006). Once an athlete becomes fatigued, they are less able to maintain postural stability, thus leading to a higher injury risk later in games or training (Gioftsidou, Malliou et al. 2006). This theory is supported by Gabbet et al. (2000) who observed that the incidence of injury was much greater in the second half of athletic competitions compared to the first. Additionally, aerobic and anaerobic fatigue induce deficits in balance as measured by multiple indices of postural control, including the Balance Error Scoring System and various force plate measures (Nardone, Tarantola et al. 1997; Johnston, Howard et al. 1998; Yaggie and McGregor 2002; Fox, Mihalik et al. 2008). While fatigue induced in the laboratory may differ from the fatigue experienced by an athlete as he or she continues throughout a competition or practice session, the results of these previous investigations suggest that fatigue and physical exertion negatively influence postural control, potentially increasing ankle injury risk.

Due to the fact that physical exertion may affect ankle injury risk, and balance training reduces ankle injury risk, a logical step would be to evaluate the effect of balance training at different stages of exertion on training efficacy. To date, Gioftsidou et al. (2006) are the only authors who have explored the effect that timing of training has on balance. These authors concluded that balance training was more effective when performed after vs. before physical exertion. However, this investigation utilized the same wobble boards for both training and balance assessments, thus it is unclear if the improvements in balance were due to training influences on the sensori-motor system, a learning effect, or both. While these results are encouraging, the Gioftsidou study had several flaws. Three trials were performed on the balance boards and the best trial was used for further comparison, as opposed to averaging of the trials. Subjects' scores may not have been representative, since a subject with poor balance may have had one "good" trial, which was then accepted as his/her score. Also, the authors did not state how long after practice the players were tested, except to say "immediately". As Fox et al. (2008) showed, if the authors waited as little as 8 minutes, they may have missed changes that actually existed due to recovery of balance ability. In addition, individuals may not have been putting forth as much effort as possible, leading to the investigators' belief that subjects were tired when that may not have been the case. This may mimic normal athletic conditions however, as players do not necessarily give their best effort every single practice session.

Several neurophysiological mechanisms and motor learning principles suggest that balance training may be more effective following as opposed to before physical exertion. The theory behind greater improvements after exertion is the theory of specific adaptations, which states that the body reacts to the specific demands placed on it and has been proven in several studies (Jurimae, Abernethy et al. 1997; Izquierdo, Ibanez et al. 2004). Also, moderate muscular exercise has been shown to improve position sense (Bouet and Gahery 2000; Bartlett and Warren 2002; Subasi, Gelecek et al. 2008), which may have carryover effects with balance training. Position sense is an important part of the sensorimotor system, which aids in balance through the control of joint stability (Riemann and Lephart 2002). In addition, the recruitment of specific muscle fibers due to postactivation potentiation may allow for better attempts at training and better training outcome (Sale 2002).

The Balance Error Scoring System (BESS) is an important assessment tool that is widely used by clinicians to assess postural control (Docherty, Valovich McLeod et al. 2006), while force plate measures are currently considered the gold standard in balance measurements. The BESS is a convenient field tool for athletic trainers due to its portability and the minimal training required to administer the test effectively. Due to the inaccessibility of force plates to the average clinician, it is evident that the BESS is a more clinically applicable tool. Currently, no studies have shown whether the BESS is sensitive to changes in postural control following balance training in the same way as force plate measures. Thus, it follows that if the BESS is sensitive to changes in postural control it may be used by clinicians to objectively track balance changes over time.

Although this study does not specifically measure the influence that timing of a balance training program has on injury risk in athletes, it is the first step toward such application. If ankle injuries can be prevented by balance training, and balance training is more effective when performed following physical exertion due to specificity of training, perhaps the incidence of ankle injuries may be decreased by performing balance training following physical exertion. In addition, this study tested single-limb balance because deficits in this ability have been shown to increase injury risk.

Due to the high incidence of ankle injuries in sport, it is evident that the most effective means of injury prevention and rehabilitation are warranted to reduce the rates of initial and recurrent injuries responsible for lost training time and the ability to participate in competitions. If a simple change in the time when balance training is administered improves the efficacy of a program, this knowledge could greatly improve our ability to prevent and treat ankle injuries. Therefore, the purpose of this study was to compare the efficacy of a 6-week balance training program when performed prior to or following physical exertion. A secondary purpose of this study was to determine whether the BESS is sensitive to changes in force plate measures of postural control that result following the completion of a balance training protocol.

Research Questions and Hypotheses

Research Question 1: Is the efficacy of a 6-week balance training program affected by whether it is performed prior to or following physical exertion?

Independent Variables: Time (pre-test versus post-test)

Group (pre-physical exertion versus post-physical exertion).

Dependent Variables: Center of pressure elliptical sway area and sway speed.

Hypothesis 1: Balance training conducted immediately following physical exertion will result in greater improvements in balance compared to identical training performed immediately prior to physical exertion.

Research Question 2: Is the BESS sensitive to changes in balance as verified by force plate measures?

Independent Variables: BESS total score and center of pressure elliptical sway area and sway speed.

Dependent Variable: Frequencies of improvement and no improvement.

Hypothesis 2: The BESS will be sensitive to changes in balance measures collected on the force plate.

Operational Definitions

Sway Speed (SS): the average speed (resultant SS) of the movement of an individual's center of pressure during the balance assessment.

Elliptical sway area (ESA): the area of ellipse formed by 95% of the center of pressure points (Fox, Mihalik et al. 2008).

Physical Exertion: the physical activity performed by subjects as part of their team training – as in a sport-specific training session or a conditioning session led by a coach and participated in by all team members.

Balance training program: a 6-week protocol progressively increasing in difficulty (Kidgell, Horvath et al. 2007). Subjects trained 3 days per week, either immediately pre- or post-physical activity, depending on their experimental group assignment. In weeks one and two, subjects performed three 30-second static single-limb balance tasks, and 3 sets of 6 repetitions each of dorsiflexion-plantarflexion exercises and 3 sets of 6 repetitions each of inversion-eversion exercises. In weeks three and four, single-limb stance times increased to 60 seconds, and exercises increased to 4 sets of 10 repetitions.

During weeks five and six, the exercises and balance tasks were the same as weeks one and two; however, the subjects performed all balance tasks with their eyes closed.

Assumptions

The sample to be used for this investigation consisted of volunteers from the University's women's Division I and club lacrosse and field hockey teams along with physically active college students. Throughout the study, it was assumed that all of the participating athletes performed the same lower body strength training and sport-specific practice sessions outside of the balance training program. It was also assumed that subjects did not perform any balance training on their own outside of the aforementioned program, which was controlled for by the fact that all subjects were part of the same intercollegiate teams. Lastly, it was assumed that the force plate and BESS are reliable and valid instruments.

Delimitations

All of the subjects in the study were NCAA Division I or club women's lacrosse and field hockey players, or physically active college students with no history of ankle injuries in the three months prior to data collection. Also, the experimental subjects performed the same balance training program three times per week, during the six week scrimmage season.

Limitations

One limitation of this study is that the athletes used in this study may not be representative of all NCAA Division I athletes, or all Division I women's lacrosse or field hockey players. All subjects in the experimental group were female, and males may react differently to balance training. During the study, academic scheduling conflicts occurred, with the end result that the training was not exactly six weeks in duration. Balance training was performed only on Dyna-discs, and the benefits may not be the same for other training devices. Due to the six-week nature of the program, generalizations cannot be made for other lengths of training such as four or twelve weeks.

CHAPTER II

REVIEW OF THE LITERATURE

Lower extremity injuries are extremely common in athletics, and have been found to account for more than 50% of all injuries in both practice and games for NCAA sports (Hootman, Dick et al. 2007). Ankle and foot injuries, specifically, account for over 40% of all lower extremity injuries reported in high school athletes (Fernandez, Yard et al. 2007). In high school basketball, the ankle/foot category constituted 39.7% of all recorded injuries (Borowski, Yard et al. 2008). In the NCAA sport of women's collegiate lacrosse, ankle ligament sprains were recorded as 17.7% of all injuries and 10% of all injuries in women's field hockey were recorded as ankle ligament sprains (Hootman, Dick et al. 2007).

Balance ability may be a useful predictor of ankle injuries, as was found by McGuine et al. (2000) in a cohort study of high school basketball players. Several studies have demonstrated the ability of balance training programs to improve balance in subjects with healthy ankles and subjects with chronic ankle instability or a history of injury (Rozzi, Lephart et al. 1999; Michell, Ross et al. 2006; Hale, Hertel et al. 2007; Kidgell, Horvath et al. 2007). Fatiguing exercise has also been shown to have a detrimental effect on balance ability as measured by increasing postural sway (Nardone, Tarantola et al. 1997). Gioftsidou et al. (2006) theorized that balance training following physical activity may be more effective than prior to due to the fact that the mechanisms that control balance and posture have already been utilized, and therefore they may be more sensitive to training. Thus, studies need to be performed to determine if the efficacy of balance training is time-dependent; for example, if higher balance gains, and presumably more effective injury prevention, may be achieved from balance programs performed immediately after the completion of physical activity.

The Balance Error Scoring System (BESS) is a clinical tool that was originally designed to evaluate postural instability in athletes who suffer a mild head injury (Riemann and Guskiewicz 2000). As an on-field measurement, the BESS is very convenient, since the only materials needed to perform the test are a foam pad and a stopwatch. The BESS has been demonstrated to be sensitive to postural deficits, including those resulting from functional ankle instability (Docherty, Valovich McLeod et al. 2006). Also, the BESS has been shown to be sensitive to fatigue (Wilkins, Valovich McLeod et al. 2004). To date, no studies have assessed the sensitivity of the BESS in response to balance training programs. Therefore, it is important to determine if the BESS is sensitive to balance training when compared to laboratory measures, since most clinicians do not have ready access to techniques such as force-plate testing. Also, if the BESS is sensitive to changes in balance ability due to balance training, the BESS may be a useful tool to track the improvement of an individual's balance ability during a balance training program or during rehabilitation.

Epidemiology

Lower extremity injuries have been demonstrated to be extremely prevalent in many different levels of athletics. One study found that over 50% of all injuries occurring in 15 different NCAA sports over a 16-year period were to the lower extremity during both practice and games (Hootman, Dick et al. 2007), while a similar lower extremity injury rate of almost 53% was found in a study of nine high school sports over a one-year period(Fernandez, Yard et al. 2007). Ankle injuries alone have been shown to account for 22.6% of all high school athletic injuries (Nelson, Collins et al. 2007). Related studies of individual high school sports have found ankle injury rates of 39.7% in basketball (Borowski, Yard et al. 2008), 13.3% in rugby (Collins, Micheli et al. 2008), 13.6% in baseball (Collins and Comstock 2008), and 23.4% in soccer (Yard, Schroeder et al. 2008). Furthermore, an 8-year study of English soccer academies showed a similar injury rate with ankle injuries accounting for 19% of total injuries (Cloke, Spencer et al. 2008). Two seasons of study of English Premiership Rugby Union clubs revealed that ankle injuries occurred at a rate of 11% during matches and 15% during training (Sankey, Brooks et al. 2008). NCAA women's lacrosse shows a 17.7% incidence of ankle ligament sprains, and NCAA women's field hockey shows a 10% incidence (Hootman, Dick et al. 2007). This study also revealed an ankle ligament injury incidence of 14.8% across the 15 sports studied, which the authors estimated to equal an annual average of more than 11,000 ankle sprains across the entire NCAA (Hootman, Dick et al. 2007).

Injuries also have a tendency to occur more frequently toward the end of practices and games. Gabbett (2000) studied three seasons of nine rugby league teams and discovered that over 70% of all injuries were sustained in the second half of matches. Also, more injuries occurred toward the end of the season as opposed to the beginning, suggesting that player fatigue may be a contributing factor in injury occurrence. Additionally, Sankey et al. (2008) demonstrated a higher prevalence of injuries in the second and fourth quarters of rugby matches, 30% and 35%, respectively, compared to

12% and 23% in the first and third quarters. Lateral ankle ligament injuries also showed a much higher incidence (71%) in the second and fourth quarters. These data suggest that lower extremity injuries are more likely to occur following sustained physical exertion.

Improving Balance

Many different tools have been introduced for use in balance training programs, both for healthy subjects and those with chronic ankle instability. In addition to traditional balance programs utilizing foam pads and balance boards, tools such as exercise sandals and Both Sides Up balance trainers, known as BOSU balls, have demonstrated promise in improving balance. For example, a study utilizing exercise sandals demonstrated increased lower leg muscle activity compared to the same exercises performed without the balance sandals (Blackburn, Hirth et al. 2003). In contrast to the implications of the previous study, Michell et al. (2006) did not find a significant difference in balance improvement between subjects who performed the same balance exercises with or without the balance sandals. All subjects showed improvements in balance after training for 8 weeks, however, the authors stated that due to their non-random assignment of control subjects to the same training group as their matched counterparts with functional ankle instability (FAI), other effects of the balance sandals may not have been detected. For example, control subjects with good ankle stability but poor anterior-posterior postural stability may all have been assigned to the same group.

Gauffin et al. (1988) utilized a round board with a half-sphere attached to the bottom of it to train soccer players with functional instability for eight weeks (Gauffin, Tropp et al. 1988). These subjects performed single limb stance on the ankle disk with the functionally unstable limb for ten minutes five times per week. The subjects were pre- and post-tested on a force plate and LEDs were used to determine segmental movement. The confidence ellipse for sway area showed a decrease of $184 \pm 69\ mm^2$, which was statistically significant, indicating improved postural control. Sheth et al. (1997) also trained subjects with ankle disks for eight weeks and observed an increase in the onset time of the anterior tibialis muscles during a simulated inversion ankle sprain. This may be a useful adaptation due to the fact that the anterior tibialis is an ankle invertor, therefore an earlier onset may limit ankle inversion.

Two separate studies involving subjects with either chronic or functional instability found significant improvements in balance ability after only four weeks of training (Rozzi, Lephart et al. 1999; Hale, Hertel et al. 2007). Hale et al. utilized a balance training program for individuals with chronic ankle instability consisting of attempts at the Star Excursion Balance Test (SEBT), while Rozzi et al. included healthy subjects along with subjects with FAI in their training which utilized the Biodex Stability Sytem. The healthy subjects in the latter study also showed significant improvement compared to their pre-test scores.

Another study found significant improvements in healthy subjects after only two weeks of balance training, and the improvements continued through four weeks of training (Rasool and George 2007). Subjects performed single leg stances of progressive difficulty. The measurement of subjects' balance ability was the SEBT, and subjects showed improvements not only in total score, but in all 8 individual directions after two weeks. After four weeks, all but two directions showed additional improvement.

The BOSU ball has also been demonstrated to improve balance ability (Yaggie and Campbell 2006). Yaggie and Campbell (2006) used a 4-week BOSU ball balance training program in healthy subjects and showed an improvement in the time subjects were able to balance on the BOSU ball and an improvement in a shuttle run obstacle course. Interestingly, this study showed a retention effect when the subjects were post-tested again two weeks after the completion of the training program.

Balance training has also been shown to be an integral part of neuromuscular training to improve performance in athletes. A controlled cohort repeated measures study that included 6 weeks of plyometrics, core strengthening, resistance training, interval speed training, and balance training for female high school athletes demonstrated improvements in vertical jump, single-leg hop distance, speed, bench press, squat, knee range of motion, and knee varus and valgus moments when compared to both their pre-test measures and to the untrained control group (Myer, Ford et al. 2006). Due to the nature of this study, it is impossible to tease out the effects of balance alone on the subjects' improvements, but the authors postulated that the improvements in single-leg hop distance and single limb balance tasks were most likely due to the balance training segment of the protocol.

Another study of healthy soccer players compared the efficacy of balance training between athletes who performed balance training prior to their sport-specific training and athletes that performed balance training immediately following their sport-specific activities (Gioftsidou, Malliou et al. 2006). The 12-week balance training program consisted of training on the Biodex Stability System, a 45 second single limb stance on a mini-trampoline while kicking a soccer ball with the other leg, and maintaining single-limb balance for 45 seconds on three balance boards. The balance boards used in this study were constructed by the authors and included one that restricted movement in the anterior-posterior direction, one that restricted movement in the medial-lateral direction, and one that permitted unrestricted movement. The Biodex training consisted of a three-minute attempt to move a cursor depicting the subject's CoP to a target on the screen. Although the study found that a single soccer practice session did not appear to effect the balance ability of the players, players who performed the balance program immediately after soccer practice showed a greater improvement in balance ability following the 12-week training program compared to who trained before practice.

A six week program implemented by Kidgell et al. (2007) in subjects with a history of ankle injury showed significant improvements in balance ability after the training. The subjects' balance was tested by using postural sway measures separated into medial-lateral and anterior-posterior sway paths, and the maximum medial-lateral sway was used as the most reliable measure. The subjects in this study demonstrated a significant improvement in balance ability upon completion of the balance program. McKeon et al. (2008) utilized a four-week balance training program for single-limb balance on subjects with Chronic Ankle Instability (CAI) and found significant improvements in force plate measures and the SEBT.

The specific balance program (Kidgell, Horvath et al. 2007) that will be utilized in this study showed improvement as described above. This program is well designed and may be easily executed in the short amount of time necessary to work with athletic teams. Subjects trained 3 times per week for six weeks performing closed kinetic chain exercises on ankle disks (Dyna Disc). The exercises consisted of static standing, anterior-posterior tilting, and medial-lateral tilting with increasing difficulty. The exercise program was divided into three phases with the first phase consisting of weeks 1 and 2, phase two consisting of weeks 3 and 4, and phase three consisting of weeks 5 and 6. During the first phase, exercises consisted of static standing (3 sets x 30 seconds), anterior-posterior tilting (3 sets x 6 repetitions) and medial-lateral tilting (3 sets x 6 repetitions. Phase two exercises consisted of static standing (3 sets x 60 seconds), anterior-posterior tilting (4 sets x 10 repetitions) and medial-lateral tilting (4 sets x 10 repetitions. Phase three exercises consist of static standing (3 sets x 30 seconds), anterior-posterior tilting (3 sets x 6 repetitions) and medial-lateral tilting (3 sets x 6 repetitions) with eyes closed during all tasks. While this study utilized subjects with a history of ankle injury, this program is similar in structure to the program utilized by Wederrkopp et al. which significantly reduced the injury rates of healthy athletes performing the program and as such can be expected to produce similar balance ability improvements in a healthy athletic population (Wedderkopp, Kaltoft et al. 1999).

Behm et al. studied the effects of acute stretching on balance, force, and reaction and movement times. Subjects who were in the stretching group performed three stretches to discomfort for 45-seconds three times for four conditions: hip extensors and flexors, and for dorsiflexion with knee extended and flexed. Force output showed no significant difference between the control and experimental group, however the balance scores of the control group improved while the stretch group worsened (stretch group decreased 9.2% while control group increased 17.3%; $P < 0.009$). In addition, while the control group improved their reaction and movement times (5.8% and 5.7% decreases), the stretch group's times worsened (4.0% and 1.9%; $P < 0.001$) (Behm, Bambury et al. 2004).

Balance Ability and Injury Risk

Balance has been shown to be a predictor of ankle injury risk (McGuine, Greene et al. 2000; Hrysomallis, McLaughlin et al. 2007). McGuine et al. (2000) reported that healthy high school basketball players who demonstrated larger sway measures (i.e. worse balance) were more susceptible to ankle injury. Hrysomallis et al. (2007) studied the single limb balance ability of Australian Footballers using force plate measures. They found that poor balance ability was a significant predictor of ankle ligament injury.

Tropp et al. (1984) used stabilometry recordings with a force plate and looked at the correlation between pathological readings and injury in subjects. In both the healthy subjects and the subjects with a history of ankle injury, subjects with pathological stabilometry recordings had a 42% chance of an ankle joint injury, compared to the subjects with normal readings who had an 11% chance of ankle joint injury. This is extremely important, since many studies focus on individuals with functionally unstable ankles and not on healthy populations. If poor balance ability is predictive on ankle injury risk in healthy individuals, it is plausible that improving the balance ability of these individuals may lower their risk of acute ankle injury.

Injury Prevention by Improving Balance

Many knee and ankle injury prevention strategies have been proposed that include balance training as part as an overall training program, sometimes involving equipment such as balance boards and ankle disks. Caraffa et al. (1996) utilized a single-leg balance training program of increasing difficulty to reduce the incidence of ACL injuries in semi-professional and amateur soccer players. Their program utilized different balance boards, including a BAPS board, and a neuro-muscular facilitation technique. Ten ACL injuries were recorded in the balance training group, compared to 70 ACL injuries in the control group.

An intervention program for at-risk high school football players (McHugh, Tyler et al. 2007) used single-limb balance training on foam pads performed 5 days a week during preseason and twice per week during the season for 13 weeks. The incidence of non-contact inversion sprains for high at-risk players, classified as players with a history of ankle sprain and who were overweight according to BMI, decreased from 5.7 injuries per 1000 exposures before the intervention to 1.4 injuries per 1000 exposures after the intervention. The intervention players showed a decrease in injury incidence of 77%.

A balance intervention program for soccer players with a history of inversion ankle sprains resulted in a significantly lower incidence (0.13 injuries per 1,000 playing hours) of ankle sprains in the intervention group when compared to the control group (3.33 injuries per 1,000 playing hours) (Mohammadi 2007). Two groups which used either strength training or orthotics as the intervention did not show a significant finding. The balance group utilized an ankle disk and progressed difficulty by changing surfaces and vision conditions.

Another study using volleyball teams introduced an injury prevention program consisting of a balance board training program and drills to correct improper techniques on take-off, landing, and side-to-side movements (Bahr, Lian et al. 1997). Ankle injury incidence decrease to 0.5 injuries per 1,000 players hours from the original rate of 0.9 injuries per 1,000 player hours.

A study of Dutch volleyball players with a history of ankle sprains showed a lower incidence of acute lateral ligament injuries following a balance training program compared to a control group who did not participate in an intervention (Verhagen, van der Beek et al. 2004). The balance program in this study included a progression of single limb activities with a balance board and a ball intended for throwing purposes. A European handball intervention program which included balance activities on an ankle disk showed an injury incidence odds-ratio of 0.17 for players who used the intervention (Wedderkopp, Kaltoft et al. 1999). The intervention was not well-described, but included balance activities increasing in difficulty. In a continuation of the previous study, the authors found a significantly lower risk of traumatic injury in subjects that used an ankle disk compared to subjects who performed the intervention without an ankle disk (odds ratio of 4.8) (Wedderkopp, Kaltoft et al. 2003).

Fatigue and Physical Exertion

Fatigue is an important part of human movement, especially athletics, and may decrease performance and increase the risk of injury (Sankey, Brooks et al. 2008). Fatigue may be divided into two categories: central fatigue and peripheral fatigue. Debate exists about the definitions of these two terms, but for the purposes of this study, they are defined as follows. Central fatigue is "a progressive reduction in voluntary activation of muscle during exercise" (Gandevia 2001), while peripheral fatigue is "fatigue produced by changes at or distal to the neuromuscular junction" (Gandevia 2001). Simply put, central fatigue is more related to the central nervous system and general cardiovascular changes, whereas peripheral fatigue is more specific to the individual muscles involved in performing the task in question.

In a study using healthy individuals, subjects performed both fatiguing and non-fatiguing exercise on a treadmill or a cycle ergometer (Nardone, Tarantola et al. 1997).

Subjects were considered to be fatigued when heart rate exceeded 60% of their maximum heart rate. This study induced predominantly central fatigue, but some peripheral fatigue was also likely induced due to the use of muscles in the lower extremity during the fatigue protocol. After fatiguing exercise, the sway area obtained during double-leg stance increased on average to about 192% of the control values and the sway path increased 132%, which was a significant increase for both. The median frequency of oscillation also showed an increase after fatigue. The increase of sway area shows that the subjects were using larger areas in which to stabilize themselves, and the sway path indicates they were traveling farther from their original position. An increase in the frequency of oscillation suggests that subjects were wavering faster than before fatigue.

Two different studies of healthy subjects induced peripheral fatigue of the lower extremity by using a Cybex dynamometer. Yaggie and McGregor (2002) performed maximal ankle inversion, eversion, dorsiflexion, and plantarflexion at 60 degrees per second with fatigue occurring when three consecutive repetitions below 50% of their maximum joint torque were obtained. Johnston et al. (1998) used increasing intervals on the machine in a pedaling-like motion until subjects were using less than 50% of their initial maximal strength. Following the fatigue protocol, subjects demonstrated an increase in postural sway, medial-lateral displacement, and anterior-posterior displacement in the first study (Yaggie and McGregor 2002), and a significant decrease in balance ability as measured by the KAT platform (Johnston, Howard et al. 1998). These results suggest that peripheral fatigue and central fatigue have similar effects on balance measures.

Fox et al. (2008) used both aerobic and anaerobic exercise protocols to elicit fatigue in healthy subjects prior to testing them on the BESS and recording force plate sway measures. The aerobic protocol consisted of the yo-yo intermittent recovery test at level 1, and the anaerobic protocol consisted of maximum-effort sprints between cones using the same yo-yo test. For the aerobic protocol subjects were considered to be fatigued when they missed a total of two runs, while the anaerobic protocol was performed for a full two minutes. Both protocols elicited central fatigue, but most likely also included some amount of peripheral fatigue due to the use of leg musculature, especially during the turning portion of the runs. Both the anaerobic and aerobic protocols showed adverse affects on the BESS, as the errors basically doubled at three minutes post exercise and then decreased until returning to baseline levels at 13 minutes. Sway speed and elliptical sway area showed increases lasting up to 8 minutes post-exercise, with subjects' scores returning to baseline within 13 minutes.

One study of healthy female subjects had them perform calf raises to exhaustion prior to assessing balance ability , which was done using force plate and accelerometer values (Adlerton, Moritz et al. 2003). Both the acceleration of the subjects' center of pressure and the amplitude of those movements increased following physical exertion.

According to Caron et al. (2003), the body's motion during stance conditions oscillates similar to a rigid pendulum, and therefore center of gravity measurements may be used to represent movements of the whole body. Their study of ten healthy male subjects utilized isometric soleus contractions to induce fatigue and then measured the subjects' postural control by having them stand as still as possible on the force plate. Subjects showed a significant increase in center of pressure velocity and standard deviation after fatigue, but did not show a significant difference in center of gravity measures. One possible reason for this finding is that the researchers only fatigued the soleus muscle, when other muscles such as the peroneals and anterior tibialis are also involved in postural control. Since the hip and other musculature were not being monitored, other muscles may have compensated for the soleus fatigue. Also, due to their unorthodox fatigue protocol of having subjects work down to 40 to 60 seconds of 60% of the maximum contraction may not have sufficiently fatigued the subjects. However, these results are still applicable in our study due to the physical exertion performed by the subjects.

Small et al. utilized an eccentric hamstring strengthening program and trained male soccer players either during a warm-up for practice or during the cool-down period. At 45 minutes into training and after training (105 minutes), the cool-down players demonstrated significantly better eccentric hamstring peak torque changes (31.5 ± 25.7% versus -4.9 ± 25.0%; $p < 0.02$ and 40.7 ± 24.4% versus -6.4 ± 23.2%; $p < 0.02$). Small et al. posit that these improvements are due to the law of specificity, demonstrating that training in a fatigued state causes improvements in a fatigued state. The authors hypothesize that training in a fatigued state may reduce the risk of hamstring injuries, due to the higher occurrence of hamstring injuries in a fatigued state (Small, McNaughton et al. 2009).

Balance Training After Exertion

Due to the increased risk of injuries toward the end of games and matches (Gabbett 2000; Sankey, Brooks et al. 2008), it has been theorized that fatigue increases injury risk. Poor balance is also an indicator of higher injury risk (Tropp, Ekstrand et al.

1984; McGuine, Greene et al. 2000; Hrysomallis, McLaughlin et al. 2007), and is negatively influenced by fatigue and physical exertion (Nardone, Tarantola et al. 1997; Johnston, Howard et al. 1998; Yaggie and McGregor 2002; Fox, Mihalik et al. 2008). Based on these findings, it is plausible that the greater risk of injury in a fatigued state is attributable to the associated balance deficits. Gioftsidou et al. (2006) assessed balance in healthy soccer players before and after a 12 week balance training program that was performed either prior to or following team practices. Subjects performed single-leg stance on three different balance boards as previously described, and the Biodex Stability System to determine balance ability. The results indicated that all subjects who performed the balance training protocol improved in balance ability, but that the post-practice balance group improved their balance significantly more than the pre-practice group. The authors postulate that these results are due to the specificity of training, since fatigue negatively affects balance. They state that postural control and stability mechanisms are "primed" by the activity beforehand. Another theory for these possible changes is that the postactivation potentiation may be induced during practice due to recruitment of high threshold, fast motor unit muscles and therefore enabling better muscle control (Sale 2002). Postactivation potentiation can be described as the increase in muscle isometric twitch and low frequency titanic force which often follows a conditioning activity (Sale 2004).

While these results are encouraging, the Gioftsidou study has several flaws. Three trials were performed on the balance boards and the best trial was used for further comparison, as opposed to averaging of the trials. Subjects' scores may not have been representative, since a subject with poor balance may have had one "good" trial, which was then accepted as his/her score. Also, the authors did not state how long after practice the players were tested, except to say “immediately”. As Fox et al. (2008) showed, if the authors waited as little as 8 minutes, they may have missed changes that actually existed due to recovery of balance ability. In addition, individuals may not have been putting forth as much effort as possible, leading to the investigators’ belief that subjects were fatigued when that may not have been the case. This may mimic normal athletic conditions however, as players do not necessarily give their best effort every single practice session.

Force Plate

Force plates are laboratory tools considered to be the gold standard for assessing postural stability as indicated by variables such as sway area and sway speed. According to Lin et al. (2008), A-P and M-L center of pressure sway velocities and sway area obtained from force plates all demonstrate good-to-excellent reliability. Center of pressure measures have also been demonstrated to have good between- and within-days reliability, which is very important when using them to assess balance ability and postural control over a period of time. A study of healthy adults performing double-limb stances on a force plate (Pinsault and Vuillerme 2008) determined that three 30-second trials provide excellent test-retest reliability for many center of pressure values, including the center of pressure mean velocity (comparable to sway area as defined above) and the center of pressure surface area (comparable to elliptical sway area as defined above).

Tropp et al. (1984) used stabilometry recordings with a force plate to evaluate the correlation between fore plate measures and ankle injury. In both the healthy subjects and the subjects with a history of ankle injury, subjects with pathological stabilometry recordings had a 42% chance of an ankle joint injury, compared to the subjects with normal readings who had an 11% chance of ankle joint injury.

Fox et al. (2008) utilized center of pressure measures for their study to determine postural stability. The measures they used were average sway velocity and elliptical sway area. For the purposes of their study, sway velocity was defined as the "average speed at which an individual's COP moved within the base of support". Elliptical sway area was defined as "the area defined by the minor and major axes of an ellipse that encompassed an area containing 95% of the COP data points".

Ground reaction forces caused when an individual shifts his or her weight are measured by the force plate, which are then used to compute the x- and y-coordinates of the individual. Sway speed and elliptical sway area are then computed by a custom Matlab program (The Mathworks, Inc, Natick, MA). Sway speed is calculated as the average speed at which the individual's center of pressure moved. Elliptical sway area is calculated as the 95% confidence ellipse of the individual center of pressure points during the trial (Fox, Mihalik et al. 2008).

Balance Error Scoring System

Another important tool that is used widely by clinicians is the BESS. The BESS is used to assess postural deficits associated with mild head injury (Docherty, Valovich McLeod et al. 2006), but so far has not been used to determine changes in postural control due to rehabilitation and balance training. Learning effects have also been shown in both athletes aged 9 to 14 years and in high school aged athletes when the BESS is administered repeatedly over a 7-day interval (Valovich, Perrin et al. 2003; Valovich McLeod, Perrin et al. 2004). Performance on the BESS may also be affected by fatigue, as a fatigue protocol consisting of jogging, sprinting, push-ups, and sit-ups in male Division I athletes produced a decrease in performance on the BESS (Wilkins, Valovich McLeod et al. 2004). Time after fatigue may also be a factor, as BESS scores have been shown to return to baseline within 20 minutes post-exercise (Susco, Valovich McLeod et al. 2004; Fox, Mihalik et al. 2008). If learning effects exist, it might follow that if an individual increases his/her balance ability by balance training, the BESS may then be sensitive to these changes. If the BESS is sensitive to these changes in postural control, then clinicians may be able to use the BESS as a clinical tool for tracking changes in an individual's balance ability.

Summary

Lower extremity injuries, and especially ankle injuries, are extremely prevalent in sports, and specifically in NCAA Division I women's lacrosse and field hockey (Fernandez, Yard et al. 2007; Hootman, Dick et al. 2007; Nelson, Collins et al. 2007). Poor balance ability has also been shown to be a predictor of injury (Tropp, Ekstrand et al. 1984; McGuine, Greene et al. 2000; Hrysomallis, McLaughlin et al. 2007). Fatigue or physical exertion appears to play a role in the occurrence injury, as a significantly larger number of injuries occur later in games and practices compared to earlier stages (Gabbett 2000; Sankey, Brooks et al. 2008). While this situation may seem dire, a significant number of lower extremity injuries may be preventable by using intervention programs (Caraffa, Cerulli et al. 1996; Hewett, Lindenfeld et al. 1999; Wedderkopp, Kaltoft et al. 1999; Verhagen, van der Beek et al. 2004; McHugh, Tyler et al. 2007; Mohammadi 2007) including the 6-week balance program utilized by Kidgell et al. (2007) which has been shown to improve balance ability over time. However, it is unknown at this time what effect, if any, the state of the athlete during the implementation of the balance training program has on the balance improvements produced by these programs. As a fatigued state, such as that following physical exertion, has been shown to increase injury risk and impair balance ability, perhaps balance training following exertion, thereby mimicking this deleterious condition, may increase balance improvements provided by balance training (Gioftsidou, Malliou et al. 2006).

In addition, while force plate measures serve as the gold standard for measuring postural stability (Caron 2003; Fox, Mihalik et al. 2008; Lin, Seol et al. 2008; Pinsault and Vuillerme 2008), their use in a clinical setting is impractical. Therefore, if the BESS proves sensitive to detecting changes in balance performance, it will provide the clinician a more readily available and applicable tool for objectively tracking an athlete's balance performance over time.

CHAPTER III

METHODS

Subjects

A sample of convenience consisting of 43 NCAA Division I women's lacrosse and field hockey players from the University of North Carolina at Chapel Hill and 11 physically active college-aged students served as subjects for this study. The non-athletes were utilized as a control group that did not take part in balance training. An *a priori* power analysis determined that a sample of this size was necessary to achieve a statistical power of 0.80 in order to identify a significant difference between balance training groups. Subjects ranged in age from 18 to 24 years and were actively listed as players on the rosters of their respective teams or were physically active students at the University. In order to be considered physically active, subjects must participate in moderate physical activity for at least twenty minutes three times per week. Subjects were excluded from participation if they had sustained lower extremity injury in the last six months that resulted in a limitation of their physical activity, concussive injury within the past three months that was not resolved, or had a neurological or sensory condition affecting balance. Further, a total of 7 subjects were excluded from post-testing (final subjects per group included 18 before, 16 after, and 11control). One subject was excluded due to non-compliance with the training protocol, one was excluded due to an ankle injury, one was excluded due to not completing at least 15 training sessions, and six subjects were excluded because they were no longer active members of their respective rosters at the time of post-testing. Subject descriptives can be found in Table 2.

Measurement and Instrumentation

Center of Pressure (CoP) data were measured during single-limb stance using a Bertec 4060-NC piezoelectric force plate (Bertec Corp, Columbus, OH) at a sampling rate of 1000 Hz (Riemann, Guskiewicz et al. 1999) using Motion Monitor software (Innovative Sports Training, Inc, Chicago, IL). Raw force plate voltage signals were amplified by a gain of 5 using a Bertec AM-6701 amplifier. CoP force plate measures have been determined to be valid for determining postural sway and reliable both within- and between-days by multiple previous studies (Lin, Seol et al. 2008; Pinsault and Vuillerme 2008).

The Balance Error Scoring System (BESS) was used as a measurement tool in this study. The test consists of six different trials of eyes-closed balance attempts (double-leg, single-leg, and tandem stances) on both firm and foam surfaces. The subject maintains each stance for twenty seconds while the evaluator tracks the number of balance errors and adds all errors for each condition for a composite score. Errors on the BESS include lifting hands off the iliac crests, opening the eyes, stepping, stumbling, or falling, moving the hip into more than 30 degrees of flexion or abduction, lifting the forefoot or heel, and remaining out of the testing position for more than 5 seconds. Due to its subjective nature and the fact that the principal investigator was not blinded to group assignment, the BESS was always scored by a secondary researcher. The BESS has been demonstrated to have high intertester reliability and to be a valid instrument for testing an individual’s postural control (Riemann, Guskiewicz et al. 1999).

Procedures

Subjects reported to the Neuromuscular Research Laboratory for an initial testing session immediately before initiation of a 6-week balance training intervention. During this initial visit, subjects read and signed an approved informed consent form and a questionnaire to verify inclusion/exclusion criteria. Subjects were quasi-randomly assigned to pre- or post- physical activity balance training groups within each team to ensure that an equivalent number of players from each team were placed into the two groups. Following group assignment, subjects completed three 20-second single-limb stance attempts on the force plate with hands on their iliac crests, the contralateral foot lifted off the ground, and their eyes closed. All testing was conducted on the dominant leg, defined as the stance leg when kicking a ball for maximal distance. Also, all six conditions of the BESS were administered. The order of BESS and force plate tests was counterbalanced between subjects. After pre-testing of the control group, the subjects were instructed to continue their normal activities but to not introduce new balance training into their usual activities. Additionally, at the time of post-testing, due to subject drop-out and exclusion by the researchers, the before group consisted of ten women's lacrosse players and eight women's field hockey players, and the after group consisted of ten women's lacrosse players and six women's field hockey players.

In the experimental groups, the balance training program was performed three times per week for six weeks either immediately before or after regularly scheduled practice sessions at the practice facilities of the respective teams. The balance training program involved a series of single-limb stance and tilting exercises performed on Dyna-Discs (Exertools Inc.) which progressively increased in difficulty throughout the intervention period as described by Kidgell et al. (2007). All activities were single-limb tasks, performed on the dominant limb, which were eyes-open for the first four weeks and eyes-closed during the last two weeks. The anterior-posterior and medial-lateral tilts consisted of balancing on the dominant limb and dorsiflexing and plantarflexing the ankle, or inverting and everting the ankle, respectively. In effect, the subjects were instructed to attempt moving their ankle while balancing on the same limb. A detailed description of the balance training program is provided in Table 1. All tasks were performed at the instruction of a certified athletic trainer.

Following the six week balance training program for the experimental groups, subjects were assessed using the same force plate and BESS tasks provided that they had completed at least 15 of the 18 training sessions (83%). These measures were performed in the same order as at the pre-intervention testing sessions. The control group subjects were also assessed in the same way.

Data Reduction and Analysis

The force plate variables that were utilized in this investigation included average sway speed, which is the average speed of the movement of an individual’s center of pressure (CoP), and elliptical sway area, which is the area of an ellipse which encompasses 95% of the individual’s CoP data points (Fox, Mihalik et al. 2008). These variables were calculated using custom computer software (Matlab version 7.7; Mathworks Inc, Natick, MA). Mean values collapsed across trials were analyzed using SPSS statistical software (version 18; SPSS Inc, Chicago, IL) with an alpha level set *a priori* at $\alpha \leq 0.05$. Three separate 3(Group) x 2(Time) ANOVAs were performed for average sway speed, elliptical sway area, and BESS total score, to evaluate main effects for Time and Group, and the Group x Time interaction effect. Post-hoc testing of significant interaction effects was performed using planned pairwise comparisons with a Bonferroni adjustment. Specific comparisons were performed between groups at each time point using independent samples t-tests and within groups across time using paired samples t-tests. Changes in total BESS scores were analyzed using a X^2 test of association to evaluate the sensitivity of the BESS to changes in balance ability over time relative to that of force plate measures. The expected frequencies for the X^2 test were derived from force plate data. Change scores (pre-test – post-test) were computed for each force plate variable, and improvement was categorized as a change score greater than or equal to the lower bound of the 95% confidence interval collapsed across balance training groups. Observed frequencies for the BESS were calculated in an identical manner.

Table 1

Balance Training Protocol			
	Weeks 1 &2	Weeks 3 &4	Weeks 5 &6
Single-limb stance	3 times 30 seconds with eyes open	3 times 60 seconds with eyes open	3 times 30 seconds with eyes closed
A-P and M-L tilting	3 sets of 6 repetitions with eyes open	4 sets of 10 repetitions with eyes open	3 sets of 6 repetitions with eyes closed

CHAPTER IV

RESULTS

Statistical analyses of the reduced data revealed that changes in balance were not significant in the experimental groups or control group. Non-significant interaction effects were also found due to the lack of significant changes (Table 3).

Significant main effects for time ($F_{1,32}$= 15.596, P < 0.001) and group ($F_{2,32}$ = 4.235, P = 0.021) were demonstrated for elliptical sway area as all groups decreased elliptical sway area, but the group x time interaction effect was not significant ($F_{2,32}$ = 1.716, P = 0.192) (Table 3, Figure 1). Post-hoc testing on group main effect revealed that the Before and After groups were significantly different (P = 0.019). We conducted supplementary analyses (repeated measures t-tests) to evaluate changes in elliptical sway area within each group between test points. These analyses indicated that only the After group improved, while the Before and Control groups did not (Tables 8-10). The supplementary analyses reveal that only balance training performed after exertion affected elliptical sway area scores.

Significant main effects for time ($F_{1,32}$ = 7.060, P = 0.011) and group ($F_{2,32}$ = 3.691, P = 0.033) were identified in the sway speed measure as all scores decreased at post-test, but the group x time interaction effect was not significant ($F_{1,32}$ = 0.479, P = 0.623), indicating that the timing of balance training did not affect sway speed scores. In addition, no significant results were found between pre- and post-test measures for any group via our supplementary analyses. These results are presented in Tables 4, 8, 9 and 10 along with Figure 2.

With respect to the BESS measure, there was a significant main effect for time ($F_{1,32} = 23.216$, $P < 0.001$) as the BESS scores decreased, but no main effect for group ($F_{2,32} = 0.451$, $P = 0.640$), and the group x time interaction effect ($F_{2,32} = 2.682$, $P = 0.080$) was non-significant (Table 5, Figure 3). In this case, supplementary analyses indicated that both the Before group and the Control group significantly decreased their number of total BESS errors (Tables 8 and 10), but there were no differences detected between groups and the timing of balance training did not significantly affect the reduction in total BESS scores.

Chi-square goodness of fit tests comparing the frequency of improvement as determined by the BESS and the two force plate measures were significant for sway speed (χ^2 (1) = 7.556, $p = 0.006$), but not for elliptical sway area (χ^2 (1) = 0.134, $p = 0.714$). This indicates that there was a significant association between the frequencies of improvement following training determined using the BESS and the sway speed measure, but not the elliptical sway area measure. However, the BESS demonstrated only 68.8% and 56.5% sensitivity, and 27.8% and 27.3% specificity in identifying balance improvements detected by the sway speed and elliptical sway area measures, respectively (Table 7).

Table 2

Subject Descriptives by Group				
	Height (cm)	**Weight (kg)**	**Age (years)**	**Number**
Before Exertion	167.22 ± 4.722	62.27 ± 5.70	19.39 ± 1.24	18
After Exertion	166.69 ± 4.29	62.24 ± 7.19	18.75 ± 0.86	16
Control	169.55 ± 11.35	66.35 ± 12.80	20.36 ±3.07	11

Table 3

Pre-test and post-test values by group (mean ± standard deviation)

	Elliptical Sway Area		**Sway Speed**		**Balance Error Scoring System**	
	Pre-Test	**Post-Test**	**Pre-Test**	**Post-Test**	**Pre-Test**	**Post-Test**
Before	22.723 ± 13.287	18.663 ± 6.912	17.086 ± 6.880	14.149 ± 1.790	16.389 ± 5.982	12.111 ± 6.192
After	36.411 ± 19.543	25.906 ± 9.137	18.204 ± 6.143	15.349 ± 2.352	16.313 ± 6.332	14.688 ± 4.868
Control	25.408 ± 8.975	20.599 ± 7.642	13.707 ± 1.635	12.706 ± 2.795	19.091 ± 3.562	12.273 ± 3.744

Table 4

Elliptical sway area statistical values

Elliptical Sway Area ANOVA			
	F	df	P
Time*	15.596	1	< 0.001
Group*	4.235	2	0.021
Time x Group	1.716	2	0.192

* $P < 0.05$

Table 5

Sway speed statistical values

Sway Speed ANOVA			
	F	df	P
Time*	7.060	1	0.011
Group*	3.691	2	0.033
Time x Group	0.479	2	0.623

* $P < 0.05$

Table 6

BESS statistical values

Balance Error Scoring System ANOVA			
	F	df	P
Time*	23.216	1	< 0.001
Group	0.451	2	0.640
Time x Group	2.682	2	0.080

* P < 0.05

Table 7

BESS chi-square statistical values

	Sensitivity	**Specificity**	**Degrees of Freedom**	**Chi-Square**	**Asymptomatic Significance**
Elliptical Sway Area	56.5%	27.3%	1	0.134	0.714
Sway Speed*	68.8%	27.8%	1	7.556	0.006

* P < 0.05

Table 8

Before Exertion Group t-tests (mean ± SD)				
	Pre-test	Post-test	t	P
Elliptical Sway Area	22.723 ± 13.287	18.663 ± 6.912	1.693	0.109
Sway Speed	17.086 ± 6.880	14.149 ± 1.790	1.859	0.080
BESS*	16.389 ± 5.982	12.111 ± 6.192	3.424	0.003

* P < 0.05

Table 9

After Exertion Group t-tests (mean ± SD)				
	Pre-test	Post-test	t	P
Elliptical Sway Area*	36.411 ± 19.543	25.906 ± 9.137	3.216	0.006
Sway Speed	18.204 ± 6.143	15.349 ± 2.352	1.951	0.070
BESS	16.313 ± 6.332	14.688 ± 4.868	1.040	0.315

* P < 0.05

Table 10

Control Group t-tests				
	Pre-test	Post-test	t	P
Elliptical Sway Area	25.408 ± 8.975	20.599 ± 7.642	2.219	0.051
Sway Speed	13.707 ± 1.635	12.706 ± 2.795	1.743	0.112
BESS*	19.091 ± 3.562	12.273 ± 3.744	3.892	0.003

* P < 0.05

Figure 1

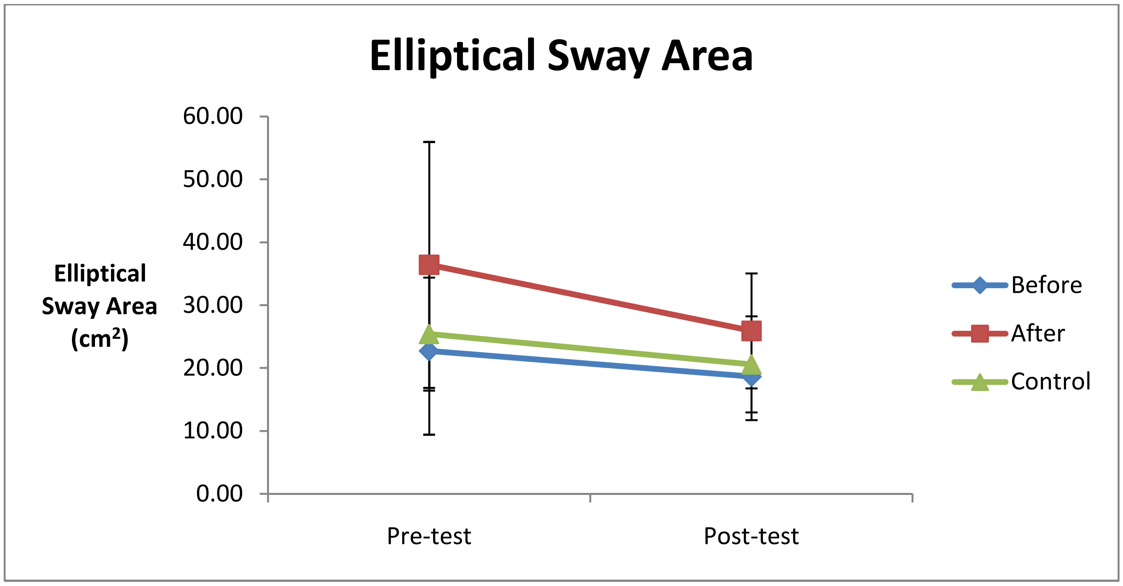


Figure 2

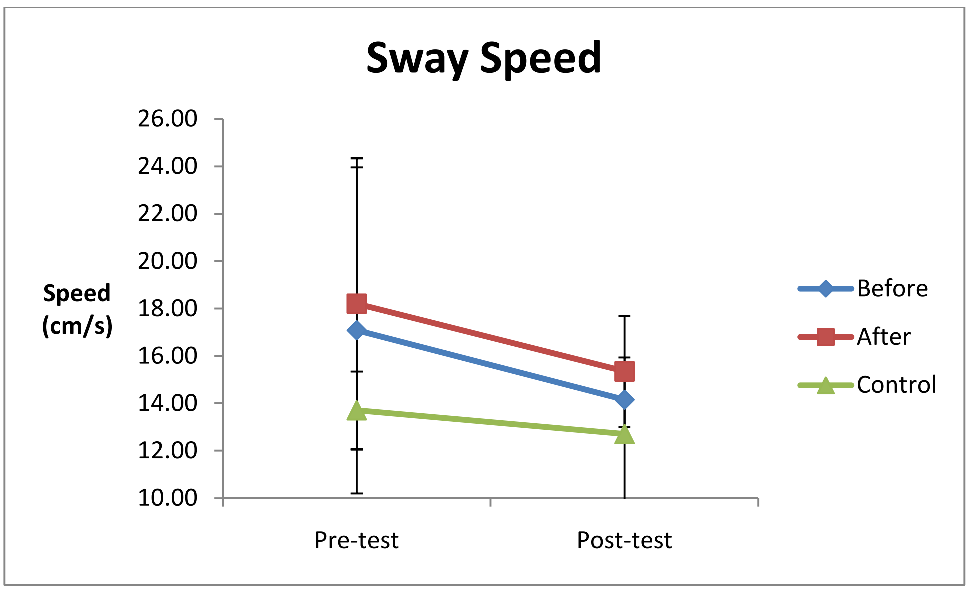
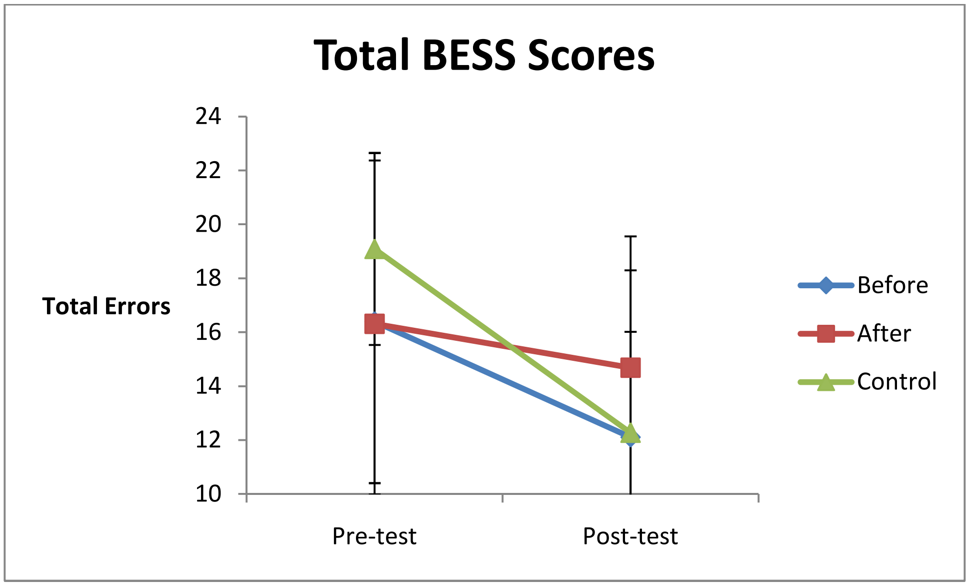


Figure 3


Total BESS Scores
Total Errors
24
22
20
18
16
14
12
10
Pre-test
Post-test
Before
After
Control

CHAPTER V

DISCUSSION

The primary findings of this investigation were that the effects of balance training did not differ when performed before versus following physical exertion, and that the BESS is not capable of detecting balance changes associated with training. Specifically, changes in balance in all groups were non-significant, and the BESS was not sensitive or specific to changes in balance following the six-week balance training protocol.

Balance training has been used as an intervention in many different studies, however many of them that have shown improvements in balance have used subjects with a history of ankle injury or functional ankle instability (Gauffin, Tropp et al. 1988; Sheth, Yu et al. 1997; Rozzi, Lephart et al. 1999; Hale, Hertel et al. 2007). In contrast, our sample excluded individuals with acute injury within six months of data collection, but did not discriminate between individuals with and without a history of previous injury or functional ankle instability. Because individuals with a history of injury have been shown to have balance deficits (Tropp, Ekstrand et al. 1984), we believe that previously injured subjects have more room for improvement during balance training and may show better outcomes, which is corroborated by previous studies utilizing healthy subjects and measuring postural stability with eyes closed which have found no significant improvements in postural stability after periods of balance training (Chong, Ambrose et al. 2001; Riemann 2003). These studies also utilized a progression to increase difficulty as the subjects increased their balance ability, and therefore could be considered even more challenging than our program.

In addition, the limited number of balance studies that have been performed on healthy subjects have often used the same tasks for both training and balance assessment such as the Star Excursion Balance Test (Rasool and George 2007), the time to balance on a BOSU ball (Yaggie and Campbell 2006), duration of a single-limb stance (Emery, Cassidy et al. 2005), or a BAPS board (Hoffman 1995). The specificity of the training to the testing measures may indicate that these previous studies identified learning effects of their specific training tools such as those found with repeat administration of the BESS (Valovich, Perrin et al. 2003; Valovich McLeod, Perrin et al. 2004), as opposed to improvements in general balance ability derived from enhancement of sensorimotor function. Also, balance training has been shown to reduce recurrent injuries in individuals (Wedderkopp, Kaltoft et al. 1999; Soderman 2000; Verhagen, van der Beek et al. 2004), however balance ability was not measured in these investigations and therefore the authors did not note any changes. We conclude that a six week program of single-limb stance on an unstable surface is insufficient to improve balance ability in healthy, elite-level athletes as measured in a laboratory or clinical setting.

We found that both experimental groups improved their balance ability, without regard to timing of training. In addition, the control group also improved their balance ability, indicating that the balance training program did not improve balance ability to a greater extent than what we would expect due to chance. This lack of improvement may be due to the fact that our experimental subjects were healthy, high-level athletes, who already had good balance ability. Gymnasts have often been considered to have excellent balance, due to the nature of their training and activities. Also, elite-level gymnasts have spent years training static and dynamic balance. However, studies show that gymnasts are not significantly better at these tasks than other athletes (Bressel, Yonker et al. 2007; Gautier, Thouvarecq et al. 2008), indicating that although six weeks of balance training in healthy, non-athletic subjects is effective as demonstrated by previous studies(Yaggie and Campbell 2006; Rasool and George 2007), it may not be enough to create an improvement in healthy, elite-level athletes. In addition, our balance training protocol was designed from a study that utilized subjects with functional ankle instability (Kidgell, Horvath et al. 2007), and therefore may be non-specific to our subjects

Possible explanations for the finding that timing of training did not influence the efficacy of balance training include the fact that the specificity of training principle did not apply. This could have occurred due to the time between the end of practice and the beginning of the training which may have been large enough to allow the players to return to a non-fatigued state due to team activities such as stretching and discussing schedule and activities with coaches. Also, the end of practice sometimes involves either lighter activity or some of the players stand on the sideline, therefore some of the subjects may have already cooled-down several minutes before the completion of practice. Last, the recruitment of specific muscle fibers through postactivation potentiation (Sale 2002) may not have taken place due to the nature of activities immediately preceding the balance training. For example, if the activity the subjects performed immediately prior to their balance training was hamstring curls, the lack of activation of muscles such as the anterior tibialis and the soleus could have prevented the postactivation potentiation of these muscles from occurring thereby negating the effect. Based on these factors, it is likely that on some occasions training in both balance groups was similar, as the effects of physical activity may have dissipated in the After group.

According to our findings, the BESS is not sensitive or specific to changes in balance and, therefore, cannot be used to identify changes in balance following training in healthy individuals. We postulate that this may be due to the fact that the BESS total score incorporates conditions that do not include single-limb stance. For example, the specificity of training principle previously mentioned indicates that the double-leg and tandem stances may not be trained due to different demands placed on the body during stance attempts. As our balance training protocol exclusively involved single-limb stance, the training may have had minimal influences on these conditions. Due to the use of BESS totals as opposed to single-limb conditions only, even if subjects improved on single-limb conditions, the lack of improvement on double and tandem stances may have obscured subjects' improvements. In addition, we believe that the improvement that the control group showed on the BESS is due to a learning effect as demonstrated by previous researchers (Valovich, Perrin et al. 2003; Valovich McLeod, Perrin et al. 2004). The pre-test measure was the first time the control subjects had attempted the BESS, while most of the experimental subjects had already attempted the test at least once as part of the pre-season medical screening process for their respective sports. Only 6 out of the 34 experimental subjects had not previously performed the BESS for pre-season baseline purposes, while none of the control subjects had ever performed the BESS previously. The six subjects who had not performed the BESS before were in their first semester with their respective teams. This discrepancy may explain why we observed significant changes in the control group, but not the experimental groups. Another possible explanation for our findings is the use of males in the control group and not the experimental group. Males have been shown to have poorer single-limb stability than females (Rozzi, Lephart et al. 1999), and thus the males in the control group may have skewed the results.

Although we did not find that our balance training program improved balance ability, we cannot deduce whether the balance training program may have reduced the likelihood of re-injury as other studies have found (Wedderkopp, Kaltoft et al. 1999; Soderman 2000; Verhagen, van der Beek et al. 2004). We believe that a balance training intervention composed solely of single-limb stances on an unstable surface may not be sufficient to improve balance ability in healthy individuals. In addition, the timing of such an intervention does not affect the outcome, and therefore programs should be administered at the convenience of the clinician and the patient.

We have several possible explanations for our findings, including the pre-training exertion activity, the type of subjects and the fact that we could not wholly determine proper performance of the program, the injury status of our subjects, and our method for analyzing balance ability. Since we used athletic teams during a practice season, some subjects performed their balance training immediately following weight lifting rather than the typical practice routine. This may have allowed their lower extremities to cool-down, especially if on some days the lifts concentrated on upper body musculature. The teams also met immediately following practice to discuss with the coaches, during which time they were simply standing for several minutes at a time. This may have negated the effects of exertion, essentially making the after-exertion balance training group the same as the before-exertion group. While we could see the individuals that made no attempt to perform the exercises correctly, and who were pulled from the final subject data, due to the fact that training sessions were conducted by one trainer and involved often eight athletes or more simultaneously, some subjects may not have performed the exercises correctly. In addition, our balance protocol was adapted from a study using only athletes with functional ankle instability (Kidgell, Horvath et al. 2007), which was a factor we did not account for when recruiting subjects. We believe that the primary cause for our lack of effect is the characteristics of our subjects, as in the differences between the experimental and control groups, and the fact that our before and after experimental groups were not as different as would have been ideal.

Our results also differ with the only other study to date which has investigated the effect that the timing of balance training has on the efficacy of the program (Gioftsidou, Malliou et al. 2006). We believe that this is because we attempted to improve upon the Gioftsidou study and therefore our results may be more accurate. First, our subjects did not train on the apparatus that they were tested on, in an attempt to show a true improvement in balance ability and not a learning effect. In addition, we utilized the average of three trials in order to gain a score more representative of an individual's balance ability, whereas Gioftisdou et al. utilized the best out of three attempts. This may have allowed a subject with poor balance ability to appear to have better ability by having a single good trial.

The limitations of this study include that the athletes used may not be representative of all NCAA Division I athletes, or all Division I women's lacrosse or field hockey players. All subjects in the experimental group were female, and males may react differently to balance training. During the study, academic scheduling conflicts occurred, with the end result that the training was not exactly six weeks in duration. Balance training was performed only on Dyna-discs, and the benefits may not be the same for other training devices. Due to the six-week nature of the program, generalizations cannot be made for other lengths of training such as four or twelve weeks.

We believe that our study clearly indicates the need for studies to determine if more intensive and dynamic training programs can improve balance ability. In addition, it needs to be determined if this specific balance training program can reduce the incidence of injury. This study was designed to be very clinically applicable, and we believe that this may have helped lead to our findings.

Clinically, although this program did not increase the balance ability of the subjects as measured in the laboratory, it may still be useful to the clinician if it lowers the incidence of injury. As previous work has demonstrated that this program improves balance in subjects with a history of ankle injury, we recommend for clinicians to utilize this program for athletes with a history of ankle injury, and to implement balance training when it is most convenient for both them and their athletes, since we found that the timing of balance training does not change its effectiveness. We do not recommend this program for healthy athletes, since we did not find that it improved balance. In addition, we do not recommend that clinicians attempt to utilize the BESS as a way to track changes in balance in healthy individuals, and that the BESS should continue to be utilized as stated in previous literature until more studies have been performed to determine if an athlete will need a new baseline after either injury or completion of a balance training program.

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