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Adaptations to balance training using the Shuttle TNT System in female NAIA athletes

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Abstract. Balance training has been demonstrated to produce positive adaptations to multiple populations, including the elderly and athletes. Despite the usage of the Shuttle TNT System in physical therapy settings, the literature on this particular equipment is scarce. The purpose of this study was to determine if training on the Shuttle TNT System is a viable method for improving balance scores in a female athletic population over a period of four weeks, three times per week for 30 minutes. Furthermore, the author investigated potential links between limit of stability forward, backward, left and right, and vertical jump performance. An ANOVA and a Pearson product moment correlation were used to analyze statistical change after the intervention. Limit of stability and vertical jump scores showed a statistically significant change ($p \leq .05$), and correlations of .643 and .696 were found between limit of stability-left and limit of stability-forward when ran against vertical jump scores. The study concluded the Shuttle TNT System is a viable option to improve limit of stability scores in a female volleyball population. Further studies are necessary to analyze correlations between limit of stability scores and vertical jump performance in other sports.
Key words: *limit of stability, center of pressure, posturography, vertical jump, college women*.

Introduction

Balance training has been incorporated in many types of sporting activities for decades, and its relationship to athletic performance has been documented since at least the turn of the millennium (1, 2). Some sports, such as skeet shooting and archery require high levels of static balance, which can be defined as holding a given position with as little movement as possible (3). Other sports, such as volleyball and American football demand a finely-tuned sense of dynamic balance, where an athlete maintains a stable support base while executing specific movements (4). Regardless of the circumstances, an athlete that can demonstrate a high level of balance, whether it is static or dynamic, has a better chance of being successful in his or her respective sport than others who are not able to stabilize themselves as efficiently, assuming all other factors related to athletic performance are otherwise equal (5).

Balance training has demonstrated it can produce various positive adaptations, such as lower extremity function, neuromuscular function at rest versus at maximal isometric contraction, correcting/limiting strength asymmetries, and the influence balance training has on adaptations to plyometrics (6-8). Taube, Gruber, and Gollhofer (2008) also highlight the plasticity of the sensorimotor system, and reiterate the importance of balance training as a whole, regardless of the population at hand (9). However, it has also been demonstrated that static and dynamic postural control is independent of strength (10), implying that these two factors should be trained independent of one another.

Center of pressure (CoP) and limit of stability (LoS) are two factors closely related to balance. CoP can be defined as the point where vertical ground reaction forces are being applied (11). Meanwhile, LoS is known as the maximal possible sway of a body before balance is lost (12). Multiple demographics have been examined regarding one or both of these factors. Athletes receive positive adaptations to CoP and LoS when subjected to balance training (13, 14).

Balance studies in which subjects were exclusively female show similar improvements. Baghbaninaghadehi, Ramezani & Hatami (2013) studied fifteen female basketball players and showed that functional fatigue has a significant effect on static balance (3). Additionally, Myer et al. (2006) conducted another study in which a plyometric and dynamic balance training intervention was applied on an all-female population, and showed CoP scores decreased for both populations (15).

Multiple studies have been published regarding jump training and its influence on facets of athletic performance, such as vertical jump (VJ) in females (16- 21). Many sports involve these explosive-type movements and are integral to success. Newton et al. (2006) displayed a four week jump training program can slow the effects of declining jump performance in women volleyball players at the end of a season (22). Female soccer athletes have shown increased athletic performance in terms of vertical jump, kicking speed, and kicking distance (23, 24). Basketball players have also benefited from jump training by increasing lower body power and reducing knee valgus (25).
Zech et al., (2010) documented the effectiveness, or lack thereof, balance training has on VJ through a systematic review of literature (26). They determined that balance training can improve neuromuscular and postural control, however mixed or non-significant results were found regarding jump height. They postulated this was because there are little to no strength improvements with balance training.
The Shuttle TNT System was originally developed in the mid-1960s for maintaining cardiovascular fitness of astronauts in microgravity environments. The Shuttle TNT System has been used by various professional sports franchises, universities, and physical therapy settings for improving vertical jump performance and to rehabilitate from reconstruction surgery in the lower extremity. However, a void in the literature was found when discussing the Shuttle TNT System as a way to improve balance scores.
Additionally, to the authors' knowledge, there have not been any studies attempting to find correlations between direction in LoS and VJ scores. Finding a potential link between LoS and VJ in an athletic female population could provide practitioners with another method to refine their athletes' jumping ability to be as efficient as possible during competition. Since the primary focus of this study was on dynamic balance versus static balance, CoP scores were not used.
Thus, the primary objective of this study was to determine whether using the Shuttle TNT System is a viable option to improve LoS scores in a female athletic population, and to investigate if a correlation between LoS and VJ exists.

Material and Method

Participants. Thirteen female participants volunteered in this study and were required to be a female athlete from an NAIA institution. Each participant signed an informed consent form prior to the initiation of the study, which was accepted by the IRB at the College of Saint Mary. Athletes who were suffering from musculoskeletal injuries were excluded from this study. Subjects were also required to attend all training sessions, or be removed from the study should this circumstance arise. All heights of subjects were self-reported. Further descriptive statistics can be found in Table 1.

Table 1. Anthropometric data for all subjects

	Age (yrs.)	Height (cm)	Weight (kg)	Body Mass Index (BMI)	Dominant hand/foot
Group 1 (n=13)	19.66±.87	174.77±4.12	76.56±9.17	25.06±2.75	Right: 13 Left: 0

Protocol. Equipment used for this study included the Shuttle TNT System (Shuttle Systems, Bellingham, WA), a VertiMetric™ device (Lafayette Instrument Company, Lafayette, IN), and a BalanceCheck™ computerized posturography plate (Bertec Corporation, Columbus, OH).
Subjects participated in the study two days per week for four consecutive weeks. Subjects participated in the study on days which they strength trained in accordance to their strength and conditioning program. Prior to and after the intervention, each subject's VJ using one countermovement was tested. The value taken for VJ was the best of three jumps, with rest intervals of 30 seconds between each attempt. LoS was also tested pre and post-intervention. Testing included four directions relative to the athlete: forward (LoSF), backward (LoSB), left (LoSL) and right (LoSR), all of which were performed on a solid surface.
Subjects were first asked to position themselves on the seat of the Shuttle TNT System, which was set at a 45 degree angle. One foot was then placed on a volleyball, which was pinned between the subjects' foot and the kick plate of the Shuttle. The foot not engaged in activity was elevated from any contact surface to prevent increased stability throughout an exercise.

Subjects were informed that an exercise be restarted in the event of letting the ball fall off of the kick plate. After receiving these instructions, subjects performed all desired repetitions of a unilateral leg press with a given resistance on each leg, followed by a bilateral leg press of the same resistance, totaling three exercises. Between switching exercises, subjects were allowed to use their hands to position the volleyball(s) in a self-selected position. After completion of the bilateral leg press, subjects were given a three minute rest period prior to beginning the final set. Knee joint angle was measured at 90 degrees at the lowest portion of the exercise prior to beginning the first set each day to provide the subjects with a kinesthetic and visual cue for desired depth. Inflation of the volleyball was maintained at a pressure between .28 and .42 kg/cm^2 throughout the study. Usage of the volleyball was justified by the findings reported by Lubetzky-Vilnai et al., (2015), who found that young adults primarily use vision for postural control when standing on a BOSU ball, but not on foam (27). A summary of the training protocol is given in Table 2, and a photograph of a unilateral leg press is shown in Figure 1.

Table 2. Summary of training protocol

Week, Days	Repetitions per exercise	Sets	Resistance (kg)
Week 1, Days 1 & 2	15 & 20	2	8.2
Week 2, Days 3 & 4	20 & 25	2	8.2
Week 3, Days 5 & 6	15 & 20	2	11.3
Week 4, Days 7 & 8	20 & 25	2	11.3

Statistical Analysis. An ANOVA with an alpha level of $p \leq .05$ to determine significance between pre and post-test values of LoS scores and VJ. Both of these analyses were conducted using SPSS Statistics (version 24.0; Chicago, IL).

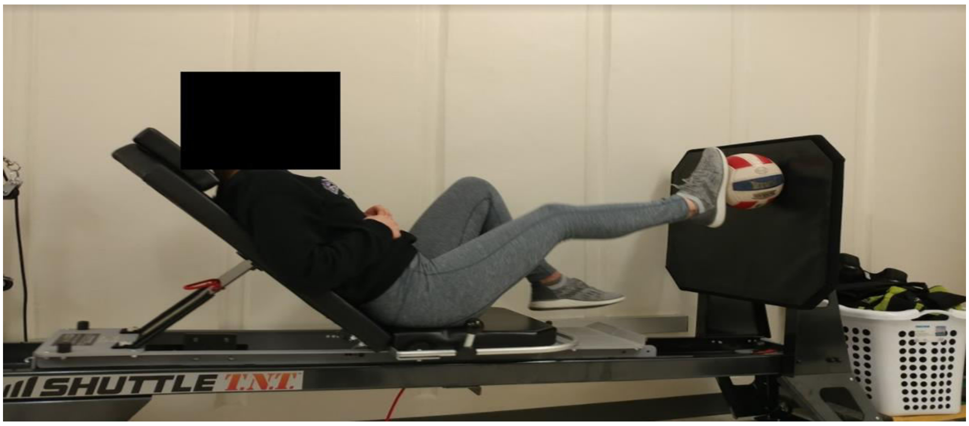

Figure 1. Photograph of a unilateral leg press

Results

Significance was found for all tests of within-subjects effects, the specific details of which are shown in Table 3. No significant correlation was found between LoSR nor LoSB and VJ (.296 and -.339, respectively). However, a moderate correlation of .643 was found between LoSL and VJ. A moderate correlation of .696 was also discovered between LoSF and VJ. Based on results from the aforementioned test, a Pearson product moment correlation was also conducted between any direction of LoS which showed a significant change and VJ. By observing Table 2, VJ did not significantly improve over the weeks of training for the women. LoSB had decreases in mean scores from the pre to post testing. The other body planes did improve over time (see Figure 3). LoSF, LoSR, and LoSL showed improvements in stability scores over the past four weeks.

Table 3. Tests of Within-Subjects Effects

Source	Type III Sum of Squares	df	Mean Square	F	Significance	Partial Eta Squared
Sphericity Assumed	2541.449	9	282.383	250.601	.001	.969
Greenhouse-Geisser	2541.449	2.812	903.664	250.601	.001	.969
Huynh-Feldt	2541.449	4.494	565.562	250.601	.001	.969
Lower-bound	2541.449	1.000	2541.449	250.601	.001	.969

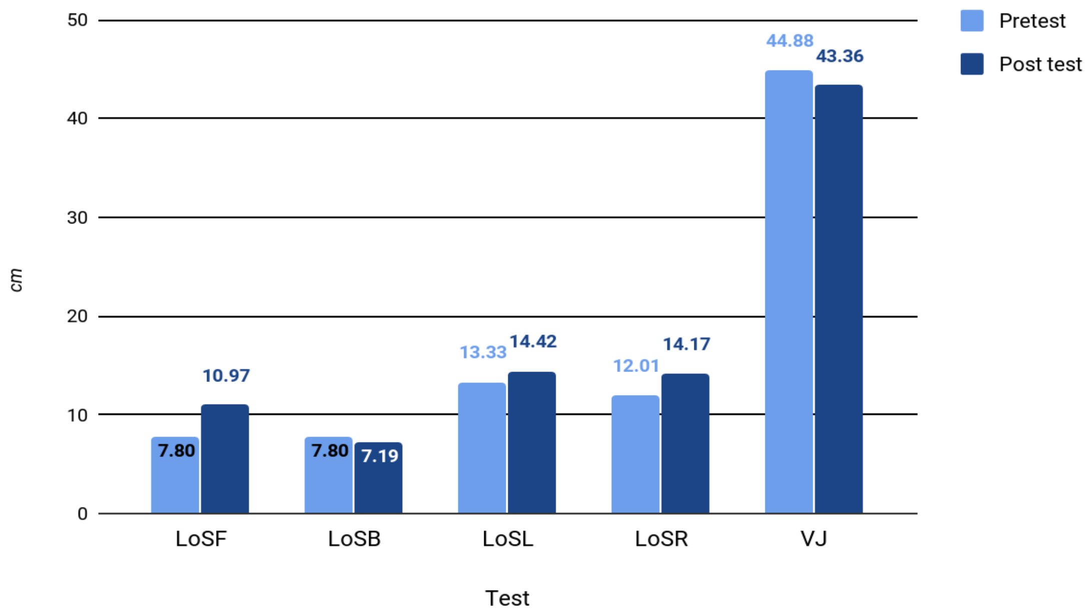

Figure 2. Estimated Marginal Means of stability and vertical jump scores

Discussion

Three of the four directions tested (LoSF, LoSL, and LoSR) in the LoS analysis showed improvement amongst the estimated marginal means of scores, while LoSB showed a decrease, as shown in Figure 2. A poor performance in LoSB could result in an athlete losing their balance when he or she is performing an action where they must move backward, such as a back-pedal movement. The decrease in LoSB could possibly be due to the difficulty in which backward stability can be trained in a horizontal plane. Just as asymmetries in balance can be easily measured and trained while standing upright (28), it may be possible to train LoSB more effectively if the athlete remains upright, although further studies are needed to test this assumption. Additionally, the non-trivial correlation between LoSL and VJ may be explained by strength and/or balance differences between the left and right leg of some subjects. Since all volleyball subjects were right-handed, it could be inferred that many, if not all subjects would show dominance in the right leg as well. In this case, dominance is defined as the limb which performs a specific activity, such as kicking a ball. By default, the left leg would be deemed as the "support" limb, which may be more effective at stabilization than the dominant leg. As stated in their meta-analysis, Ghai, Driller, & Ghai (2017) show that application of joint stabilizers enhances proprioception and stability (29). A future study could utilize the same protocol as stated above, but include more, or exclusively, athletes who show dominance on their left side instead of the right, to determine if a similar correlation occurs in LoSR. Ambidextrous athletes could also potentially show different results.

Furthermore, another possible explanation was proposed to account for the moderate correlation between LoSF and VJ. When referring to the general nature of the sport of volleyball, it is a sport that frequently involves diving, jumping, and explosive movements. When performing these types of powerful activities, athletes often perform what is known as "triple extension" (15), referring to extension of the hip, knee, and ankle prior to takeoff of a jump or bound.

Athletes who frequently engage in these types of situations may be more stable in the forefoot due to repeated activity in this position, which could be partially responsible for this correlation. Comparing results of an athletic versus non-athletic population could bridge this knowledge gap.

This study also showed a statistically significant decrease in VJ height, which does not support other findings by Yaggie and Campbell (2006), who performed balance training for four weeks and found no statistical difference in pretest and posttest values of VJ (30). The authors recommends if practitioners wish to improve VJ in their athletes using the Shuttle TNT System, that the training protocol focuses primarily on the usage of unilateral and bilateral plyometrics and strength-building exercises versus balance training, as this seems to be the most effective (5). Along with this recommendation, the author also advises that if increasing strength is the primary focus of a practitioner, a solid surface should be used for both unilateral and bilateral movements, as increases in strength and production of force tend to be greater on solid surfaces than perturbed platforms.

The outcomes of this study were twofold: 1) Shuttle TNT System is a viable option for improving overall LoS scores in a female NAIA athletic population, although LoSB showed a slight decrease, and 2) there is a fair correlation between LoSF and VJ, as well as LoSL and VJ. The latter of these two findings rejects the hypothesis stated prior to the study: that there would be little to no correlation between any direction in the LoS assessment and VJ scores. Further research is encouraged to analyze these correlations to pin down potential causes and their implications on athletic performance. The author suggests incorporating balance training in a strength and conditioning program to improve stability, the goal of which is to improve athletic performance, both statically and dynamically.

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