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ORIGINAL RESEARCH

# DANCE, BALANCE AND CORE MUSCLE PERFORMANCE MEASURES ARE IMPROVED FOLLOWING A 9-WEEK CORE STABILIZATION TRAINING PROGRAM AMONG COMPETITIVE COLLEGIATE DANCERS

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## ABSTRACT

***Background:*** Dance performance requires not only lower extremity muscle strength and endurance, but also sufficient core stabilization during dynamic dance movements. While previous studies have identified a link between core muscle performance and lower extremity injury risk, what has not been determined is if an extended core stabilization training program will improve specific measures of dance performance.

***Hypothesis/Purpose:*** This study examined the impact of a nine-week core stabilization program on indices of dance performance, balance measures, and core muscle performance in competitive collegiate dancers.

***Study Design:*** Within-subject repeated measures design.

***Methods:*** A convenience sample of 24 female collegiate dance team members (age = 19.7 $\pm$ 1.1 years, height = 164.3 $\pm$ 5.3 cm, weight 60.3 $\pm$ 6.2 kg, BMI = 22.5 $\pm$ 3.0) participated. The intervention consisted of a supervised and non-supervised core (trunk musculature) exercise training program designed specifically for dance team participants performed three days/week for nine weeks in addition to routine dance practice. Prior to the program implementation and following initial testing, transversus abdominis (TrA) activation training was completed using the abdominal draw-in maneuver (ADIM) including ultrasound imaging (USI) verification and instructor feedback. Paired t tests were conducted regarding the nine-week core stabilization program on dance performance and balance measures (pirouettes, single leg balance in passe' releve position, and star excursion balance test [SEBT]) and on tests of muscle performance. A repeated measures (RM) ANOVA examined four TrA instruction conditions of activation: resting baseline, self-selected activation, immediately following ADIM training and four days after completion of the core stabilization training program. Alpha was set at 0.05 for all analysis.

***Results:*** Statistically significant improvements were seen on single leg balance in passe' releve and bilateral anterior reach for the SEBT (both $p \leq 0.01$), number of pirouettes ($p = 0.011$), and all measures of strength ($p \leq 0.05$) except single leg heel raise. The RM ANOVA on mean percentage of change in TrA was significant; post hoc paired t tests demonstrated significant improvements in dancers' TrA activations across the four instruction conditions

***Conclusion:*** This core stabilization training program improves pirouette ability, balance (static and dynamic), and measures of muscle performance. Additionally, ADIM training resulted in immediate and short-term (nine-week) improvements in TrA activation in a functional dance position.

***Level of Evidence:*** 2b

***Key Words:*** abdominal draw-in maneuver, core stability, dancers, pirouette, transversus abdominis

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IRB approval, recruitment of volunteers, and data collection were all at Western Carolina University. Portions of this data to examine the impact of ADIM training on TrA activations during functional dance activities have been published in abstracts via APTA NEXT conference proceedings (June 2015 and 2016). Both authors received only internal funding for travel to this conference. No other sources of funding were received, thus no biases exist.

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## INTRODUCTION

Collegiate dance teams perform and compete with dance styles ranging from jazz, contemporary, hip-hop and classical ballet.[1] Their performance combines the grace and beauty of the art of dance, with the strength and endurance of a highly-trained athlete.[2] Different from competitive studio dance, collegiate dance teams perform cheers and dance routines at a number of athletic events, often on the sidelines of football and basketball games, and compete in regional and national competitions against other college programs across the country.[1] Competitive collegiate dancers are expected to perform a diverse repertoire of techniques; judged on the individual and team's execution of difficult technical skills while performing with precision and synchronization.[1] Each technical skill requires significant motor control, particularly of the extremities, but also spinal stability provided by the trunk musculature hereafter referred to as the core.[3] The spine must be maintained in erect postures through multiple combinations of movement, including pirouette revolutions. Holding the spine in an erect, extended position is viewed positively by competition judges when looking at body alignment and movement, as well as helping to maintain the center of mass vertically over the point of support; however, too rigid a stance has also been shown to lead to early toppling during pirouettes, requiring instead that subtle accommodations be made for any loss of balance.[4]

Recently, interest in improving fitness of dancers both for improved performance and injury reduction has increased.[5–8] Dance training programs have been identified as insufficiently preparing ballet dancers for the physical demands of performance[9] and subsequently injury rates (approximately 82% incidence among professional contemporary dancers during a 12 month period[10] and seeing a prevalence rate of 95% among professional ballet dancers[11]) reflect this, particularly injury to the low back.[3,12] Research has shown that professional ballet dancers appear to have reduced fitness levels in regards to muscle strength[13–15] and aerobic capacity[5,16–19] when compared to athletes from other sports. And, while improvements in fitness levels are associated with better technique across dance genre, results from the effect of fitness training are limited to 'dance performance' measures related to aesthetic aptitude.[20–23]

Kibler et al defines core stability as "the ability to control the position and motion of the trunk over the pelvis and to allow optimum production, transfer, and control of force and motion to the terminal segment in integrated athletic activities."[24(p190)] A diminished core stabilizing system, with delayed activation patterns has been shown lead to a higher incidence of lower extremity injuries[25–27] and to produce low back injury.[28,29] The core stability system, also referred to as the lumbopelvic-hip complex, provides a 'corset-like' tensioning to the trunk when activated, and is comprised of global and local stabilizing subsystems. The global stabilizing subsystem comprised of the erector spinae, rectus abdominis, external oblique and quadratus lumborum muscles provides for larger trunk motions with the capability of producing rapid, powerful torques. The local stabilizing subsystem is comprised of the transversus abdominis (TrA), multifidus, internal oblique muscles that are located deep to the global system, and provide for dynamic segmental spinal stability. Also included in the contemporary thinking of elements of the core are the pelvic floor and hip (gluteal and rotary) muscles.[30] It has been well established that specific exercises may be selected to target the many muscles contributing to the core stabilizing system.[31] McMeeken et al[32] showed increases in TrA muscle thickness as measured by ultrasound imaging (USI) which correlates highly (ICC M-mode = 0.981) with electromyographic activity. Additionally, the TrA activates in a feed-forward anticipatory fashion prior to and during lower extremity movement.[33] This occurs to minimize (compensate for) perturbing forces on static posture and dynamic balance.[34] The improved activation that comes from a core stabilization exercise program targeting specifically TrA may be inferred to improve static and dynamic balance, as Zazulak et al[35] demonstrated deficits in core proprioception predicted knee injury risk for female collegiate athletes in a three-year prospective study (n = 140). USI has therefore been utilized to assess TrA muscle activation for muscular dysfunction and motor control errors[36] causing decreased biomechanical stability, and altering control of dynamic posture responses.[35] The abdominal draw-in maneuver (ADIM) is a commonly utilized motor control exercise for the TrA muscle.[37,38]

Professional ballet dancers (n = 24), when compared to age and sex matched non-dancer control subjects (n = 24) demonstrated more accurate proprioceptive feedback about lower limb (hip, knee, and ankle) position in space as well as center of gravity in relation to base of support.[39] These proprioceptive tasks are required in the functional activities of dance, including turning, static and dynamic single leg balance, gesturing, and many others. Evidence suggests that improved proprioception in dancers may result in improved performance.[40] For instance, Lott and Laws[4] suggest that turning should be done in a manner that allows a dancer to make subtle adjustments based on changes in the alignment of center of mass in relation to base of support during a turn. Alternatively, they found that a rigid bodied dancer would have to maintain his/her body at an angle that deviated less than one degree from pure center, a nearly impossible task, or loss of balance occurred. This implies that more important than merely trunk strength and endurance, sensorimotor control is essential in attaining sufficient core stabilization during dynamic dance movements. Further, numerous studies have demonstrated the TrA as the key dynamic modulator in controlling spinal stiffness by way of its linkage and direct tensioning to the posterior thoracolumbar fascia.[41–43] Additionally, Urquhart and Hodges[44] demonstrated the TrA to have a complex role in trunk rotation, with the upper region fascicles active during rotation ipsilateral, and middle and lower region fascicles during contralateral rotation. While not observed, it is this action that may be occurring, with the core muscles working both concentrically and eccentrically throughout dance (pirouette) techniques as the dancer is spinning. Improved proprioception and ability to make trunk adjustments (both in controlling stiffness and rotary movements that may occur during pirouettes, etc.) based on dynamic alignment may result in improved single leg balance (both static and dynamic) and which could translate to a greater number of successful turns. Therefore, it may be inferred, and it is this study's hypothesis, that improved core stability will enhance dance performance.

While the physiological effects of exercise as an intervention are well documented to be mode, volume and intensity specific,[45] what has yet to be determined is if an extended core stabilization training program will improve specific measures of dance performance. The purpose of this study was to examine the impact of a nine-week core stabilization program on indices of dance performance, balance measures, and core muscle performance in competitive collegiate dancers. Specifically, this study aimed to determine if a nine-week core stabilization training program improves measures of dance related maneuvers, including: 1) static balance in single leg for time in front passé releve with arms in first position, 2) dynamic balance in single leg using the star excursion balance test, and 3) maximum number of pirouettes performed. Significant improvements were predicted in all three. Secondary purposes were to examine 1) the immediate influence of ADIM training on the same specific dynamic dance maneuvers and whether TrA thickness changes would remain at post-training testing, and 2) the nine-week program training effect on measures of trunk and lower extremity muscle performance. It was predicted that TrA thickness changes would increase upon immediate training and remain upon post-test training. Finally, it was predicted that measures of trunk and lower extremity muscle performance would all improve with the exception of single leg heel raises as gastroc-soleus is commonly already trained by dancers at a high level, which was not part of the core stability exercise program.

## METHODS

### Subjects

Subjects were enrolled by sample of convenience and completed a nine-week training program that focused on core stability training of the trunk musculature in addition to routine dance training. Originally, 26 female college-aged dancers were recruited for this investigation. All subjects were all formal members with the official Western Carolina University (WCU) Dance Team. The Institutional Review Board of WCU approved this study and all subjects signed the consent form. One subject dropped out due to injury and the other left the dance team. Figure 1 shows the study flow diagram with inclusion

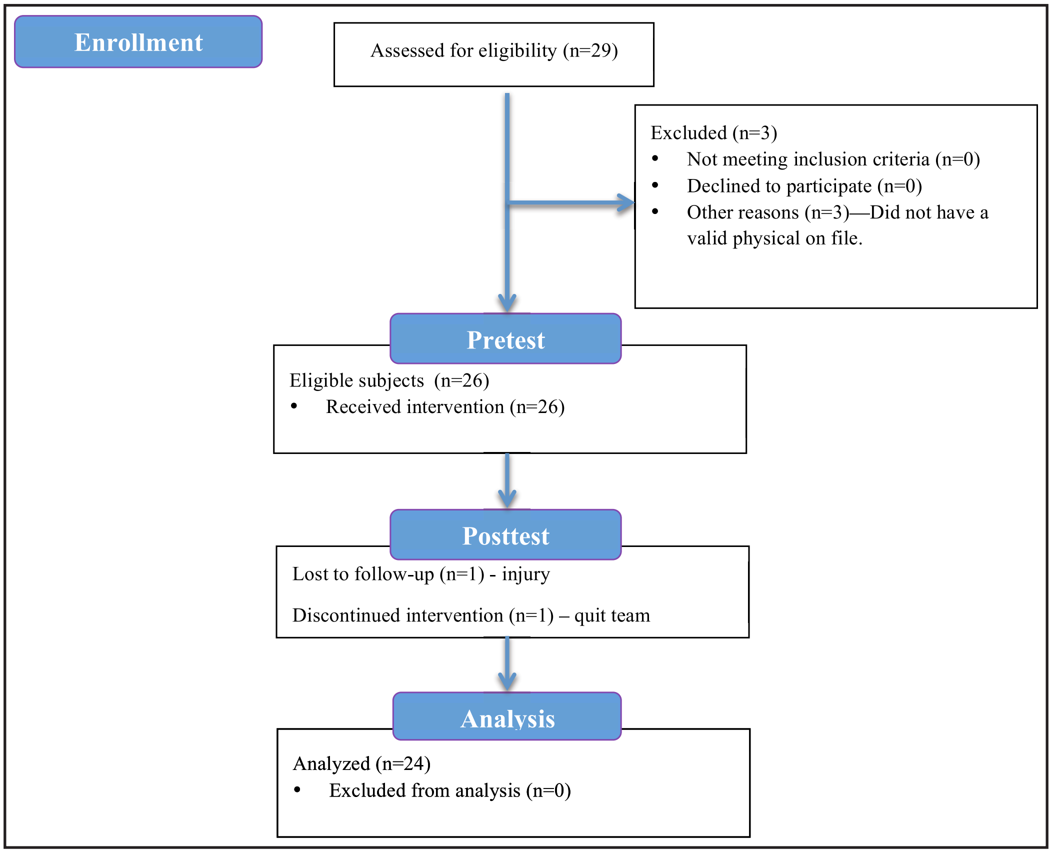


**Figure 1.** *Study flow diagram for subjects. Inclusion criteria = WCU dancer with valid physical on file and signed informed consent form. Exclusion criteria = <18 years old; history of spinal or abdominal surgery; current pregnancy; current low back pain; currently taking medications affecting balance.*

and exclusion criteria. Anthropometric and demographic data (M ± SD) for subjects (N = 24 females) was: age (years) (19.67 ± 1.09); height (cm) (164.3 ± 5.3); weight (kg) (60.3 ± 6.2); left leg length (cm) (86.25 ± 3.58); right leg length (cm) (86.33 ± 3.68); competitive dance experience (years) (9.30 ±4.57) and Beighton generalized test of hypermobility (range = 0-9, mode = 7). Because the authors were most interested in examining the impact of the core stabilization training program on the number of pirouettes, a sample size estimate was derived based on the following pretest and posttest estimates: $M_d$ = 1, $SD_d$ = 1.5, alpha = .05 and power = .80.[46] The estimated sample size was 20 subjects. Thus, the sample size of 24 exceeded this estimate.

### *Instruments and Procedures*

This section presents tests and measures administered prior to the nine-week core stabilization intervention program. Dance performance and balance tests were administered including: number of pirouettes, single leg balance in passe' releve position, and star excursion balance test, as well as muscle performance tests including: extensor endurance test, flexor endurance test, side bridge test, hip abductor strength, single leg hop, and single leg heel raise. Following instruction, selective recruitment of TrA was utilized to ensure appropriate performance of core activation prior to nine-week training, as this specific training can help to reorganize neuromotor control patterns in the central cortex to improve muscle recruitment patterns thereby resulting in increased activation levels.[47] Included in the TrA activation measures is a brief description of the short bout of TrA activation training and subsequent TrA measures. The administration of these tests and measures during posttesting (four days following the nine-week core stabilization program) is also presented. The final section presents a brief description of the nine-week core stabilization program.

***Transversus Abdominis Activation Training and Testing.***

A physical therapist with over 15 years of experience in USI capture of TrA conducted all TrA activation training and measurements. This TrA training program followed a previously established USI training protocol for TrA activation in healthy adults.[48] US imaging visualization and measurement of TrA muscle was completed by using a portable ultrasound curvilinear transducer set at 5 MHz using M-mode (LOGIQ P5; GE Medical, Pleasanton, CA). Subjects were tested individually on all occasions for each of the four instruction conditions. Instruction conditions 1 and 2 took place prior to any ADIM training. First, mean TrA activation was captured via USI in standing (Figure 2a) with instructions to "relax" and then to "move into the position" (passe' releve). Three trials were performed and TrA thickness was measured via USI by the physical therapist and averaged for relaxed standing and the dance position. USI measurements of TrA in upright positions have been deemed reliable during functional tasks.[48,49] Testing condition 2 was the same as 1 with the exception that subjects were told to "activate their core" during the passe' releve position. Again, three trials were performed and TrA thickness was captured for relaxed standing and the dance position with instructions to contract. Next, subjects received a short (15 minute) bout of TrA activation training in standing with ADIM that included instructor and USI feedback. Both written and verbal instructions of the technique were provided as part of training, along with diagrams of the muscles involved and the rationale for this technique to prevent injury. Subjects were shown their TrA muscle while at rest and when contracted via the USI video display and were told to use this continuous visual feedback to help them acquire the ADIM. The success of TrA contraction, as visualized by isolated TrA thickening beyond resting thickness, was reported by the physical therapist in the form of verbal feedback and US imaging. Training continued for 10 attempts, with subjects needing to obtain three consecutive successful isolated TrA contractions in order to continue. Subjects during testing condition 3 were told to stand with instructions "to relax" and then told to perform the dance position with instructions to apply the ADIM ("draw-in"); three trials were performed and mean TrA thickness was captured via USI. Four days following the nine-week core stabilization training program, testing condition 4 took place. Subjects in testing condition 4 were told to stand with instructions "to relax" and then told to "move into the dance position." Unlike condition 3 the instructions for condition 4 did not include the phrase to "draw-in" but were cued prior to testing session to perform according to their previous training. During all instruction conditions no visual of verbal feedback was provided; testing order remained constant across positions and instructions for all subjects.

Percent change in transversus abdominis (TrA) activation was examined during relaxed standing and passé releve position prior to any ADIM training (without instructions, and self-selected triggering pattern with instructions to "activate" their core), immediately following ADIM training, and four days after the completion of the core stabilization training program. Percentage of change in TrA thickness was computed per trial using the standing relaxed TrA measurement as minimum thickness and the dance position as the maximum TrA thickness (cm) per trial for each of the 4 test sessions. Percentage of change scores were determined by {[(maximum thickness – minimum thickness) / minimum thickness] X [100]}.[50] Mean percentage of change scores were computed for each of the 3 trials performed for the four instruction conditions.

***Dance Performance and Balance Testing***

*Pirouettes.* Subjects were told to assume the front passé position on the preferred turning leg with instructions to "perform your maximum number of consecutive turns in the front passé position." Subjects performed three trials each under instructions to: "use your preferred turning method"; "activate your core"; or "perform the draw-in that you just learned" (ADIM), respectively. Each full trial of each subject was recorded via an iPad, which was positioned at a height of 183 cm. Video recordings were analyzed in manual slow-motion using Dartfish Express with a grid overlay[51,52]. Dartfish has been established as a valid and reliable tool to measure upper (ICC = 0.98)[53] and lower extremity (ICC $\geq$ 0.91)[54] motions. A dance expert trained two raters on coding of maximum number of rotations using a

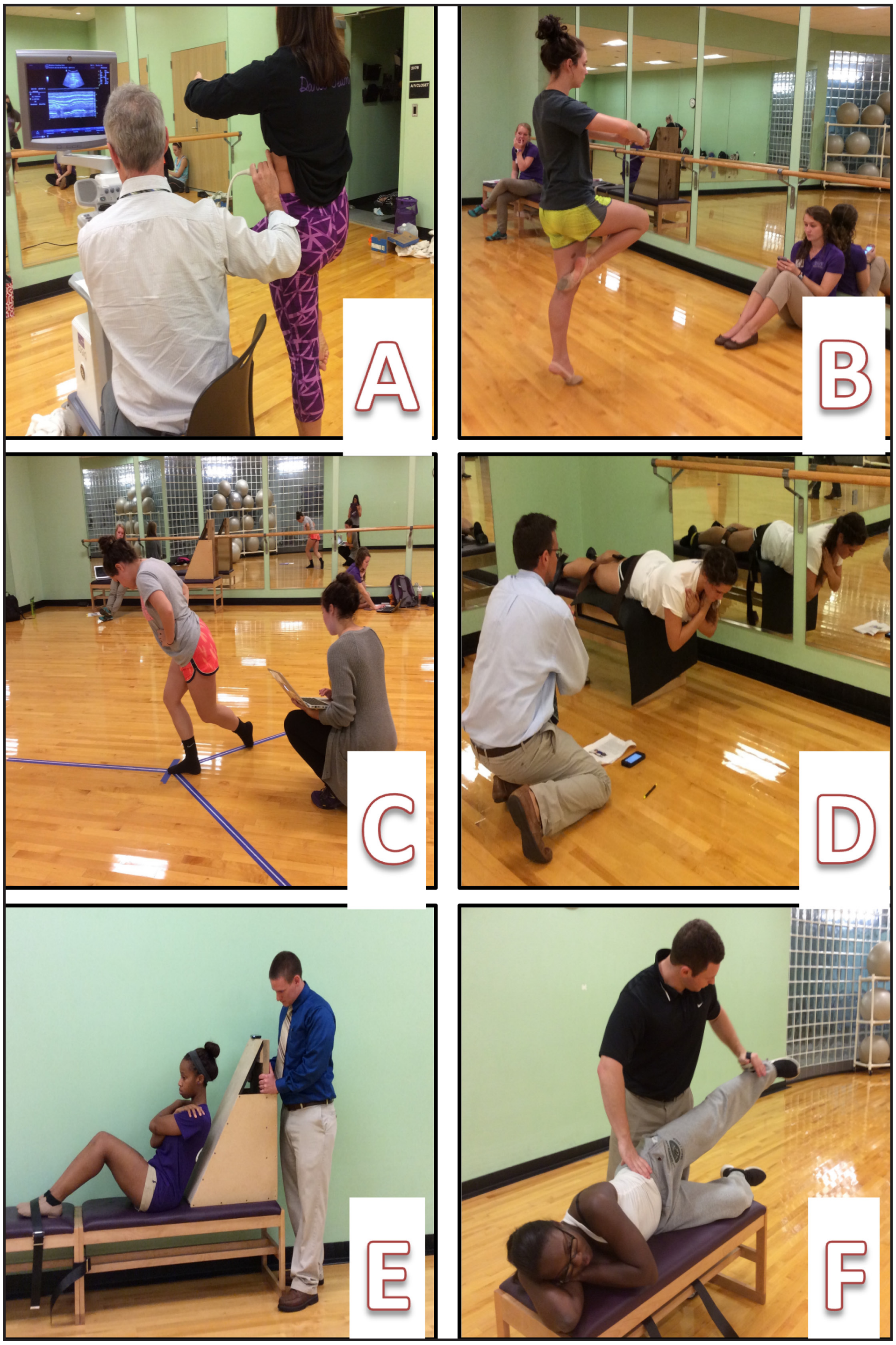


**Figure 2.** *A) Transversus abdominis activation and training, B) single leg balance in passé releve position, C) SEBT, D) extensor endurance test, E) flexor endurance test, F) hip abductor strength test.*

standardized procedure; the raters were blinded to each other's results. The observational instrument used to determine the maximum number of pirouettes included identifying the point during turning that the subject's heel struck the floor, lost balance, or hopped out of the pirouette. The final pirouette closest to the quarter revolution was counted and recorded. Interrater reliability was obtained by these two raters scoring the maximum number of pirouettes turned per trial per condition on a subsample of 13 subjects. Acceptable rater reliability has been generally been deemed to be >0.75.[46]

Mean scores were formed per subject per rater on each of the three conditions during pretesting. Since raters and subjects were randomly selected intraclass correlation model 2 was utilized to examine interrater reliability. High intraclass correlation (ICCs 2, 3) coefficients were noted on mean scores for maximum number of pirouettes turned for all instruction conditions. ICC coefficients were: .946 (95%CI = .826 to .983) for their preferred turning method instructions; .909 (95%CI = .683 to .973) for "activate your core" instructions; and .991 (95%CI = .971 to .997) for with ADIM as instructed. Each rater scored all remaining trials of each subject per instruction condition. During posttesting only the ADIM condition was performed and measured. Trial mean scores formed per subject per instruction condition per rater were averaged for the two raters and utilized for descriptive data and data analysis.

*Single Leg Balance in Passé Releve position.* Control of static balance has been examined using the timed single leg balance in a variety of populations,[55] and found to have acceptable intra and inter rater reliability (ICC > 0.90).[56] The single leg balance test was administered in the front (jazz) passé releve position on the subjects' preferred turning leg (Figure 2b). Subjects prior to each trial were told to "stand on your leg in front passé with arms in first position, when you have your balance, raise up to releve and balance as long as you can in this position." During pretesting, subjects performed three single leg balance trials under each of the following instruction conditions: "raise up to passé releve"; "as you raise up to passé releve activate your core"; and "as you raise up to passé releve draw-in" (ADIM). During posttesting subjects were tested only under the latter instruction conditions. Balance time was scored at the point that they elevated into passé releve until they came out of position. Balance time was recorded by research assistants in seconds per trial. Mean scores for the three trials were computed for each individual for each instruction condition during pretesting and posttesting.

*Star Excursion Balance Test.* Using a tape measure on the floor, each subject completed a modified Star Excursion Balance Test (SEBT) (Figure 2c) according to the methodology described by Plisky et al[57] and Filipa et al.[58] The SEBT has shown to have acceptable intra-rater reliability by Plisky et al[57] (ICC = 0.82 – 0.87), and Gribble et al[59] (ICC = 0.86 - 0.92). Notably, poor performance on the anterior reach of the modified SEBT (>4cm side to side difference) has been validated for predicting lower extremity injury.[57,60] Standing on selected leg with tip of great toe in the center of the intersecting lines, subjects were asked to reach with the free limb in three directions: anterior, posteromedial, and posterolateral. Trial performances were recorded according to weight bearing limb and direction of reach. Subjects performed 10 trials on each limb for each of the 6 reach directions. The last four trials (7-10) were recorded by a research assistant and utilized for descriptive data and data analysis (maximal reach distance in cm). The maximal reach was normalized to the dancer's leg length. This test was administered during pretesting and posttesting.

***Muscle Performance Testing***

*Extensor Endurance Test.* Subjects performed a back extensor endurance (Sörenson) test,[28,61] which has been shown to be predictive and have discriminative validity for distinguishing between subjects with non-specific low back pain (ICC = 0.88) and those without (ICC = 0.83).[62] Subjects were positioned prone on a bench with their lower body fixed to the platform by straps (gait belts) positioned around the pelvis, knees, and ankles (Figure 2d). Subjects were told to hold the upper body in a maintained horizontal position, with upper limbs held across the chest and hands on the opposite shoulders for as long as possible. The amount of time (seconds) subjects held this position was recorded by a research assistant and administered during pretesting and posttesting. Pretest and posttest scores were utilized for descriptive data and data analysis.

*Flexor Endurance Test.* Abdominal fatigue was assessed using the flexor endurance test according to McGill et al[28] (test-retest ICC = 0.97) which has shown to be a valid measure in office workers with sub acute low back pain (endurance test time significantly reduced, $p < 0.05$) in symptomatic subjects.[63] The flexor endurance test required subjects to sit on a flat bench with knees and hips flexed to 90 degrees and toes strapped to the bench, arms folded across the chest, and their back to a support angled 60 degrees from the bench

(Figure 2e). Prior to the back support being removed, subjects were instructed to maintain trunk position for as long as possible. The amount of time (seconds) subjects held this position was recorded by a research assistant. This test was administered during pretesting and posttesting.

*Side Bridge Test.* Lateral trunk musculature of each side was assessed using the side bridge test by McGill et al[28] (test-retest ICC = 0.99). Swain and Redding[29] in an observational study of female dancers with (n = 11) and without (n = 6) low back pain found the side bridge test a valid tool for discriminating between symptomatic subjects (endurance test time significantly reduced, $p < 0.05$). Subjects were positioned side lying on a bench with support arm flexed, knees and hips extended, and spine in neutral. Subjects were instructed to lift their pelvis off the bench and to hold their body in a straight line over the bench as long as possible. A research assistant recorded the amount of time (seconds) subjects held this position. This test was administered during pretesting and posttesting.

*Hip Abductor Strength.* Hip abduction strength was measured bilaterally using a handheld dynamometer, Micro FET 2 (Hoggan Scientific, Salt Lake City, UT) on each of the subjects' lower extremities as described by Fredericson et al[64] who determined the procedure has very good inter-rater reliability (ICC = 0.96), but has not been validated against a gold standard (e.g. isokinetic dynamometer). The dynamometer used a digital display that displayed the maximum static force (kg) used to "break" the maximum isometric hip abduction contraction and bring the tested leg back to the bench. Subjects were positioned side lying on a bench with hip abducted to 30 degrees (Figure 2f). Each subject performed three trials with 15 seconds of rest between trials. Each trial was recorded by a research assistant. Mean scores for the three trials were computed for each subject. This test was administered during pretesting and posttesting.

*Single Leg Hop.* Lower extremity hopping performance was assessed using a single leg hop test according to the method used by Munro and Herrington,[65] Brumitt et al[66] and Reid et al.[67] Munro and Herrington[65] found the test procedure to have good reliability (test-retest ICC = 0.80). Brumitt et al[66] found single leg hop for distance test to be a valid predictor as female athletes with a greater than 10% side-to-side asymmetry between had a four-fold increase in foot or ankle injury. Reid et al[67] found the single leg hop test to be a valid performance outcome measure compared to self-reported lower extremity function on 42 adult patients undergoing rehabilitation after ACL reconstruction. Each subject stood on selected leg with distal edge of great toe flush with the starting line. Subjects were asked to hop as far as they could while landing softly on the same foot, maintaining their balance. Six trials were performed on each limb. The last three trials on each limb were recorded by a research assistant. Mean scores for the three trials per limb were computed for each subject. This test was administered during pretesting and posttesting.

*Single Leg Heel Raise.* The single heel raise to fatigue test was used to assess and measure the strength endurance of the gastrocnemius/soleus muscle complex. While the construct validity of the single leg heel raise has yet to be established, there is acceptable reliability (test-retest ICC = 0.96).[68] The test was performed bilaterally and subjects were required to keep pace with a metronome set at 80 beats per minute. Subjects were instructed that they may lightly place their hands on ballet bars for balance purposes only but no weight was allowed to be placed through upper extremities to aid in the test. The test was only performed one time on each foot. A research assistant recorded the number of raises per leg. This test was administered during pretesting and posttesting.

### *9-week Core Stability Program*

Subjects performed an intensive nine-week core stabilization training program designed by the authors specifically for collegiate dance participants. The program was multifaceted and contained components incorporating balance/dance posture, strength, endurance, and proprioceptive control of the core and lower extremity (Figure 3).[69] The stabilization training content was distributed to each participant through video. The video was specifically designed for the study to provide step-by-step information regarding how to correctly perform each exercise. The video provided cues for correct timing for each

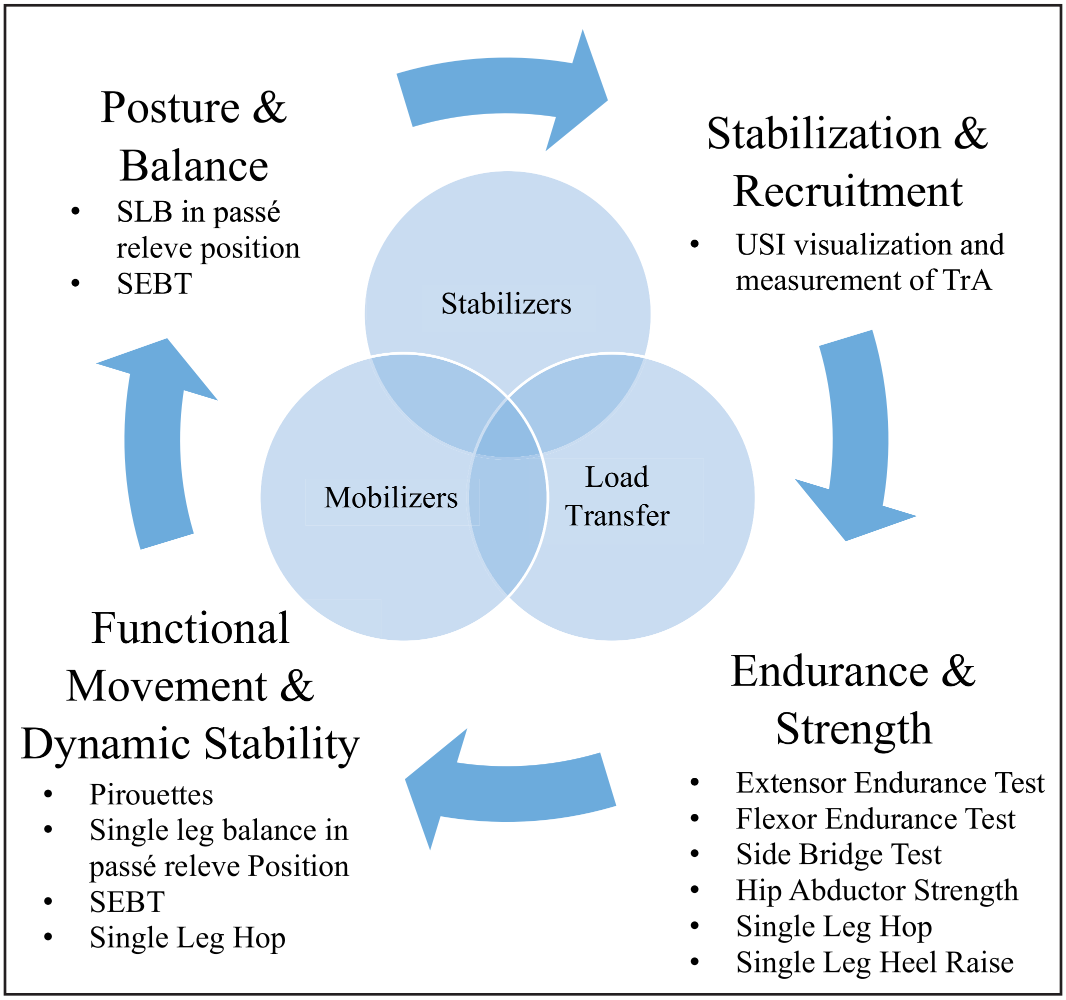


**Figure 3.** *Components of core stabilization training program and corresponding specified measures.**

*Figure adapted from Huxel Bliven KC, Anderson BE. Core stability training for injury prevention. *Sports Health*. 2013;5(6):514-522.[30]

exercise, and prompting for the number of repetitions and sets. Subjects performed exercises three times per week (with the second author two times per week following dance practice and on their own one time per week) for 30 minutes per session. The second author (dance instructor) provided cuing and feedback to reinforce TrA activation during the core exercises and throughout technical skill training at practice. The protocol for the core stabilization program consisted of a progression of three levels with 5-7 exercises per level focusing on maintaining sensorimotor control while promoting activation and strengthening of 1) TrA and internal oblique, 2) lumbar multifidus, 3) gluteus medius, quadratus lumborum and external oblique, 4) gastroc-soleus, 5) whole body major muscle groups.[70–72] The degree of difficulty for the exercises was derived from the Jeffreys core stabilization program.[73] Initial level exercises involved static contractions in a stationary position progressing to slow movements. Second level exercises progressed from static contractions in unstable situations to dynamic movements in a relatively stable position. Third level exercises involved dynamic movements in unstable situations. When participants had completed an exercise level for three weeks they were progressed to the next level.

### *Statistical Analysis*

All descriptive and statistical analyses were completed using IBM SPSS version 23 (IBM Corp. Released 2015. IBM SPSS Statistics for Windows, Version 23.0. Armonk, NY: IBM Corp.). A one-way RM ANOVA to examine differences among the four instruction conditions was conducted on mean percentage of change scores for TrA thickness. Mauchly's test of sphericity was examined, and degrees of freedom were adjusted when appropriate. Effect size was partial eta squared ($\eta_p^2$). Post hoc paired t tests were conducted if applicable to examine differences in mean scores for percent change in TrA between all instruction conditions. Alpha was set at 0.05 for these tests.

To examine the impact of the nine-week core stabilization program paired t tests were conducted on pretest and posttest mean scores for: number of pirouettes turned for the ADIM instruction condition; mean time (seconds) for single leg balance in passé releve position for the ADIM instruction condition; normalized reach (%) for modified SEBT for each limb and direction; mean time (seconds) for back extensor test; mean time (seconds) for flexor endurance test; mean time (seconds) for side bridge test per left and right side; mean hip abductor strength (kg) per left or right side; normalized distance (%) for single leg hop per left and right limb; and mean number of heel raises for single leg heel raise per left and right limb. Difference scores were computed for paired t tests measures and indicated no outliers and normality. Alpha was two-tailed for paired t tests and set at .05.

## RESULTS

The one-way repeated measures ANOVA on mean percentage of change in TrA thickness among the four instruction conditions was significant ($F_{3,69} = 54.382$, $p < .001$) and produced a large effect size $\eta_p^2 = .703$. All post hoc paired t tests (df = 23) were significant for all possible comparisons of instruction conditions ($p < .001$). Importantly mean percentage of change in TrA thickness (M $\pm$ SD) significantly increased across the following four instruction conditions, respectively: from relaxed standing to the dance position without any instructions (20.4% $\pm$ 21.8%); from relaxed standing to the dance position with instructions to activate your core (41.6% $\pm$ 32.9%); from relaxed standing to the dance position with instructions to apply ADIM (after the short bout of ADIM training) (77.1% $\pm$ 39.5%); and from relaxed standing to the dance position with instructions to apply ADIM (four days after the nine-week core stabilization training program concluded) (115.2% $\pm$51.6%). Thus, a short bout of ADIM training in standing showed subjects significantly improved their ability to activate the TrA during the passé releve position and improved their ability to do so over a long period of time.

Table 1 presents descriptive data and results of paired t tests for the dance performance, dynamic balance, and muscle performance measures. Result of paired t tests indicated the nine-week core stability training program showed significant improvements on the dance measures (i.e. pirouettes, single leg balance); dynamic balance measures (i.e. modified SEBT for right and left anterior); and muscle performance measures (i.e. abdominal flexor endurance test, side bridge test, back extensor endurance test, hip abductor strength, and left and right single leg hop).

### Discussion

This within-subjects longitudinal study used a video-recorded, clinician directed and monitored core stabilization exercise training program intervention in order to determine its effect on measures of dance performance, balance and core muscle performance. As expected, the measures of core and lower extremity muscle performance were significantly improved from our core stability program. Measures of dance and balance performance also significantly improved. Following the nine-week training program, the primary study outcome of pirouettes was significantly improved under training to use ADIM. However, the lack of clinically significant effect for the number of pirouette turns (while significantly improved, there was less than a whole number improvement) may have been due to the nature of the task (e.g., selection of TrA may have been too complex for this skill and/or changes in muscle performance as a result of training). Alternatively, individual technique and ability may supersede TrA contribution to this complicated task. However single leg heel raise, common to dancers in their general workouts but not part of this core stability program, was not improved.

As predicted, percent change in TrA thickness was significantly greater during post-training ADIM, with post-hoc tests revealing the greatest significant improvement from baseline to post-training. These findings are consistent with previous literature examining the immediate effects of a ADIM training session on TrA activation in healthy adults,[74–76] though it is important to note that measures of starting TrA

**Table 1.** *Descriptive data and paired t-tests results for pretest and posttest measures of dance performance, dynamic balance, and muscle performance.*

| Measure | Instructions/ Protocol | Pretest | Posttest | *p* value |
|---|---|---|---|---|
| Dance Performance and Balance Testing | | | | |
| †Pirouettes (revolutions) | Relax Stance | 2.40 (0.66) | Not Tested | |
| | Self Activated | 2.24 (0.64) | Not Tested | |
| | Utilize ADIM | 2.21 (0.63) | 2.55 (0.81) | .011 |
| †Single-Leg Balance (sec) | Relaxed Stance | 6.37 (4.24) | Not Tested | |
| | Self Activated | 6.73 (4.62) | Not Tested | |
| | Utilize ADIM | 6.03 (5.04) | 10.77 (10.00) | .002 |
| Modified SEBT Normalized for leg length (%) | Right-Anterior | 68.00 (0.05) | 70.96 (0.05) | .000 |
| | Right-Posterolateral | 94.77 (0.08) | 95.05 (0.07) | .355 |
| | Right-Posteromedial | 91.91 (0.11) | 93.52 (0.10) | .146 |
| | Left-Anterior | 68.59 (0.05) | 72.26 (0.06) | .001 |
| | Left-Posterolateral | 96.08 (0.08) | 94.89 (0.07) | .831 |
| | Left-Posteromedial | 94.98 (0.09) | 93.44 (0.09) | .345 |
| Muscle Performance Testing | | | | |
| Back Extensor Endurance Test (sec) | | 88.34 (34.80) | 104.80 (49.92) | .02 |
| Abdominal Flexor Endurance Test (sec) | | 108.08 (77.02) | 151.94 (123.82) | .010 |
| Side Bridge Test (sec) | Right | 30.83 (17.30) | 45.17 (19.02) | .001 |
| | Left | 31.01 (17.27) | 44.02 (18.79) | .001 |
| Hip Abductor Strength (kg) | Right | 13.75 (4.09) | 15.13 (3.32) | .019 |
| | Left | 14.24 (4.70) | 15.72 (3.30) | .027 |
| Single-leg Hop Normalized for leg length (%) | Right | 125.02 (21.69) | 134.24 (22.47) | .050 |
| | Left (take off leg and turning leg) | 125.02 (21.69) | 131.77 (22.00) | .008 |
| Single Leg Heel Raise (repetitions) | Right | 37.13 (10.05) | 37.96 (9.97) | .501 |
| | Left | 36.67 (9.54) | 37.38 (8.81) | .538 |

*Paired t tests df = 23; alpha two tailed. †Maximum number of pirouettes turned and single leg balance tests were in the front passé releve with arms in first position.

thickness were higher than one previous study, which could reflect an elevated baseline of sensorimotor control in collegiate dancing populations as compared to general populations.[49] Although there was not a significant same-day improvement in single-leg balance or pirouettes, it is important to note that this may be attributed to dancers being in the cognitive phase of motor learning of the ADIM. This early phase of motor learning may have negatively affected dancers' abilities to dual-task with applying new skill to previously mastered dance task.[77] The finding of maintained TrA activation ability during a functional activity at nine weeks following a short ADIM training session are similar to a recent five-month longitudinal study where supine instructed TrA activation (ADIM) training translated to increased activation levels during standing, loaded tasks in asymptomatic subjects.[74] Enhanced TrA thickness via ADIM scores for pretest and posttest over a self-selected pattern of activation indicate the value of US imaging biofeedback in TrA activation. The findings that TrA activation significantly improved from self-activation instructions to immediate post ADIM training indicated dancers were not aware they were not fully activating their TrA. A recent study also found no differences during self-activation instructions between young adults with and without prior ADIM training (without USI).[78] That is, adults, when told to self-activate their TrA during standing and other upright functional loaded tasks did not vary regardless of their training history. This suggests direct observation of TrA via USI rather than a self-report of core activation training sans USI may be an important component of assessment and training. These findings of improved TrA activation and core muscle performance measures (flexor fatigue, extensor fatigue, and side bridge) are similar to a recent study by Hoppes et al[38] in which subjects performed a eight-week core stabilization exercise program and improved TrA activation in neutral relaxed standing and with military body armor donned, and improved similar measures of core strength and endurance.

The authors also predicted that this nine-week core stabilization intervention would increase performance in dynamic balance. The SEBT has been used as an alternative, indirect measure of core stability because it is a measure of dynamic balance and postural control. [79] Post-hoc testing revealed only significant improvements in two out of the six reach directions, which were left and right anterior reaching directions of the modified SEBT. These present findings are in slight contrast with Sandrey and Mitzel,[80] who found that a progressive, 30 minute per session six-week core stabilization training program significantly improved all directions of the SEBT in (N = 20) track athletes training 3x/week. However, upon closer examination, these authors used anteromedial, medial, and posteromedial directions with only the right leg, whereas the current study used anterior, posteromedial and posterolateral directions for both legs. Further analysis of the improvements in only these two directions in this population could be a result of the core stability program or the focus and training of specific, dynamic technical skills as a team. That is, preparation and take off of, and transition between leaps and jumps and dynamic control of leaps and jumps in the anterior direction.[81] Regardless, as Plisky et al[57] have reported that > 4 cm side-to-side differences in anterior reach scores predicted injury status in various sports, the anterior reach improvement is valuable.

While this progressive exercise program targeted the lumbopelvic-hip region, some of the improvements are likely interacting as illustrated in Figure 2. For example, Garrison et al[82] found that a strengthening program, specifically targeting hip muscles that included hip abductors of patients (n = 43) enrolled in a rehabilitation program following ACL reconstruction were able to improve sagittal plane dynamic balance (anterior direction of SEBT). This demonstrates the importance of hip abductors in stabilizing the pelvic-hip complex in maintaining balance while attempting lower extremity anterior reach. Furthermore, the FIFA 11 + injury prevention program is an internationally utilized multifaceted warm up program that has been shown to improve measures lower extremity function and prevent non-contact injuries in football (soccer).[83] Similar to our program, the FIFA 11 + is comprised of exercises involving the core and lower extremity muscles that has been shown to improve dynamic balance (SEBT), static balance (single leg balance) and hop for distance.[84]

This is the first study to examine the effect of a progressive multi-week core stabilization training program on measures of dance performance, dynamic balance, and muscle performance. Previously Angioi et al[40] utilized a six-week conditioning program on contemporary ballet dancers and found improved select measures of fitness (lower extremity vertical jump, upper extremity press-ups and aerobic conditioning) and improved scores on a dance aesthetic competence test (developed by the author)[85] with the exercise group (N = 12) compared to a controls (N = 12). Exercises were dissimilar to those in the current study program, as they were extremity focused and without specific core (TrA) activation training. Twitchett et al[23] also examined the effect of an exercise program (10 weeks) on ballet dancers that did include one spinal strengthening exercise similar to the current study types of exercise, with the remainder of their program either extremity focused or aerobic in nature. They found their supervised, one-hour per week program improved in the intervention group (N = 8) on qualitative scores of an aesthetic dance tool compared to controls (N = 9). Likewise, Brown et al[22] also focused on extremity training, and compared both plyometric training (N = 6), and traditional weight training program (N = 6), to controls (N = 6) in eighteen college students enrolled in ballet or modern dance class. Intervention group subjects trained twice weekly for six weeks. While control subjects did not improve, both intervention groups improved in lower extremity indices of strength that relate to dance performance. However, dance specific indices were not measured. Furthermore, in a well-designed randomized study Koutedakis et al[21] employed a 2-3x/week 12-week training program (intervention N = 19, control N = 13) and found significant improvements in lower extremity strength and flexibility, aerobic conditioning, and a qualitative dance rating based on performance of a choreographed dance routine. Exercise intervention was comprised of free weight training, running, cycling or swimming. Again, no specific core (TrA) training was included. Taken together, these studies have utilized a variety of aerobic conditioning, muscle strength and power training activities that have improved indices related to the specific training exercise (specific adaptation to imposed demand) and qualitative, aesthetic impression of dance performance. However, there remains a lack of studies that positively demonstrate improvement on objective dance indices as a result of specific, focused supplementary core stabilization training.

This study demonstrates that a nine-week core stabilization intervention may improve elements of dynamic balance and trunk musculature endurance in collegiate dancers. When considering administration of this intervention, it is important to acknowledge that collegiate dance team members and other athletes may have a higher baseline of exercise familiarity and tolerance than other non-athletes. Additionally, pretesting revealed a significant increase in TrA activation after a single session of training. Further, the increase noted between self-selected and immediately following ADIM training with USI demonstrated that dancers were not aware that they were not activating the TrA fully. This identifies a quick and effective method of educating subjects to create sensorimotor control in an effort to stabilize their trunk. Of importance is the capacity to differentiate between the ability of core muscle activation immediately upon instruction and the ability to utilize core activation during the subjects' activity (dance, athletics, functional tasks, etc.). Appropriate and specific applicable motor learning should be emphasized for each individual.

This study population was limited to young adult female collegiate dance team members who were not single genre (ballet, jazz) dancers; therefore, findings could only be generalized to this population. In addition, direct measurement of TrA activation was not possible during pirouettes. Thus, the ability of the researchers to monitor TrA activation during this dance maneuver was lacking.

## CONCLUSION

An intensive nine-week training core stability program improved indices of dance performance, balance measures, and measures of core muscle performance. Testing revealed an immediate, significant increase in TrA activation after a single session of training, identifying a quick and effective method of educating dancers on core muscle activation. Additionally, ADIM training followed by a core stability program resulted in short-term (nine-week) improvements in TrA activation in a functional dance position. Measures of trunk muscle endurance (extensor endurance, abdominal flexor endurance and side bridge tests), hip abductor strength and single leg hop were improved following our training program. Results for primary objectives of this study showed improvement in the dance related activity of pirouettes, the bilateral anterior reach directions of the modified SEBT and single leg balance performed in front passé releve with arms in first position following a nine-week core stabilization training program.

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