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Original Article

The effectiveness of transverse abdominis training on balance, postural sway and core muscle recruitment patterns: a pilot study comparison across age groups

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Abstract. [Purpose] This pilot study aims to determine whether improvements in postural sway, particularly among older adults, can be augmented immediately after training participants to activate and isolate the transverse abdominis (TrA) muscle. [Participants and Methods] Fifty six participants (in three age groups) took part in a single session TrA training intervention. Aspects of postural sway, balance and muscle activation patterns were measured before and after training and compared. [Results] There was significant improvement across four of six postural sway variables for the combined sample of all age groups. Older adults improved more than younger and middle-age participants in two important postural sway variables. No marked differences were evident in static reach distance across all age groups. There were no differences between groups with regard to surface electromyography (sEMG) amplitudes despite the emergence of different activation patterns among age groups. [Conclusion] Immediate effects were induced in postural sway measures after the single session training intervention. By improving neuromuscular control of the TrA and maximizing the efficiency of related proximal core muscles center of pressure (COP) sway velocities decreased during single limb standing (SLS).
Key words: Transverse abdominis, Postural sway, Balance

INTRODUCTION

There is evidence to suggest that older adults recruit muscles differently than younger adults while performing everyday tasks. With aging comes a shift to a more conservative approach during walking and upright stance, which paradoxically may contribute to a higher incidence of loss of balance and falls[1]. This age-related shift in approach to maintain postural stability may alter the way we use proximal hip and core muscles[1–4]. Core muscles and their roles have been well researched and are often further delineated into local and global components as described by Hodges and Richardson[5]. Global core muscles are generally considered larger and more superficial expanding over many levels of the spine or pelvis playing an indirect role on spinal stability[5–7]. These muscles generally include the erector spinae, rectus abdominis (RA), latissimus dorsi and gluteus maximus. Local core muscles are typically deeper muscles with a more direct influence on segmental spinal stability such as the transverse abdominis (TrA), internal oblique (IO), multifidi and pelvic floor muscles. Recent evidence suggests

that there is significant muscle atrophy in superficial or global core muscles like the RA and external oblique (EO) associated with age[8]. In adults who have more atrophy, mediolateral stability and quality of life measures showed significant decline[9]. These same researchers established that the TrA was not one of the muscles that showed any significant muscle thickness change but did demonstrate decreases in contractile tissue and timing[8, 9]. Due to the synergistic relationship of local and global core muscles, global muscle activity is included in this study but the focus of our intervention and discussion is on local core muscles, specifically the TrA.

In an effort to meet the demands of an older but more active population, balance training has become more important than ever. Traditional approaches to balance training often focus on distal ankle strategies progressively decreasing the base of support to increase difficulty and improve aspects of balance. More recently an association between trunk function and fall risk has been found which has changed the paradigm for balance training[9–11]. Specifically, there has been a shift in balance and neuromuscular retraining to include core and proximal muscle training with some promising results[10, 11].

The core muscles have been described as a kinetic link that facilitates the transfer of torques and angular momentum between the upper and lower extremities during sports skills, occupational skills and activities of daily living[12]. Kibler et al. placed particular emphasis on core strength to provide proximal stability to improve distal mobility[13]. Others agree with this approach and suggest that due to their location core muscles functioning effectively together play a crucial role in controlling the body's center of mass which is located close to the human navel[14]. The ability to control motion around the center of mass after core muscle activation training limits the excursion of center of mass and ultimately improves balance[14]. There is new and compelling evidence to suggest a direct association between core strength training and proximal postural control with improved balance and function resulting[13, 15–17]. Spinal mobility, functional mobility (Timed Up and Go) and dynamic balance (Functional Reach Test) all improved in community dwelling older adults after a 9-week core strength training program[18]. However, the exercise protocols that elicited these improvements in functional outcomes and balance are considered moderate to advanced and often have limited compliance and carryover for many older adults outside of the clinic. Other studies using Tai Chi and Pilates interventions have shown promise with improvements in functional mobility scores and dynamic balance measures[19]. However, many Tai-Chi and Pilates-based programs have inherent practical limitations including requiring specialized certification or equipment that are often not available to clinicians. Results of more recent studies have shown that long-term and advanced core muscle strengthening may not be necessary to train core muscles to improve balance and function[20, 21]. Results from these studies also suggest that there is an immediate effect and long-term carryover of the local core muscle activation after only one training session of the transverse abdominis (TrA) using manual cueing and ultrasound biofeedback[22]. The authors further proposed that proper training and activation of the TrA will facilitate proper use of surrounding local core muscles making open and closed chain activities more efficient.

Despite growing evidence that core training improves functional mobility and balance, most studies have failed to distinguish whether these results were attained from the immediate benefits of improved neuromuscular activation or actual core muscle strength gains and hypertrophy that occur over much longer timeframes. Making this distinction is important and has a myriad of clinical implications when training this group of muscles. The answer to this question may change the current paradigm for how we train balance in older adults, specifically for those who may be at a greater risk for falls. This study aims to build on the results of recent literature by determining whether gains in functional outcomes and balance measures are feasible with improvements in neuromuscular activation and control of the TrA via an abdominal draw-in maneuver (ADIM). This study also aims to distinguish the differences in core muscle activation patterns after ADIM training among three different age groups. The effect of age is a critical covariate in this pilot study in order to determine if age-related declines in muscle thickness, muscle timing, and less efficient neuromuscular control in older adults can be mitigated with this intervention. If measurable improvements in outcomes are captured in the older group, it speaks to the viability and practicality of a simple technique as an effective addition to current balance training protocols in the clinic. In order to make this distinction it is critical to understand how to train key core muscles efficiently and identify muscle activation patterns during a common balance exercise in healthy adults. The specific purpose of this pilot study is to assess the effectiveness of a single TrA training session on aspects of postural sway and recruitment patterns of core and support leg muscles during a single leg standing activity.

PARTICIPANTS AND METHODS

Active older adults (n=56) with no prior core muscle training participated in this study. Participants were further stratified by age: younger (18–39, n=22, 24.5 ± 3.6), middle (40–59, n=16, 48.6 ± 4.4), and older (60–79, n=18, 66.4 ± 3.6) (Table 1). All participants provided written consent before data collection began. Each participant performed a Functional Reach Test (FRT) and a single leg standing (SLS) balance activity. All participants were considered active and healthy adults based on a subjective self-report of their ability to interact in the community without any assistance or limitations. Recruitment and data collection occurred from November 2016 through May 2017. Both genders were included in this study and were recruited via Rutgers University Doctor of Physical Therapy email lists, a local YMCA location and flyers placed in high traffic areas on campus. Exclusion criteria included: any recent or current episodes of dizziness, recent injury to dominant or preferred balance leg, recent abdominal or low back surgery, current low back pain, any known neurological or muscular disease with progressive symptoms. After Institutional Review Board (IRB) approval at both Rutgers University (Protocol Number:

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Table 1. Sample descriptive statistics by age group

	Young		Middle		Older		p value
	n	% or Mean ± SD	n	% or Mean ± SD	n	% or Mean ± SD	
Gender							
Male	12	54.5%	7	43.8%	4	21.1%	0.088
Female	10	45.5%	9	56.3%	15	78.9%	
Age (years)	22	24.5 ± 3.4	16	49.0 ± 4.3	19	66.4 ± 5.7	
SLS Leg							0.013
Left	4	18.2%	10	62.5%	10	52.6%	
Right	18	81.8%	6	37.5%	9	47.4%	
BMI (kg/m^2)	22	24.0 ± 3.6	16	25.1 ± 4.4	19	25.4 ± 3.5	0.461

SD: standard deviation; SLS: single limb standing; BMI: body mass index.
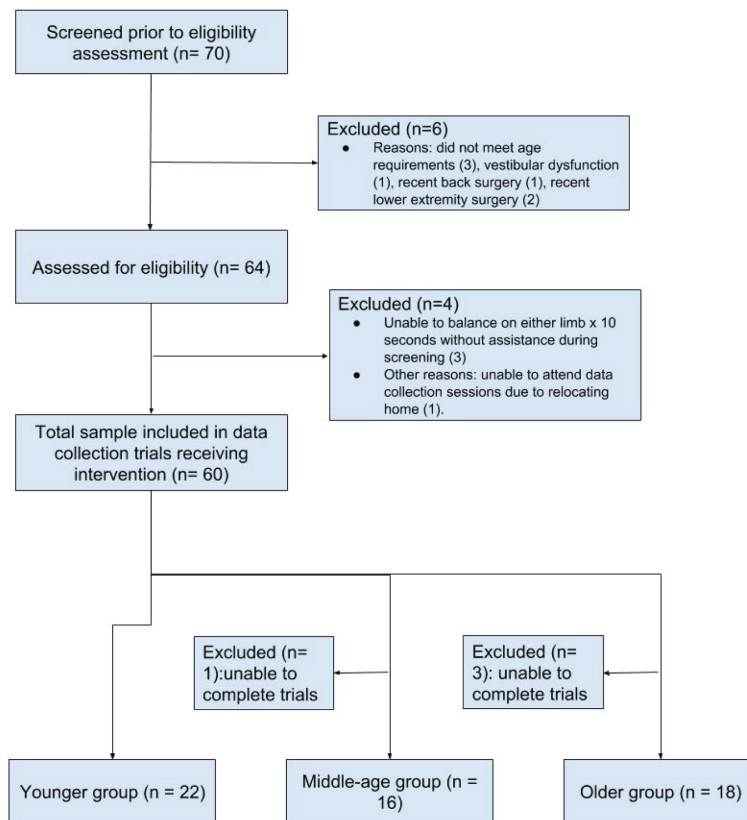
Fig. 1. Participant recruitment flow chart.

20150001267) and CentraState Medical Center, (Protocol Number: 2017-02) data were collected at two different movement analysis laboratories at those locations (Fig. 1).

The primary investigator trained all participants in the cognitive activation and isolated, volitional control of the TrA using the ADIM during a standardized, 15-minute training session. Participants were instructed in the ADIM in three different positions for five-minute durations: 1) hooklying 2) modified plank (prone on elbows and knees) and 3) bipedal standing. With each position, manual and verbal cueing and visual feedback using an M-turbo portable ultrasound unit (Fujifilm-Sonosite Inc., Bothell, WA, USA) with a 15–6 MHz linear sound head to assist in training the ADIM as originally described by Lee et al. to isolate the TrA and internal oblique while minimizing external oblique activation[19]. This current study incorporated both repeated contraction as well as 10-second isometric contractions of the TrA in each position during training. Maximum TrA thickness measurements were recorded with digital calipers in each position taken from the outer border of hyperechoic fascia line of each muscle as validated and described in previous research[23, 24]. Post-intervention FRT, postural sway and sEMG were performed in exactly the same manner as the pre-intervention protocol. Ultrasound was also used to view the contralateral TrA after the training intervention SLS to ensure isolated activation was occurring in a similar capacity as the

training sessions. TrA location was initially identified in supine hooklying position at the midaxillary line midway between the twelfth rib and iliac crest as described in previous research[22, 25]. On occasion, in order to obtain the best quality picture, it became necessary to vary the angle and pressure of the ultrasound head with each participant and each position.

Postural sway was recorded while standing on one leg on the GAITRite electronic walkway® (CIR Inc., Franklin, NJ, USA) using Protokinetic Movement Analysis software (PKMAS)® (Protokinetics LLC, Havertown, PA, USA). Participants were asked to stand on their preferred leg without assistance for 15 seconds. The preferred stance limb was established with an informal trial before data collection began to determine comfort and ability. All participants were asked to lift one foot first while one hand was still on support chair and then were asked to slowly let go of chair when ready. To minimize aberrant data during process of attaining the position and putting foot down at the end of the trial, the first and last 1.5 seconds were not used in data analyses. During the SLS trials six different outcome measures were collected measuring postural sway: Center of pressure (COP) anterior-posterior velocity (COPx) (cm/sec), center of pressure medial-lateral sway velocity (COPy) (cm/sec), total linear displacement of COP (COPpath) (cm), COP maximum velocity (COPmaxvel) (cm/sec), number of instances sway velocities in any direction were greater than two standard deviations away from the mean (COPmaxsway), and total time spent in COPmaxsway (COPtotal).

FRT was administered and measured by the same investigator using the established protocol for this test[26]. In this common clinical balance assessment, participants are asked to reach forward as far as they can with feet shoulder with apart, arm at 90 degrees without moving their feet or raising their heels. The average of three trials pre and post-intervention was used for statistical analysis.

sEMG data collection began with thorough cleansing and abrading areas of skin at pre-determined electrode sites. Precise locations of these motor point sites have been established in previous literature and were followed by the primary investigator during set up[27]. In addition, a visual and verbal flow sheet was used to optimize reliability of electrode placement for each participant. A 16-channel Noraxon, TELEmyo Direct Transmission System (Noraxon USA, AZ, USA) was used and sEMG electrodes were placed on 12 different motor points of selected muscles on each participant's support limb and bilateral trunk muscles including: TrA, RA, erector spinae (ES), EO and stance leg gluteus maximus, gluteus medius, tibialis anterior (TA) and lateral head of gastrocnemius. The middle 12 seconds of three, 15-second trials of SLS were recorded and averaged after training and were compared to baseline SLS sEMG output before intervention in the statistical analyses. sEMG data were collected at 1,080 Hz and then filtered in post-processing using a 20–400 Hz bandwidth filter. Rectified EMG data were then filtered with a 4th order zero-phase shift Butterworth filter with a cut-off frequency of 30 Hz. A custom MATLAB® script to determine the average of the rectified sEMG for each of the muscles was developed and used after initial data collection. Data from EO muscles were not included in analysis due to electrical interference from the heart. During all SLS trials a second investigator, trained in the standardized SLS procedures, stood nearby to give instructions on how to obtain SLS position and provide assistance when needed. If assistance was required or foot or hand was put on floor or chair respectively, that trial was not included.

Power was calculated to obtain a medium effect size (f=0.25) with a minimum power of 80%, using 5% alpha for a one-way analysis of variance. G*Power 3.1 software was used to compute the sample needed. The total n was 27 participants (nine in each age group). However, we over-enrolled to offset the possibility that some participants may not be able to stand on one limb for 15 seconds. Therefore, our goal was to recruit 12 participants per group for a total of n=36 participants.

Descriptive statistics (n, mean age and standard deviation) were computed separately for the three age groups and group differences were tested using either Chi square (gender and SLS leg) or independent samples t-tests (BMI). Within-group changes pre- to post-treatment were computed using paired samples t-tests. To protect against type 1 error, a Bonferroni correction was applied to related within-group comparisons of primary interest (*a priori* α=0.008 for postural sway variables and α=0.025 for sEMG analyses of LTra and RTra). Differences in changes between groups were tested using a repeated measures analysis of variance, with Tukey's LSD tests for post-hoc comparisons when the omnibus test was statistically significant. A priori α=0.05 was used for within-and-between group comparisons. Because of the exploratory nature of the sEMG trials, no specific hypotheses were formulated, but mean changes and p values are reported for descriptive purposes. SPSS 25 (IBM, White Plains, NY, USA) was used for all analyses.

RESULTS

Descriptive statistics of the participants included in the sample are reported in Table 1. While the proportion of males to females was reasonably equal for the younger and middle age groups, the older age group was predominately female (78.9%, n=15). However, the difference in gender distribution was not statistically significant (p=0.088) and is typical of this age group in the general population. The proportion of preferred leg chosen was statistically significant between groups, with participants in the younger group substantially more likely to stand on their right leg. There was no significant difference in BMI between groups. There were no harms or unintended consequences during or after this study.

For the combined sample, four of the six postural sway variables were statistically significant (p<0.008) pre- to post-intervention: COPy (mean change= −0.19 ± 0.46, p=0.002), COPpath (mean change= −5.61 ± 7.8, p<0.001), COPmaxvel (mean change= −2.22 ± 5.16, p=0.002), and COPmaxsway (mean change= −4.88 ± 11.9, p=0.003). The within group and within-and-between group's measures are reported in Table 2. For the younger age group, none of the postural sway variables

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Table 2. Measures of changes in postural sway variables: pre- to post-intervention by age group

Measure	Younger		Middle		Older		p value of differences in changes between age groups
	Mean change Pre to Post ± SD	p value of within group change	Mean change Pre to Post ± SD	p value of within group change	Mean change Pre to Post ± SD	p value of within group change	
COPx (cm)	−0.03 ± 0.78	0.845	−0.18 ± 0.63	0.262	−0.50 ± 0.69	0.007*	0.126
COPy (cm)	−0.04 ± 0.38	0.657	−0.14 ± 0.37	0.138	−0.42 ± 0.55	0.003*	0.023*
COPpath (cm)	−2.85 ± 5.00	0.014	−4.88 ± 4.13	<0.001*	−9.43 ± 11.06	0.002*	0.022*
COPmaxvel (cm/sec)	−0.65 ± 5.83	0.608	−3.28 ± 3.54	0.002*	−3.16 ± 5.28	0.018	0.189
COPmaxsway	−3.45 ± 12.53	0.210	−6.08 ± 10.81	0.040	−5.52 ± 12.68	0.074	0.774

COPx: center of pressure sway velocity in the anterior-posterior direction; COPy: center of pressure velocity in the medial-lateral direction; COPpath: center of pressure linear path length distance; COPmaxvel: center of pressure maximum velocity; COPmaxsway: number of episodes of center of pressure velocity >2 SDs from mean; COPtotal: total time of COPmaxsway.
*p values for within-group changes <0.008 and for within-and-between group changes <0.05.

Table 3. Mean changes of sEMG pre- to post-intervention by age group

	Young			Middle			Older			p value of differences in changes across age groups
	Mean change Pre to Post[a]	SD	p value of within group change	Mean change Pre to Post	SD	p value of within group change	Mean change Pre to Post	SD	p value of within group change	
Tibant	0.8	2.0	0.078	−0.3	2.3	0.561	−0.3	3.5	0.697	0.301
Latgastroc	0.3	0.8	0.089	0.4	0.6	0.018	0.1	1.0	0.648	0.595
LTrA	2.0	2.2	<0.001*	1.1	1.8	0.025*	0.5	0.9	0.024*	0.033*
RTrA	2.3	2.6	0.001*	0.7	0.8	0.002*	0.4	0.9	0.067	0.004*
LRA	0.3	0.7	0.066	0.0	0.1	0.586	0.0	0.1	0.426	0.026
RRA	0.1	0.5	0.412	0.0	0.1	0.625	0.0	0.1	0.265	0.285
LLS	0.3	0.8	0.101	0.2	0.6	0.167	0.0	0.4	0.979	0.458
RLS	0.1	0.3	0.053	0.1	0.6	0.340	−0.1	0.3	0.482	0.291
Glutemax	0.1	0.4	0.271	0.0	0.1	0.173	−0.1	0.2	0.200	0.165
Glutemed	0.3	0.6	0.069	0.0	0.3	0.612	0.0	0.3	0.745	0.205

[a]Values of mean change values and standard deviations are reported as actual value multiplied by 10^5 to reduce the number of leading zeros.
Tibant: tibialis anterior; Latgastroc: lateral gastrocnemius; LTrA: left transverse abdominis; RTrA: right transverse abdominis; LRA: left transverse abdominis; RTrA: right transverse abdominis; LRA: left rectus abdominis; RRA: right rectus abdominis; LLS: left lumbar spine; RLS: right lumbar spine; glutemax: gluteus maximus; glutemed: gluteus medius.
*p values for within-group changes <0.025 and for within-and-between group changes <0.05.

showed statistically significant change pre to post-treatment (p>0.008 for all measures). However, for the middle age group, both COPpath (mean change −4.88 ± 4.13) and COPmaxvel (mean change −3.28 ± 3.54) decreased significantly (p<0.008) pre- to post-treatment. In the older age group, COPx (mean change −0.5 ± 0.69), COPy (mean change −0.42 ± 0.55) and COPpath (mean change −9.43 ± 11.06) all decreased significantly pre- to post-treatment. Among these variables, changes in COPy (F=4.83, p=0.023) and COPpath (F=4.102, p=0.022) were significantly different between groups, indicating a greater degree of improvement in the older group compared to the other two age groups. All post-hoc comparisons indicated that participants in the older group improved significantly more than both younger and middle age group participants (all p values <0.02). The results of the FRT revealed that all three age groups increased their reach distance from pre- to post-treatment, though none of the within-group changes were statistically significant. There was no significant difference in the changes between groups (F=0.147, p=0.841).

Changes pre- to post-intervention were significantly different between age groups for three of the sEMG variables: Left transverse abdominis (LTrA) (F=3.64, p=0.033), Right transverse abdominis (RTrA) (F=6.23, p=0.004), and Left Rectus Abdominis (LRA) (F=3.910, p=0.026). For both LTrA and RTrA, participants in the young age group showed greater activation of these muscles than participants in either the middle or older age groups (p ≤0.004 for all comparisons). For LRA, participants in the young age group showed statistically greater activation than participants in the middle age group (p=0.039), but not the older age group (p=0.198) (Table 3).

DISCUSSION

Results of this study demonstrated that older adults benefitted most from TrA training and cognitive activation in several postural sway measures. Postural sway velocity was measured in the anterior-posterior direction (COPx), medial-lateral direction (COPy), the total linear displacement of COP (COPpath) and maximum velocity (COPmaxvel) during SLS. Two additional postural sway measures (COPmaxsway and COPmaxtime) were compiled after initial data collection was completed. COPmaxsway was the number of instances participants' COP velocities in any direction were more than two standard deviations from the mean and COPmaxtime was the total time in those instances. Similar episodes of aberrant sway were identified by Desai et al. as possible indicators of loss of balance and fall predictors[28]. In our study, for the combined sample, we found statistically significant pre- to post-intervention improvement in four of the six postural sway variables measured: COPy, COPpath, COPmaxvel, COPmaxsway. When the sample was stratified by age group, however, different patterns emerged.

The change pre- to post-intervention was statistically significant within the older age group (−0.50 to 0.69, p=0.007) for Center of Pressure Velocity in the anterior-posterior direction (COPx). Though changes were seen in the hypothesized direction for both younger and middle age groups, differences between groups was not statistically significant. The lack of statistical significance in COPx in the younger and middle age groups may be explained by the task itself. The transition from bipedal to single limb standing does not induce a large change in location of center of mass in the anterior-posterior direction. Therefore, increases in muscle output and control of COPx are minimal for younger and middle age groups. Activation and control of the TrA may not contribute greatly in most individuals in COPx due to the position of the trunk as it remains over the support limb in neutral. Despite only small changes in mechanical demands in this plane there was a statistically significant difference in older groups. This may be explained by overall increase in sway in all planes in older adults due to normal age-related physiological declines and the benefit of proximal stability to offset these deficits.

Training and resultant improved neuromuscular control of the TrA appeared to have a much more significant effect on controlling Center of Pressure Velocity in the medial-lateral direction (COPy). COPy decreased significantly between all 3 groups (Table 2) with participants in the older group demonstrating the most improvement after training. During SLS, the physiological demands and movement of the center of pressure are greater and the effort required and resultant position in SLS generally increases the sway velocity in the medial-lateral direction[29, 30]. In order to maintain the eyes, shoulders and pelvis level while remaining balanced, muscle activity in the gluteus medius and COPy increase dramatically[31, 32]. Results of this study are in agreement with previous studies that suggest that activation of the TrA enables the stabilizing pelvic muscles to work more efficiently while decreasing the velocity of COPy in younger populations[22]. However, our study expanded on these findings demonstrating even greater effects of TrA training for COPy in older participants. These findings are clinically important due to the fact that the largest improvement was seen in the group arguably at most risk for loss of balance and falls and medial-lateral sway has been found to be a reliable predictor of falls[28].

Center of Pressure Total Linear Excursion (COPpath) has been validated as a measure of balance in a previous study and improvements in this outcome measure may signify a universal effect on balance that the TrA and core muscles have on dynamic stability[33]. In the present study there were decreases within all 3 groups after training with older adults showing significantly more improvement than middle age group (p=0.02) and younger group (p<0.001). Small variances in the participants' body mass distribution and the exact location where participants held their leg in space could have affected both COPx and COPy directly. Therefore, decreases in COPpath may be the most informative and clinically important because measuring total path length takes into account movement in all planes and is a realistic measure of postural control. Improvements in COPpath of each foot during gait has been correlated with gold standard balance measures such the Berg Balance Scale[30]. The decrease in COPpath among all groups and the significant decrease in the older group is an intriguing finding and suggests a proximal influence of TrA activation on postural sway and control of the center of mass in all planes.

Center of Pressure Maximum Velocity (COPmaxvel) (p=0.002), Maximum Sway Velocity (COPmaxsway) (p=0.04) and COPtotal (p=0.04) Table 2 showed statistically significant decreases within the middle age group after training. A similar effect of the training was seen in the older group; COPmaxvel (p=0.018), COPmaxsway (p=0.07) and COPtotal (p=0.07) Table 2. No statistically significant changes occurred in the younger adults. As a group, all three of these sway parameters have to do with maximum velocities measured three different ways. Desai et al. identified that COP sway velocity outliers can be potential precursors to falls[28]. Since the majority of these postural sway outcomes in the older groups met or approached statistical significance our results suggest that effective activation of the TrA mitigates momentum development partly as a result of decreasing postural sway velocity Table 2. Since all of our participants in this study were healthy and active, they were all able to make the postural corrections and control momentum adequately enough to stay upright on one foot even prior to training. After the intervention four of the six postural sway outcomes (COPx, COPy, COPpath and COPmaxvel) improved in the older group which may have even further clinical significance in higher fall risk populations. If these maximum velocity episodes during a task are precursors to falls than this finding is very compelling and provides further evidence that proper activation of the TrA improves mechanisms that control COP velocity, and more than likely center of mass displacement, resulting in improved balance in older adults.

The FRT is a common and validated clinical balance tool measuring a person's ability to reach forward while maintaining

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their feet in a fixed position. Results from this study showed that reach distance increased, but only slightly in all three groups after TrA training. These results may be explained by the biomechanical effects of TrA activation, which increases trunk and hip extensor rigidity via the thoracolumbar fascia and its continuation with the sacrotuberous ligaments[22, 28, 34, 35]. Initial activation of the TrA may facilitate reaching forward but ultimately with the arm elevated to 90 degrees and the hip and trunk progressively flexed, the tension in the thoracolumbar fascia limits further reach which may explain the lack of statistical significance in reach distance. The authors recognize that other factors like fear of falling, hamstring length and dorsiflexion range of motion limitations may also limit forward reach distance in the older participants more than the younger group making between group comparisons less reliable.

Balance strategies in older adults are different from those used by younger populations. With increasing age comes decreased visual acuity, compromised afferent feedback from feet and decreased proprioceptive accuracy. Thus, older adults rely on simultaneous contraction of muscles around the ankle to provide maximum stability[2–4, 36, 37]. Regardless of the activity and external demands older adults attempt to maximize stability throughout their lower extremity with low level, isometric muscle activation inducing a cocontractive effect[36, 37]. Proximally at the trunk and pelvis older adults tend to have less reliance on trunk and pelvic stabilizers to maintain balance, creating what has been termed an "inverted ankle activation pattern" with a fixed ankle and more mobile trunk[36]. This strategy, however, decreases the adaptability of the ankle and foot and their ability to conform to changing terrain and react to sudden unknown forces. As a result, a slower, more calculated gait pattern with more variation, increased energy expenditure and increased risk for falls often ensues[38–42]. Younger adults also have a distinct pattern during balance activities and respond to gravitational demands and small external perturbations by using ankle strategies in an alternating and rhythmical pattern of anterior and posterior lower leg muscles[2]. Proximally, younger adults stiffen their trunk and hip muscles creating what was described in previous research as a "pendulum strategy"[36]. This pattern, along with intact systems such as vision, joint proprioception and somatosensation allows for subtle adaptations during gait and balance activities while decreasing overall physiological cost of bipedal locomotion and balance[41, 42]. Although our results did not approach statistical significance due to decreased power for sEMG, a pattern of balance strategies seemed to emerge before and after TrA training in older adults. Prior to training the TrA older adults had higher sEMG output in distal muscles, the tibialis anterior and lateral gastrocnemius. Proximally, older adults had lower levels of trunk and hip muscle activation to maintain balance and demonstrated only small increases in hip and global core muscle use after training. These results are consistent with previous studies that have identified older adult populations who attempt to stabilize distally by contracting all muscles of the lower leg resulting in a stable but non-compliant lower extremity[40, 41]. These same authors have suggested that this strategy has deleterious effects on dynamic balance resulting in mechanically stiff or fixed joints reducing freedom of movement and increasing overall energy expenditure particularly during gait and higher level balance activities[42]. Prior to training, younger adults had decreased distal muscle contributions and much higher proximal muscle activation. Interestingly, this pattern of activation was similar but magnified after TrA training with TrA, bilateral rectus abdominis, lumbar paraspinals, gluteus medius and gluteus maximus all increasing activity to maintain balance in single limb standing. This finding supports the findings of previous literature that suggests a proximal reliance in younger populations to maintain balance while "freeing up" the ankle and foot to allow for more efficient adaptation to terrain and unknown external perturbations[36, 37]. In a similar study examining younger adults only, a similar distal pattern of use but differed in their results referring to increased proximal muscle use of external obliques and lumbar paraspinals[22]. These differences in proximal outcomes may be explained by the nature of comparison where they looked at changes in percent of a reference (maximum) voluntary contraction while this study used the pre-training single leg stance muscle output as the baseline measurement.

Although compelling, the results of sEMG garner closer investigation. Our view of muscle activity in the lower leg was limited to the lateral gastrocnemius and tibialis anterior. Future investigation should include muscle recruitment patterns of the peroneal group in the lateral compartment as well as the soleus. In addition, changing the activity during sEMG to a more dynamic task such as walking capturing all muscles of the lower leg should be analyzed. A more discrete pattern of balance strategies might emerge when the foot and body are continually adapting to external forces and changing terrain. In order to clearly distinguish whether all muscles of the lower leg are contracting simultaneously or if an alternating pattern of recruitment develops, a closer look at the temporal activation of these muscles is merited. It might also be intriguing to determine if more intensive or longer duration training of the TrA among older adults results in distal muscle recruitment profiles that are closer to younger adult muscle recruitment profiles.

We have identified some limitations of this study. It was our immediate goal of this pilot study to identify the effects of TrA training between age groups. We acknowledge that the improvements within all three groups observed after training might have occurred, in part, due to the effects of learning and practice. In a future study we intend on including a group of age-matched participants who do not receive any intervention between the initial and second measurement intervals. We did not control for footwear, ankle range of motion or vision and proprioception which are each confounding variables that could influence postural sway and functional reach distance. It was our opinion that the benefits of each participant's comfort and support provided by the footwear during testing outweighed the small variability that might be introduced from these variables. In addition, all participants that were included were all self-reported healthy, independent ambulators without fall history, extensive medication use or recent pathology. Our results therefore, may not be generalizable to all adults in these stratified age groups. The study was not powered adequately to detect differences in sEMG in many of the muscles targeted in this study and thus differences on sEMG variables should be interpreted as descriptive. Although there appeared to be the

emergence of a trend in muscle recruitment in our sample, the statement that older adults were "cocontracting" throughout the support limb could not truly be confirmed as we did not specifically look at timing or comparative muscle output around the ankle and hip. We aim to investigate this pattern more closely in future related studies.

Older adults benefitted most from TrA training with measurable improvements in various aspects of postural sway during a SLS task. This study is unique in that it measured the immediate effects of TrA training and neuromuscular activation on postural sway measures and sEMG muscle activation patterns during a common but challenging balance activity. The design of this study and measured results are different than most previous TrA studies that have focused on increasing strength over much longer data collection timeframes. To our knowledge it was also the first study to compare the effects of this training technique among three different age groups. By improving neuromuscular activation and volitional control of the TrA using an easily administered and clinically feasible technique such as the ADIM, acceleration velocities, total COP distance traveled and instances of aberrant sway velocities all decreased at varying levels of statistical significance. Improvements in any one of these postural sway parameters may contribute to improved balance, decreased risk of falls and preservation of functional independence. After training, sEMG results in younger and middle-aged participants demonstrated a biomechanical stiffening of proximal trunk and hip musculature allowing for more natural ankle strategies and improved control of the center of mass over a fixed distal point. Older adults demonstrated a different pattern that was indicative of a strategy that prioritizes stability in all support limb joints and trunk muscles. Based on the results of this study, future studies should aim to incorporate TrA training as an adjunct to traditional methods of balance training.

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