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Suspension Training Improves Dynamic Balance and Core Endurance in Young Healthy Adult Females

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Abstract Many exercise modalities have been developed and marketed to improve core muscle function; likewise, there are multiple training programs that aim to improve balance. These variables are of interest given they are inherent to performing activities of daily living (ADLs), preventing injury, and maintaining physical activity levels. Our previous work shows suspension training (SuT) is effective at improving body composition, muscular strength, and muscular endurance in college aged females; however, it is unknown whether core muscle function and balance also improve. The purpose of this study is to determine the effect of six weeks of SuT on balance and core muscle function. **Methods:** Eighteen SuT naïve females (19.8 ± 0.3 yrs; 166.7 ± 1.1 cm; 61.3 ± 1.7 kg), randomly assigned to a suspension training group (TRX), progressed through a six-week supervised training program consisting of 18, 50 to 60-minute interval style workouts. Six control participants (CON) (20.8 ± 0.7 yrs; 165.4 ± 1.3 cm; 63.5 ± 2.7 kg) maintained their normal activity levels. Dynamic balance was assessed using the Star Excursion Balance Test (SEBT). Static balance was assessed using the Balance Error Scoring System (BESS) Test. Core endurance was assessed using the Sport-Specific Endurance Plank Test. The same test protocols were applied for pre- and post-testing. **Results:** Dependent measures t-test analysis showed significant improvements ($p<0.05$) in right leg stance SEBT scores (expressed as percentage of reference leg length) in all directions: anterior (5.0± 1.5%), posteromedial (9.2± 2.7%), and posterolateral (6.8± 2.2%), in the TRX group. The TRX group also showed left leg improvements ($p<0.05$) in posteromedial (6.4 ± 2.5%) and posterolateral (8.1 ± 2.4%) directions. There was an improvement in plank time (35.5 ± 10.3 seconds: $p<0.05$) in the TRX group. No difference in BESS Test scores were observed over time. There were no changes in any dependent variables in the CON group. **Conclusions:** These data suggest that six weeks of SuT facilitated improvements in bilateral dynamic balance and core endurance. Further work including additional assessments of core stability and balance measures is needed to investigate the lack of improvements observed in static postural control.

Keywords Suspension Training, Dynamic balance, Static balance, Core endurance, Interval training

1. Introduction

In recent years, suspension training (SuT) has gained popularity as a modality of full-body, unstable resistance training. Unlike stable resistance training, SuT promotes instability by altering the user's center of mass, requiring constant activation of both core and peripheral stabilizer musculature in order to maintain equilibrium while also working against resistive forces generated by gravity and body weight [1-4]. These attempts to counterbalance disequilibrium increase stress placed on the neuromuscular system. In response, sensory feedback from proprioceptors and muscle spindles is enhanced, allowing for greater neural recruitment patterns of stabilizer musculature, and ultimately improvements in balance and stability [3,5,6]. As opposed to hypertrophy, neuromuscular adaptations are also responsible for strength gains observed during the initial stages of unstable resistance training [3,7]. Although muscle activation magnitudes are comparable in both stable and unstable resistance training, the increased neuromuscular adaptations imposed by instability reduces an individual's total force output, making it more difficult to achieve higher intensity ranges [3,8]. Nonetheless, while utilizing unstable resistance training devices, interval style training may be useful to compensate for this reduced ability to achieve higher intensity ranges. For example, SuT interval style training elicited a cardiorespiratory response concurrent with moderate intensity exercise when a work rest ratio of 30 seconds to 60 seconds was utilized [2].

Our prior work [1] examining the effectiveness of a six-week SuT interval style training program on fitness revealed significant improvements in muscular endurance, muscular strength, flexibility, cardiorespiratory fitness, and lean body mass. However, the study did not assess any neuromuscular adaptations allowing for strength gains

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that could lead to improvements in dynamic or static stability. Additionally, numerous studies have examined neuromuscular adaptations of instability training on various unstable surfaces such as wobble boards, BOSU balls, inflatable discs, and sand [3,7,9,10]; yet limited studies have sought to determine the effects of SuT exercise programs on neuromuscular adaptations. To our knowledge, only two studies evaluate this relationship, and both sample populations consist of collegiate student athletes [4,11]. With respect to core strength, we identified two studies which compared core muscle activation between floor-based planks and suspended planks. Both studies noted significant increases in activation while suspended, but neither evaluated long-term effects of this heightened activation on core strength adaptations [12,13].

With current identified literature evaluating the effectiveness of SuT exercise programs on neuromuscular adaptations being limited to collegiate student athlete populations, transferability of findings to general populations is difficult due to divergent needs and characteristics of the two populations. One reason for this is with both generic, stable resistance training and unstable resistance training, athletes observe significantly lower strength adaptations compared to non-athletes, including lower cross-sectional area and force [14,15]. Secondly, unstable resistance training is not primarily used by athletes as performance enhancements are hindered by the modality's reduced total force output [14]. However, this limitation is not a concern for general populations seeking to stay active. Therefore, the purpose of this study is to determine the effectiveness of a 6-week SuT exercise program on static and dynamic balance, and core muscle endurance in college females.

2. Methods

2.1. Participants

Twenty-four healthy females with no-SuT experience volunteered to participate in this study. Participants with a BMI less than 18.5 kg/m^2 and greater than 29.9 kg/m^2 were excluded from the study. Each participant completed a Physical Activity Readiness Questionnaire and additional health questionnaires to assess current physical activity levels and health status. Upon clearance, participants were randomly assigned to a control (CON) group or suspension training group (TRX). The TRX group (n=18) participated in a 6-week, 18-session SuT exercise program while the CON group (n=6) was asked to maintain their usual levels of physical activity and diet for six weeks.

2.2. Testing Procedures

Written consent was obtained from all participants and all procedures performed in this study were approved by the Institutional Review Board at College of Charleston. Anthropometric measurements were taken prior to exercise testing. Height and weight were collected using a standard medical stadiometer (SECA Corp., Chino, CA) and a digital medical scale (SECACorp., Chino, CA), respectively. Leg length was measured bilaterally in centimeters from the inferior portion of the anterior superior iliac spine to the inferior portion of the medial malleolus. Leg dominance was determined by asking the participant which leg she would use to kick a soccer ball. Body composition, reported as lean mass and percent body fat, and bone mineral density were assessed using dual energy x-ray absorptiometry (DXA: GE Lunar Prodigy). Next, participants warmed up on a cycle ergometer at a comfortable pace for ten minutes and then performed a battery of exercise tests. Muscular strength was assessed via leg press and chest press using one repetition maximum (RM) and five RM testing protocols [16]. Next, balance and core assessments were counterbalanced to avoid a testing effect. Testing order remained consistent for each participant during pre- and post-testing.

The Balance Error Scoring System (BESS) Test [17] was administered to assess static balance in three stances: double leg (feet touching side by side), single leg, and tandem (heel-to-toe). Stance order was randomized for each participant. Participants were instructed to remove their shoes and to stand on an Airex balance pad (Airex AG, Sins, Switzerland) for each stance position. Once they felt stable, participants were instructed to put their hands on their hips and close their eyes and try to maintain their position for 20 seconds with as little movement as possible. Errors were marked if hip flexion or abduction exceeded 30 degrees; a heel or forefoot lifted from the surface; the participant stepped, stumbled, fell, or remained out of position for more than five seconds; or if the participant opened their eyes or their hands left her hips [17].

Dynamic balance was measured in the anterior, posteromedial, and posterolateral directions using the modified Star Excursion Balance Test (SEBT) [18]. With their shoes off, participants began standing in a neutral body position with their hands on their hips and both feet on the ground, situated just behind the point of intersection of the three lines where the posteromedial and posterolateral lines were 135° from anterior. For each direction and foot, participants were instructed to reach out and lightly tap the tape as far away as possible. After every maximal reach, participants returned to the neutral body position. Participants were given three practice trials for each motion to enhance familiarization. Afterwards, participants completed three trials per foot in each direction in a randomized order. Trials were excluded and repeated if the participant lost balance, failed to return to the neutral stance, missed the tape, used her reach leg for stability, or if her heel on her stance foot left the ground [18]. The maximum distance of three successful trials for each foot were recorded and averaged.

The Sport-Specific Endurance Plank Test Protocol [19] assessed core endurance. Participants continuously progressed through a series of stages consisting of a 60 second basic plank, then 15 seconds each of the following stances: right arm raised, left arm raised, right leg raised, left leg raised, right arm and left leg raised, left arm and right leg raised, and finally a basic plank for 30 seconds. Participants who successfully completed these stages were instructed to repeat the stages additional times until failure. Failure was marked by an inability to maintain proper body alignment between reference lines after two verbal corrections. Participant positioning was standardized by identifying reference lines marked 5 centimeters above and 5 centimeters below the midline of the subject's iliac crest while in a basic plank position [19]. Time to exhaustion and highest level reached were recorded.

2.3. Exercise Training

Table 1. Suspension Training Protocol

TRX Exercise	Time Exercising	Time Between Exercises
TRX Squat	0:30	1:00
Single Leg Lunge (R)	0:30	0:00
Single Leg Lunge (L)	0:30	1:00
Inverted Push-Up	0:30	1:00
Atomic Push-Up	0:30	1:00
Chest Press	0:30	1:00
Back Row	0:30	1:00
Single Row (R)	0:30	0:00
Single Row (L)	0:30	1:00
Swimmers Pull	0:30	1:00
Triceps Press	0:30	1:00
Preacher Triceps	0:30	1:00
High Bicep Curl	0:30	1:00
Pronated Bicep Curl	0:30	1:00
Hamstring Curl	0:30	1:00
Hip Press	0:30	1:00
Hamstring Bicycle	0:30	1:00
W- Row	0:30	1:00
T- Row	0:30	1:00
Suspended Pendulum	0:30	1:00
Side Plank Reach (R)	0:30	0:00
Side Plank Reach (L)	0:30	1:00
Total Time	11:30	19:00

Listed are the 22 exercises performed during each of the 18 SuT sessions. The total time listed is accurate for the initial 30:60 work rest ratio. Total time training was different for the other work rest ratios.

Table 2. Suspension Training Intervals by Week

Week	1	2	3	4	5	6
Work:Rest Ratio (s:s)	30:60	30:60	45:60	60:60	60:45	60:30

Weekly work: rest ratios utilized for each SuT exercise.

The experimental group participated in three SuT exercise sessions per week for six- weeks, equating to 18 total sessions. A full-body training program with 22 exercises was designed in consultation with the manufacturer of the SuT device (Table 1). Every major muscle group was addressed by at least one exercise. During the first two weeks, a baseline work rest ratio of 30:60 seconds was implemented. For the final four weeks, work rest ratios were adjusted weekly (eg. 45:60, 60:60, 60:45, 60:30) in accordance with progressive overload training principles to promote training adaptations [20] (Table 2).

Body weight was used as resistance and the participants had full discretion in determining the intensity by adjusting their distance from the fulcrum to suit their level. Participants completed as many repetitions as possible using proper form within a 30-second exercise period. Training sessions were supervised by research assistants who received prior training on performing the exercises and cuing the participants on technique in addition to encouraging them for maximal effort.

At least 24 hours prior to each initial training session, participants attended a familiarization session where they were instructed on how to use the SuT equipment and guided through a few repetitions of each exercise within the training protocol. All exercises were performed using the TRX Home Trainer ® . Training sessions took place at the Human Performance Laboratory at the College of Charleston. Participants who missed more than one training session in a week or more than two total training sessions during the intervention period were dismissed from the study.

2.4. Statistical Analysis

All data were normally distributed and analyzed using Microsoft Excel. SEBT reach distances data were normalized to leg-length and reported as a percentage of leg length for each direction. Dependent measures t-tests evaluated changes within treatment groups and independent measures t-tests compared differences between groups at a significance level of alpha = 0.05. All data are presented as mean ± standard error (SE). Percent change in dependent variables was calculated by subtracting the pre value from the post value, dividing that number by the post value, then multiplying by 100. ((post-pre/post) * 100)).

3. Results

3.1. Participant and Demographic Data

Table 3. Baseline Participant Anthropometric Data

	n	Age (yrs)	Height (cm)	Mass (kg)
TRX	18	19.8 ± 0.3	166.7 ± 1.1	61.3 ± 1.7
CON	6	20.8 ± 0.7	165.4 ± 1.3	63.5 ± 2.7

Expressed as mean ± SE. TRX, Suspension Training Group; CON, control

A total of 36 participants (TRX n=20, CON n=16) were recruited and randomized for this study. Eighteen completed the six-week SuT training program while six participants maintained normative diet and exercise, serving as controls, over the same period. At baseline, no demographic differences in any variables existed between the TRX group and CON group (Table 3). Besides dynamic balance in the anterior direction on the left foot, no significant differences existed in all dependent variable conditions at baseline (Table 4).

Table 4. Baseline Participant Anthropometric Data

	TRX	CON
Dynamic Balance (Percent of Reference Leg (%))		
Right		
Anterior	74.6±1.0	76.1±2.8
Posterolateral	98.0±2.3	98.0±6.3
Posteromedial	106.1±2.7	104.8±4.5
Left		
Anterior	74.3±1.1	84.7±3.9*
Posterolateral	99.7±2.6	106.6±5.4
Posteromedial	106.5±2.4	107.3± 4.8
Endurance Plank (Time (s))	106.1±9.6	140.3±24.6
Static Balance (Number of Errors)		
Single Leg (Dominant)	5.4±0.6	6.2±1.5
Single Leg (Non-Dominant)	6.2±0.7	6.7±0.8
Double Leg	0.4±0.4	0.0±0.0
Tandem Leg (Dominant Leg in front ONLY)	3.3±0.8	2.5± 0.8

Expressed as mean ± SE. TRX, Suspension Training Group; CON, control.
*Significant difference between groups (p<0.05)

3.2. Dynamic Balance

Pre- and post- testing dynamic balance scores are shown in Table 5. Following the six-week intervention period, significant improvements were observed in all conditions except for the left leg anterior direction (p<0.05). For all directions on both the left and right legs, no significant differences were observed in the CON group.

Table 5. Dynamic Balance Performance

	TRX		CON	
	Pre-	Post-	Pre-	Post-
Right				
Anterior	74.6±1.0	79.6±2.2*	76.1±2.8	73.3±0.9
Posterolateral	98.0±2.3	104.8±2.2*	98.0±6.3	93.4±3.5
Posteromedial	106.1±2.7	115.3±2.8*	104.8±4.5	108.2±3.8
Left				
Anterior	74.3± 1.1	78.6±2.6	84.7±3.9	77.1±3.9
Posterolateral	99.7±2.6	107.8±2.3*	106.6± 5.4	96.5±2.8
Posteromedial	106.5±2.4	112.9±2.5*	107.3±4.8	104.2± 2.6

Expressed as mean ± SE. TRX, Suspension Training Group; CON, control.
*Significant difference from pre- to post- testing (p<0.05)

3.3. Core Endurance

Endurance plank time in the TRX group improved by an average of 34.5 seconds (p<0.05). Time increased from 106.1 ± 40.9 seconds at baseline to 141.6 ± 46.9 seconds post-intervention. No significant improvement occurred in the CON group (Figure 1).

3.4. Static Balance

For both the TRX and CON groups, no significant changes were observed in all BESS Test conditions (single leg dominant, single leg non-dominant, double leg, tandem) after the six-week period (Figure 2).

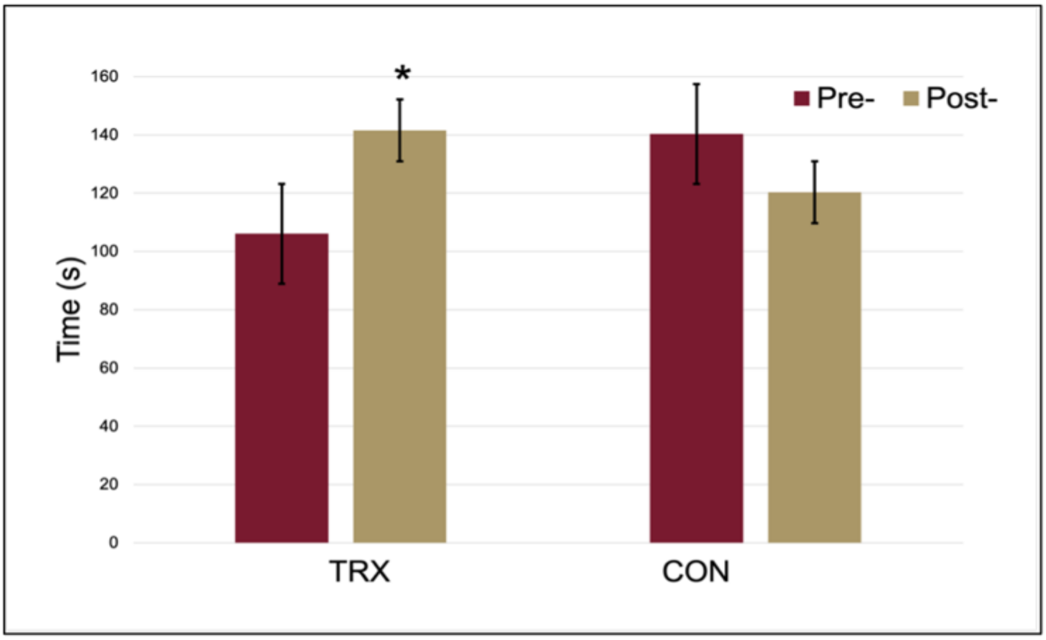

Figure 1. Sport-Specific Endurance Plank Test performance. Pre- and Post- intervention scores are displayed for both the TRX group and CON group. *Significant difference from pre- to post- testing (p<0.05)

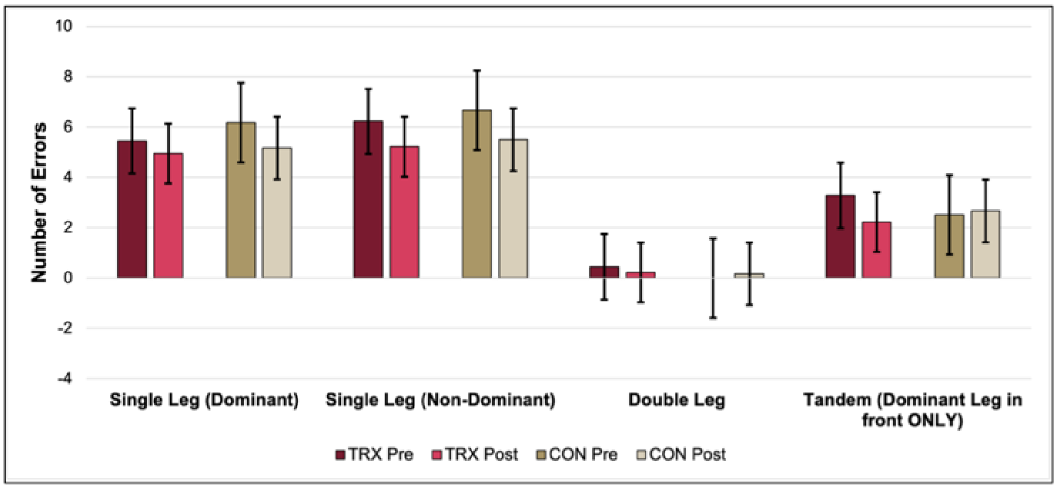

Figure 2. BESS Test performance to assess static balance. Pre- and Post- intervention scores are displayed for both the TRX group and CON group. *Significant difference from pre- to post- testing ($p<0.05$)

4. Discussion

This study examined the effects of a 6-week SuT exercise program on static and dynamic balance and core endurance in college-aged females. These variables were measured in both the TRX and CON groups before and after the six-week intervention period. The results showed this interval style SuT exercise program improves dynamic balance and core endurance but not static balance. This differs from our hypothesis that significant differences in both static and dynamic balance and core endurance would improve in the TRX group after the six-week long SuT intervention.

4.1. Dynamic Balance

Most unstable devices used during resistance training programs target static balance as opposed to dynamic balance. Therefore, many studies assessing the effects of unstable resistance training evaluate static balance [3]. However, activities of daily living (ADLs) and physical activity heavily rely on dynamic balance, making it important to identify training modalities that improve this component of balance. After seven weeks of twice weekly resistance training programs, Kibele et. al [21] did not report any training advantages for either stable or unstable resistance training groups in forty college-aged students (22.5 ± 2.1 years). However, it should be noted that the stable resistance training group utilized free weights, which provide a degree of instability.

Conversely, Aslani et. al [11] found that performing hopping and SuT exercises three times a week for four weeks significantly improved dynamic balance by 14.5% and 14.0%, respectively in male university student-athletes (25.6 ± 2.8 years). No significant differences were reported in the control group where participants maintained their normal activity. In accordance with Aslani et. al, we observed significant changes in dynamic balance in the TRX group. On the right leg, dynamic balance improved by 6.7%, 7.2%, and 9.4% in the anterior, posterolateral, and posteromedial directions, respectively. On the left leg, dynamic balance improved by 8.7% and 6.4% in the posterolateral and posteromedial directions, respectively. While our findings were in line with this study, our population differed in that we only included adult females, none of which were collegiate-level athletes. Therefore, it appears that SuT can enhance dynamic balance in heterogeneous populations, but future research should be conducted to confirm this idea. More specifically, investigating the training benefits in an older adult population could be useful as a potential fall-prevention intervention.

4.2. Core Endurance

In our current study, core endurance significantly increased by 36% in the TRX group after the 6-week SuT intervention. Kibele et. al [21] reported only an 8.9% increase in abdominal endurance after 7-weeks of twice weekly instability training in females (22.5 ± 2.1 years). This is approximately one quarter of the change in abdominal endurance observed in our current study. However, possible factors relating to this disparity may include fewer training sessions (14 versus 18 in the current study), longer rest intervals between sets (3 minutes versus a maximum of 1 minute in the current study), a smaller number of exercises, and a lower training load.

Training on unstable surfaces, will activate core musculature to promote stability. For example, electromyography (EMG) was conducted on 21 participants (21.9 ± 2.4 years) in four planking conditions: floor based, arms suspended, feet suspended, and feet and arms suspended. Root mean square EMG was significantly higher in the three suspended conditions than the floor-based conditions [12]. These increases in muscle activation are thought to enhance the endurance capabilities of the core musculature [22].

Similarly, Luk et. al [13] examined EMG of core musculature in young adult males (21.40 ± 1.78 years) performing various positions of prone and supine bridge exercise using SuT. There was a significant increase of average muscle activity (%MCV) of the rectus abdominis, rectus femoris, thoracic erector spinae, and lumbar multifidus in the prone bridge feet suspended group (21.8%) compared to the control group (13.7%). This suspended prone position is similar to positioning used for the inverted push-ups, atomic push-ups, and suspended pendulum exercises performed by the TRX group in our current study. Based on these findings by Luk et. al, it is suggested that similar muscle activation occurred as the TRX group performed their prone exercises. In addition, Luk et. al [13] reported that %MCV of the rectus abdominis, rectus femoris, thoracic erector spinae, lumbar multifidus, and biceps femoris were also greater in the supine feet suspended position than the control supine position But, %MCV in the gluteus maximus was significantly lower in the supine feet suspended position compared to the supine control. This positioning mimics positioning of the hamstring curls, hip press, and hamstring bicycle exercises performed by the TRX group in our current study and suggests greater activation of the listed muscles while performing these exercises.

4.3. Static Balance

Our results regarding static balance were quite surprising. Given the adaptation benefits of increased instability on strength, unstable surfaces such as BOSU balls and wobble boards are frequently used/incorporated in training programs. Such equipment increases demands on static balance, therefore, changes in static balance is commonly measured in instability studies.

In our current study, no significant changes in static balance were observed in either the TRX or CON groups. These results are not consistent with other studies assessing the effects of unstable resistance training on static balance. A reason for the inconsistency might be explained by the skill-specific nature of balance and proprioception. In two separate review articles, Willardson [5,10] explains that neuromuscular patterns, or motor engrams, are created as an individual practices and masters a specific movement pattern. As something foreign is introduced to the movement, such as a change in surface, the neuromuscular system may become confused. In our current study, most exercises performed by the TRX group required the participant's feet to be on the stable ground while the SuT apparatus provided instability. However, static balance, assessed via the BESS Test, required participants to stand on a foam pad. Therefore, this may have disrupted the neuromuscular patterns formed during the intervention period, resulting in no significant difference in static balance scores. Similarly, the exercises performed by the participants were dynamic, whereas the BESS Test requires the participant to remain static. In addition, around half of the exercises required the participant's hands to be in contact with the SuT apparatus while her feet remained on the ground. This extra point of contact and upper body activation is not present during the BESS Test. These may have further disrupted neuromuscular adaptations, resulting in no significant improvements in static balance. Our results regarding static balance were quite surprising. Given the adaptation benefits of increased instability on strength, unstable surfaces such as BOSU balls and wobble boards are frequently used/incorporated in training programs. Such equipment increases demands on static balance, therefore, changes in static balance is commonly measured in instability studies.

Cosio-Lima et. al [6] evaluated the effects of sit-up and back extension exercises performed on a physioball or the floor on static balance in female college students (23 ± 5.80 years). After training five days a week for five weeks, single-leg static balance significantly improved in the physioball group by a mean of 10.73 seconds in the unliteral stance with both eyes closed and by a mean of 9.13 seconds in the unilateral stance with both eyes closed and knees flexed to 60 degrees. During these training sessions participants performed the exercises with their trunk on the physioball and feet touching the stable ground. Likewise, the participants had their foot in contact with the stable floor during single-leg static balance testing. In this earlier study the specificity of the training environment carried over to the testing environment, whereas in our study, the training and testing environments were not directly aligned, potentially masking any training effects. The lack of balance transfer is supported by research conducted on healthy young adults (25 ± 4 years) that specifically aimed to identify task-specific training effects and found no improvements across four different balance tests, concluding that the effects of balance training are highly specific [23].

4.4. Study Limitations

The current study shows improvements in dynamic balance and core endurance in college-aged females following 6-weeks of a SuT exercise program. However, there are a few study limitations to be addressed. The first limitation is that this is a homogeneous sample, thus caution is advised when extrapolating results to other groups where variables such as age, sex, and the presence of health conditions differ. Secondly, while the TRX group was asked to only use the intervention program as their weekly exercise and the CON group was asked to maintain usual exercise, but participant physical activity was not recorded. Therefore, the potential influence of outside physical activity is unaccounted for. Lastly, data for this study was collected across multiple years (2019 - 2021) because data collection was significantly disrupted by the emergence of COVID-19. Post-testing data was collected for the TRX group. However, several CON participants were unable to be scheduled in a timely manner, accounting for the disparity in the number of TRX and CON participants.

5. Conclusions

A plethora of research has suggested instability training to be beneficial in enhancing balance, core strength, and core endurance due to neuromuscular adaptations. Following this trend, the current study demonstrates significant improvements in dynamic balance and core endurance in healthy college-aged females after the completion of a short-term interval-style SuT exercise program. Additionally, our prior work [1] observed significant improvements in body composition, muscular fitness, cardiorespiratory fitness, and flexibility in female participants following the same SuT exercise program protocol. Therefore, it is suggested that SuT exercise programs may be superior to other resistance training programs since SuT not only improves many measures of fitness, but also improves measures of functional performance such as dynamic balance and core endurance. For this reason, it may be advantageous to market this type of resistance training modality to college-aged females to promote health, as this population has been observed to participate in less resistance training than their male counterparts [24].

Further work is necessary to determine the extent that these results can be extrapolated to other demographic populations. Thus, future research directions include evaluating the effects of the same SuT exercise program when performed at home, with a middle-aged or elderly population, when the dose response is adjusted, and when balance and core assessments are changed.

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