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Impact of Core Stability Exercises Combined with Proprioceptive Training on Postural Stability in Obese Adult Females: A Randomized Controlled Trial

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ABSTRACT

Background: Obesity may change body alignment, and the buildup of adipose tissue impairs balance and interferes with daily activities. **Purpose:** To investigate the improvement of postural stability in response to core stability exercises and proprioceptive training in obese adult females. **Methods:** A randomized controlled trial was conducted with fifty-four obese adult females who participated and were randomly distributed into three groups: group A engaged in a core stability exercise and proprioceptive training program in addition to a caloric restriction diet; group B engaged in a proprioceptive training program and caloric restriction diet, while group C engaged in a core stability exercise program and caloric restriction diet. The intervention duration for all groups was 12 weeks. Outcome measures included deviations for static balance using the Sensamove Sensbalance MiniBoard, the percentage of maximum reach distance, the composite score of the modified star excursion balance test for dynamic balance, body mass index, and waist-hip ratio. **Results:** After treatment, statistically significant improvements were noted in the composite mean values and maximum reach distance in all groups compared to before treatment ($p < 0.05$). A statistically significant improvement was observed in all static balance indices ($p < 0.05$) in group A, while in groups B and C, there was clinical improvement in the mean value of all indices, with a statistically significant difference only for the front deviation. **Conclusion:** Combined core stability and proprioception training exercises demonstrated a statistically significant impact on postural stability, with more remarkable clinical improvement than each exercise alone in obese adult females.

Key words: Postural Balance, Obesity, Exercise Therapy, Proprioception, Core Stability

INTRODUCTION

Obesity is a complicated chronic illness that shortens the lifespan, damages health, and raises the risk of long-term health problems (Wharton et al., 2020). Based on the World Health Organization, 39% of adults over the age of 18 are overweight, and 13% are obese (Şavkin & Aslan, 2017). Obesity affects more than 40% of reproductive-aged females (Schon et al., 2024). A high body mass index (BMI) is associated with higher postural sway, and obesity reduces postural and balance control because it affects joint proprioception. So, body weight is an important indicator of postural balance (Alice et al., 2022).

Postural stability is a complicated physiological process comprising the interaction of motor responses, sensory inputs, and central nervous system (CNS) functions (Carini et al., 2017). To perform daily functional skills, including standing, walking, sprinting, and reaching, postural stability precisely controls the alignment and balance of the body (Omofuma et al., 2023). Exercises that strengthen the relevant muscles, improve postural stability, and train the sensorimotor system are necessary for enhancing body balance (Karakaya et al., 2015). According to earlier research, participants' static balance can be improved with proprioceptive training, and their dynamic balance can be improved with core stability exercises (Karakaya et al., 2015). In integrated kinetic chain activities, core stability refers to the capability to regulate the trunk's movement and position over the pelvis and legs, enabling the best

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possible force and motion production, transfer, and control to the terminal segment. By testing trunk stability and postural control, core stability exercises can activate particular trunk muscle motor patterns (Szafraniec et al., 2018). Weak core muscles are frequently shown to cause balance problems; hence, it's critical to strengthen the core muscles through various training programs (Ardakani et al., 2020). Stability and coordination, motor learning stimulation, maintaining good posture and balance, and enhancing bodily control depend on appropriate proprioceptive training (Han et al., 2016). Proprioceptive exercises can enhance the body balance controller's ability to adjust to environmental changes, particularly the effector, central processing, and sensory information system (Rejeki et al., 2018).

Among the numerous factors that could influence the maintenance of postural balance is body weight, which is suggested to be a strong predictor for body balance, and being obese is considered a potential contributing factor for falling (Ostolin et al., 2020). Young adults (18–25 years old) are prone to overweight and obesity during the transition from adolescence to adulthood in developing and developed countries. Levels of overweight and obesity, together with other cardiovascular risk factors, increase with age, even within this age span (Poobalan & Aucott, 2016). A proper posture and a strong core structure are crucial for balance. Core stability allows the individual to stay in balance and helps maintain it (Szafraniec et al., 2018). Wang et al. (2008) showed a relationship between obesity and proprioception deficit. Appropriate proprioceptive training is important for maintaining proper body posture and balance and improves body control (Ferlinc et al., 2019).

Study Problem and Rationale

Excess adipose tissue in obesity affects postural stability by changing body alignment, impairing balance, and raising the risk of falls. Prior studies have examined the effects of proprioceptive training and core stability exercises independently on dynamic balance (Roşu & Cordun, 2022; Beydagı & Talu, 2021; Szafraniec et al., 2018; Shah & Varghese, 2014) and static balance (Karakaya et al., 2015; Yee et al., 2023; Imai et al., 2014; Kaji et al., 2010). Researchers have examined how proprioceptive training and core stability work together to improve dynamic (Barnes et al., 2014) and static (Markovic et al., 2015; Chikkale & Joshi, 2022) postural stability. However, obese adult females were not included in these investigations because they were done on distinct populations. To the best of our knowledge, no research has explicitly examined how proprioceptive training and core stability exercises affect postural stability in obese adult females. Given the rising incidence of obesity and the resulting balance impairments, this study aims to ascertain if combining these two exercise regimens leads to more notable gains in postural stability than utilizing them separately.

METHODS

Study Design, Trial Registration, and Ethics

It was a randomized pre-post-test control trial between March 2024 and June 2024. The trial was registered at the Pan African Clinical Trial Registry following WHO and ICMJE standards (PACTR202403583803304). The institutional review board at the Faculty of Physical Therapy, Cairo University (No. P.T.REC/012/004956), accepted it.

The Sample Size Power Analysis

As stated in Akbari et al. (2014), the stability index was used with 80% power at the $\alpha = 0.05$ level, two measurements for three groups, and an effect size of 0.438. Utilizing Cohen, J. (1988), the F-test MANOVA repeated measures within and between interactions. There should be a minimum of 54 participants, with 18 participants in each group. The sample size was determined via the G*Power software (version 3.0.10).

Participants

Fifty-four obese adult females were recruited from the Faculty of Physical Therapy, "Kafr Elsheikh University," in Kafr Elsheikh Governorate, Egypt, to participate in this research. They were aged between 18 and 24, and their BMI varied from 24.9 to 34.9 kg/m². Females were excluded if they had neuromuscular or neurological diseases, visual disability, a history of vestibular disease, diabetic peripheral neuropathy, musculoskeletal disorders, systemic disease, a history of orthopedic or neurological surgeries, or endocrinal disorders (Sweta & Solanki, 2021).

Participants were randomly assigned into three groups: group A ($n = 18$) engaged in a core stability exercise and proprioceptive training program in addition to a caloric restriction diet; group B ($n = 18$) engaged in a proprioceptive training program and caloric restriction diet, while group C ($n = 18$) engaged in a core stability exercise program and caloric restriction diet. All groups underwent the intervention for 12 weeks.

Procedures

An online randomization application (http://www.randomizer.org/) was used to randomly assign all participating women to one of the three groups (ratio 1:1:1): group A (n = 18), group B (n = 18), and group C (n = 18). A researcher with no clinical role in this study created cautiously numbered index cards containing random group assignments based on the generated random numbers. This ensured that the allocations were concealed; the index cards were wrapped and then placed in sealed envelopes that were concealed from both groups. After that, the first author, who was delivering the interventions, first opened each envelope before grouping the participants based on the index card that had been chosen. The participants' group assignments were hidden from them. Following randomization, no participants withdrew (Fig. 1).

Outcome Measures

They were taken at baseline and after a 12-week intervention.

Primary Outcome Measures

1. Static postural stability:
   It was evaluated using the Sensbalance Mini board (Sensamove, Netherlands). It is a valid and reliable tool for assessing static postural balance (SINDHI & Saxena, 2023; Larsen et al., 2018). The participant stood for 30 seconds on both legs with feet about 15 cm apart on an instrumented wobble board and was motivated to follow the on-screen instructions. The board saves the participant data in the program and creates a database of them. It provides stability indices (front average deviation, back average deviation, right average deviation, and left average deviation).
2. Dynamic postural stability:
   The modified Star Excursion Balance Test (mSEBT), a valid and reliable method for assessing dynamic postural balance, was used to evaluate dynamic postural stability (Haqiyah et al., 2021). The participant stood in the star's center, keeping a single-leg stance. The unsupported leg must lightly touch each marked line for one second, moving clockwise for the unsupported right leg and counterclockwise for the unsupported left. Three full attempts were allowed, with a three-minute break in between. The average of the three tries was the distance traveled in each direction. The percentage maximized reach distance (%MAXD) was used to equalize all reach distances. The measurement can be calculated using the formula [%MAXD = (reach distance/LL) x 100]. For every participant, the limb length (LL) was measured from the medial malleolus of each extremity to the anterior superior iliac spine. For each lower extremity, the overall score was computed as the average of the three reach distances [Comp = (ANT + PM + PL)/(3 x LL)) x 100] (Noviana et al., 2022). Excellent reliability estimates have been reported for mSEBT (ICC from.87 to.93) (Picot et al., 2021) (see Figure 2**).**

Secondary Outcome Measures

Weight, BMI, and waist-hip ratio were measured as secondary measures before and after the treatment program (twelve weeks). Weight was measured while the participant was standing upright in the middle of the weighing machine, with

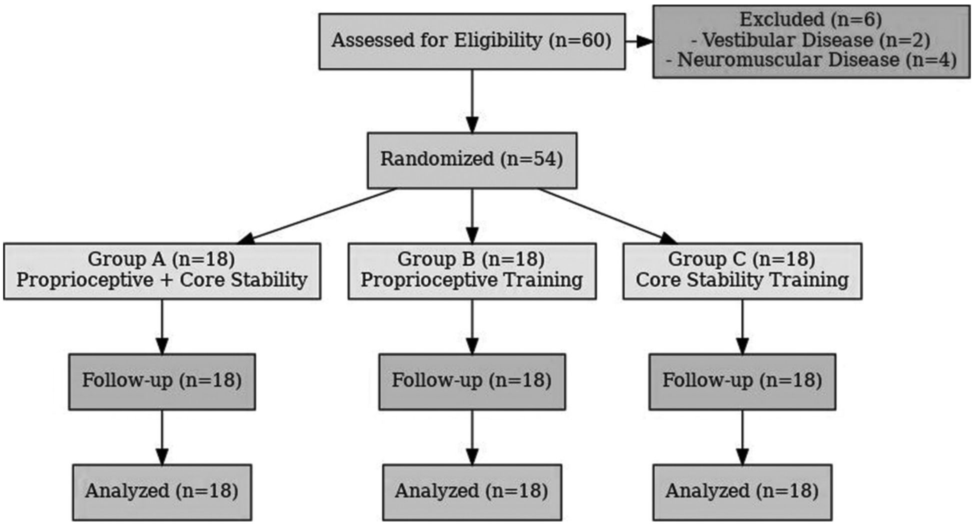

Figure 1. Flow chart of the study

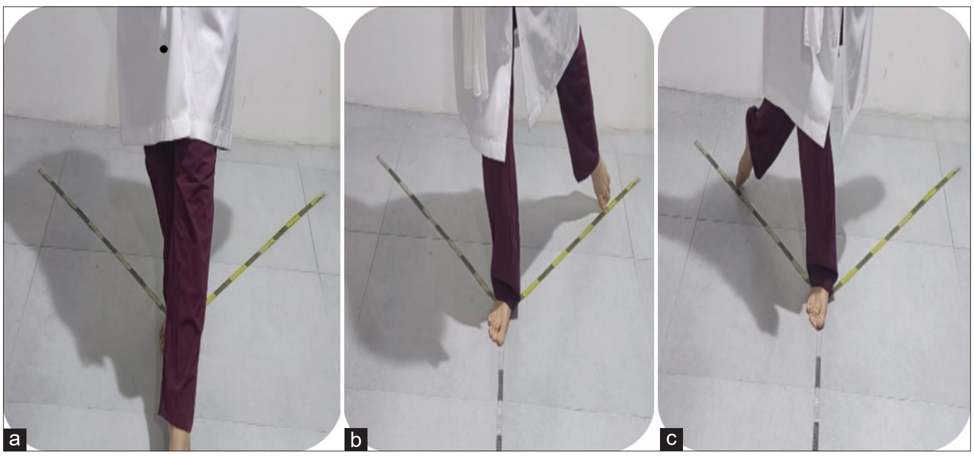

Figure 2. mSEBT for the right leg (a) anterior direction, (b) posteromedial direction, (c) posterolateral direction)

the body evenly spaced between the feet, without shoes, and wearing light clothing. A participant's height was measured while standing barefoot on a level surface with the line of vision aligned with their body. BMI was computed as follows: weight (kg/m^2) (Bertin et al., 2021). According to WHO recommendations, utilizing a stretch-resistant tape, the waist circumference was taken halfway between the lower edge of the least palpable rib and the uppermost of the iliac crest; the hip circumference was taken in the standing position over the widest area of the gluteal and greater trochanteric regions (Kałużna et al., 2021).

INTERVENTION

Proprioceptive Training Program

Each participant in groups A and B engaged in proprioceptive training exercises. Fourteen main exercises, on and off the balancing board, with modifications on every exercise, made up the training regimen (Table 1). The program included four exercises: (1) one without any materials, (2) one with a ball alone, (3) one with a balancing board alone, and (4) one with a ball and a balancing board. All four recommended exercises had comparable difficulty and intensity levels each week, gradually increasing throughout the 12 weeks (Table 1). Each session commences with a focused 5-minute warm-up designed to prepare the body for movement. During this crucial phase, the therapist thoughtfully selects from one of four dynamic exercise modalities: the first involves no additional materials, the second incorporates a ball to challenge coordination, the third utilizes a balancing board to enhance stability, and the fourth combines both tools for a comprehensive workout. Each modality is specifically aimed at stimulating and strengthening both ankles, thereby enriching proprioceptive input and promoting better body awareness (McGowan et al., 2015). The therapist selects one of the four recommended exercises to perform during each warm-up that targets both ankles to enhance proprioceptive input. The main training session lasts 20–25 minutes and is conducted three times per week over 12 weeks. Once an exercise is used in a week, it is not repeated. At the end of the session, a cool-down period follows, consisting of light stretching and 5 minutes of slow walking to gradually lower heart rate and aid recovery (Sadeghi et al., 2021; Verhagen et al., 2004).

Core Stability Exercises

Each participant of groups A and C engaged in core stability exercises. For 12 weeks, there were 24 sessions of 45 minutes each, held twice a week. We followed the same procedure as de Oliveira (De Oliveira et al., 2021). Participants warmed up by walking for four to five minutes in a straight circuit of thirty meters. Then they performed five exercises: Supine bridge: Raise hips to make a straight line between your shoulders and knees while lying down with your feet flat on the ground and your knees bent around 90 degrees, holding position for 10 sec., 10 repetitions (reps). Curl up: Place hands under the lower back, flatten it, bend one leg, draw the abdominal muscles in, and raise the head, neck, and shoulders, holding the position for 10 sec., 10 reps on each side. Side bridge (lateral plank): Lift the trunk to form a straight line between the shoulders and feet while side-lying with the upper body resting on the forearm and the elbow flexed to 90 degrees, holding a position for 10 sec., 10 reps on each side. Ventral Plank: Lift your body to make a straight line between your shoulders and feet while prone on your elbows, holding position for 10 sec., 10 reps. Anti-rotation trunk exercise (bird dog): With a neutral spine position, quadruped, capable of performing unilateral arm and leg lifts before progressing on to simultaneous opposite arm and leg raises, holding position for 10 sec., 10 reps on each side.

Caloric Restriction Diet

Every individual in every group followed a 12-week calorie-restricted diet. This dietary strategy involves reducing the average daily caloric consumption by 15–40% without impairing vital nutrients or causing malnutrition (Tacad et al., 22). The Harris-Benedict Equation, which states that overall daily energy expenditure (TDEE) = basal metabolic rate (BMR) x activity factor, was first utilized to calculate the overall daily calorie consumption needed for maintaining each participant's body weight. BMR is 447.593 + (9.247 x kg of weight) + (3.098 x cm of height) - (4.330 x years of age). According to the Harris-Benedict Equation, the activity factor is 1.2, as the study participants had a low level of exercise (Eckerson, 2018). Following that, we created a diet plan based on the Food and Nutrition Board's Institute of Medicine recommendation that adults should consume between 45% and 65% of their calories from carbohydrates, 20% to 35% from fat, and 10% to 35% from protein (Trumbo et al., 2002). Then, over 12 weeks, the overall caloric intake was gradually reduced by 15–40%.

Statistical Analysis and Normality Test

The data was examined for the presence of extreme values, homogeneity of variance, and the assumption of normalcy. The Shapiro-Wilk test was used to determine whether all of the measured variables were normally distributed because it revealed that they were. The Shapiro-Wilk test was used over the Kolmogorov-Smirnov test since the sample size was $n < 50$. All variables had a normal distribution, according to the results ($p > 0.05$). After performing Levene's test for equality of variances, it was determined that the homogeneity of variance assumption was satisfied ($p > 0.05$). The homogeneity of variance-covariance matrices was evaluated using Box's M test, and the findings showed that the assumption was met ($p > 0.001$). For statistical analysis, SPSS for Windows, version 20 (SPSS, Inc., Chicago, IL), was used. 0.05 is the alpha threshold.

RESULTS

Demographic Data for Subjects

As represented in Table 2, no significant changes were detected across the three groups in the mean values of age, weight, and height ($p = 0.950$, 0.519, and 0.223).

Table 1. Proprioceptive training program

No material	Ball	Balance board	Ball & balance board
Exercise 1 Standing on one leg with the knee bent. Maintain your balance for five seconds while stepping out on the opposite leg with the knee bent. Do this ten times for both limbs. Variations 1 2 3 4	Exercise 3 Form pairs. Both assume a one-legged stance with their knees bent. Maintain a 5-meter distance. Keep your balance while throwing and/or catching a ball five times. Do this ten times for both limbs. Variations 1 2	Exercise 5 Standing on one leg with the knee bent on the balancing board. After 30 seconds of maintaining your balance, switch up your stance leg. Do this twice for both limbs. Variations 1 2 3 4	Exercise 7 Form pairs. One stands on the balancing board with both feet. Balance yourself while throwing and/or catching a ball 10 times with one hand. Do this two times for both players on the balancing board.
Exercise 2 Standing on one leg, knee and hip bent. Maintain your balance for five seconds while stepping out on the opposite leg with the hip and knee bent. Do this ten times for both limbs. Variations 1 2 3 4	Exercise 4 Form pairs. With both hips and knees bent, assume a one-legged position. Maintain a 5-meter distance. Keep your balance while throwing and/or catching a ball five times. Do this ten times for both limbs. Variations 1 2	Exercise 6 Standing on one leg with the hips and knees bent on the balancing board. After 30 seconds of maintaining balance, switch up your stance leg. Repeat two times for both limbs. Variations 1 2 3 4	Exercise 8 Form pairs. On the balance board, one player stands in a one-legged stance with their knee bent, while the other player is standing in the same place on the ground. Balance yourself while throwing and/or catching a ball 10 times with one hand. For both limbs and both players on the balancing board, repeat twice. Variations 1 2
Variations on basic exercises: 1. The limb is extended. 2. The standing limb is bent. 3. An extended standing limb with closed eyes 4. A bent, standing limb with closed eyes 5. An extended standing limb and upper hand approach. 6. A bent standing limb and upper hand approach. 7. An extended standing limb, and the lower hand approach. 8. A flexed standing limb and lower hand approach.		Exercise 10 With one foot on the balance board, take a slow step over it. During the stepping over, keep the balance board horizontal. Do this ten times for both limbs.	Exercise 9 Form pairs. On the balance board, one player assumes a one-legged stance with their hips and knees bent, while the other player stands in the same place on the ground. Using one hand, throw and/or catch a ball ten times while staying balanced. For both limbs and both players on the balancing board, repeat twice. Variations 1 2
		Exercise 11 On the balance board, place both feet. Ten knee flexions should be made while staying balanced.	Exercise 13 Form pairs. With both feet on the balancing board, one stands. Ten times, while maintaining your balance, play the ball using an upper-hand approach. For both limbs and both players on the balancing board, repeat twice. Variations 5 6 7 8
		Exercise 12 With a single-legged stance and a flexed knee, perform ten knee flexions while keeping your balance. Do this twice for both limbs.	Exercise 14 Form pairs. On the balance board, one player stands in a one-legged stance with their knee bent, while the other stands in the same position on the ground. Using an upper-hand technique, play the ball ten times while staying balanced. For both limbs and both players on the balancing board, repeat twice. Variations 5 6 7 8

Table 2. Demographic data of subjects in the three groups

Demographic data	Group A (n=18)	Group B (n=18)	Group C (n=18)	p-value
Age (years)	20.7±1.7	20.7±1.8	20.9±1.9	0.950
Weight (kg)	78.6±6.7	77.1±8.3	80.3±9.4	0.519
Height (cm)	160.9±6.6	163.6±6.7	160.1±5.0	0.223

Data was represented as mean±SD, P-value

Impact of Treatments on Postural Stability

1. Static postural stability
   A statistically significant improvement was detected in all static postural stability indices ($p < 0.05$) in group A, while in groups B and C, there was clinical improvement in the mean value of all indices with only a statistically significant difference for the front deviation (Table 3). Nevertheless, the findings of the one-way MANOVA showed that there was no discernible overall impact of the treatment on postural stability:
   $F(1, 75) = 1.079$, partial $\eta^2 = 0.014$, $p = 0.302$.

Dynamic Postural Stability

In all groups, statistically significant improvements were noted in the composite mean values and (%MAXD) compared to before treatment ($p < 0.05$) with non-significant change in between-group comparison after treatment ($p > 0.05$) as illustrated in Table 4.

Efficacy of Treatments of the Anthropometric Measures

There was a statistically significant decrease in BMI in the three groups ($p = 0.001$). Regarding the waist-hip ratio, there was no statistically significant change in the three groups ($p > 0.05$). By comparing all groups, there was no significant difference in the mean values across the three groups pre- and post-study ($p > 0.05$) (Table 5).

DISCUSSION

This study aimed to identify whether combining core stability and proprioception training exercises would result in greater benefits on postural stability in obese adult females compared to each exercise alone. Results indicate that significant improvement was detected in all static postural stability indices in group A, while in groups B and C, there was clinical improvement in the mean value of all indices, with only a statistically significant difference for the front deviation. In all groups, statistically significant improvements were noted in the composite mean values and (%MAXD) compared to before treatment, with a non-significant change in between-group comparison after treatment. There was a statistically significant decrease in BMI in the three groups. There was no statistically significant change in the three groups regarding the waist-hip ratio.

Regarding static postural stability, the findings of the assessment proved that there was a statistically significant

Table 3. A comparison between the before and after studies means values of static postural stability between and within groups

Static postural stability	Group A (n=18)	Group B (n=18)	Group C (n=18)	P-value[1]
Front average deviation				
Pre-study	1.64±0.8	1.49±0.7	1.48±0.8	0.801
Post-study	0.82±0.4	0.99±0.6	1.01±0.5	0.490
% of change	50%	34%	32%	
(P-value)	0.001*	0.010*	0.016*	
Back average deviation				
Pre-study	-2.38±1	-1.82±0.6	-1.96±1	0.205
Post-study	-1.44±0.5	-1.4±0.4	-1.55±0.5	0.684
% of change	39%	23%	21%	
P-value[2]	0.001*	0.077	0.085	
Left average deviation				
Pre-study	-1.47±0.5	-1.32±0.7	-1.36±0.7	0.773
Post-study	-0.87±0.4	-1±0.5	-1.13±0.5	0.335
% of change	41%	24%	17%	
(P-value)	0.001*	0.051	0.142	
Right average deviation				
Pre-study	1.83±0.6	1.73±0.8	1.5±0.5	0.316
Post-study	1.32±0.6	1.43±0.7	1.4±0.6	0.876
% of change	28%	17%	7%	
P-value[2]	0.004*	0.091	0.563	
Performance				
Pre-study	79.4±5.7	81.8±6.5	82.1±6.3	0.370
Post-study	86.6±4.6	84.1±6.3	84.8±5	0.356
% of change	9%	3%	3%	
P-value[2]	0.001*	0.103	0.057	

Data was represented as mean±SD, P-value[1]: significance value between groups, P-value[2]: significance value within group, *: significant

Table 4. Comparison between the before and after study mean values of % MAXD of both sides between and within groups

	Group A (*n*=18)	**Group B (*n*=18)**	**Group C (*n*=18)**	***P*-value[1]**
Percentage of maximum reach distance of right side				
Composite				
Pre-study	63.39±4.13	63.5±5.24	65.28±5.82	0.466
Post-study	72.5±5.64	71±7.36	69.61±5.84	0.398
% of change	14%	12%	7%	
(*P*-value)	0.001*	0.001*	0.001*	
Anterior				
Pre-study	64.4±3.99	64.83±5.64	64.61±5.56	0.974
Post-study	74.78±5.63	73.83±8.56	70.44±5.74	0.141
% of change	16%	14%	9%	
P-value[2]	0.001*	0.001*	0.001*	
Postero				
Pre-study	67±5.41	67.17±7.35	69.94±9.16	0.420
Post-study	74.94±4.77	72.33±7.22	73.22±8.6	0.532
% of change	12%	8%	5%	
(*P*-value)	0.001*	0.001*	0.008*	
Postero-lateral				
Pre-study	58.72±8.77	58.05±7.55	61.33±8.95	0.474
Post-study	68.22±11.16	66.61±10.38	64.83±9.13	0.615
% of change	16%	15%	6%	
P-value[2]	0.001*	0.001*	0.015*	
Percentage of maximum reach distance of left side				
Composite				
Pre-study	65.83±4.67	62.44±5.96	64.39±5.42	0.176
Post-study	73.89±5.51	69.5±7.6	69.61±5.82	0.072
% of change	12%	11%	8%	
(*P*-value)	0.001*	0.001*	0.001*	
Anterior				
Pre-study	65.39±7.11	66.22±6.22	66.83±5.93	0.927
Post-study	75.11±7.04	73.44±8.93	72.67±6.82	0.622
% of change	15%	11%	9%	
P-value[2]	0.001*	0.001*	0.001*	
Postero				
Pre-study	71.67±6.23	67.33±5.19	69.11±6.32	0.099
Post-study	79±7.28	74.44±7.79	73±8.38	0.065
% of change	10%	10.5%	6%	
(*P*-value)	0.001*	0.001*	0.002*	
Postero-lateral				
Pre-study	60.67±7.89	56.94±8.45	58.17±9.38	0.422
Post-study	67.78±7.14	61.67±8.45	63.94±7.76	0.069
% of change	12%	7%	10%	
P-value[2]	0.001*	0.001*	0.001*	

Data was represented as mean±SD, *P*-value[1]: significance value between groups, *P*-value[2]: significance value within group, *: significant

lowering in the mean value of the average deviation of all directions, and there was a statistically significant increase in the mean value of performance by 9% in group A. The improvement of the static balance may be explained by integrating core stability exercises with proprioceptive and balance exercises that could provide synergistic benefits, such as strengthening the core muscles and enhancing vestibular function, which results in improving balance (Gong et al.,

Table 5. Comparison between before and after study mean values of BMI and W/H ratio between and within groups

Measured variables	Group A (*n*=18)	Group B (*n*=18)	Group C (*n*=18)	*P*-value[1]
BMI				
Pre-study	30.4±2.6	29.2±2.4	31.3±2.9	0.071
Post-study	29.2±2.3	28.6±2.3	30.4±3	0.107
% of change	4%	2%	3%	
(*P*-value)	0.001*	0.001*	0.001*	
W/H ratio				
Pre-study	0.79±0.05	0.81±0.07	0.83±0.04	0.181
Post-study	0.78±0.04	0.8±0.07	0.82±0.04	0.167
% of change	1.3%	1.2%	1.2%	
P-value[2]	0.055	0.338	0.067	

SD: standard deviation, *: Significant: 0.001

2024). This is in agreement with many studies that proved that combining core stability exercise and proprioceptive training improves balance in adult students (Anjasmara et al., 2021), healthy older women (Markovic et al., 2015), and diabetic peripheral neuropathy patients (Chikkale & Joshi, 2022). Regarding groups B and C, despite there being no statistically significant change in the mean value of all stability indices except the front average deviation, there is clinical improvement in the mean value of all stability indices. The findings of group B are matched with much earlier research that indicated that intensive proprioceptive exercises improve the level of static balance and the parameters of postural sway in healthy individuals (7), female footballers (Göktepe & Günay, 2019), and adults with diabetic peripheral neuropathy (Song et al., 2011). Conversely, Yee et al. (2023) concluded that proprioceptive training couldn't improve the static balance of young competitive gymnasts; this may be attributed to the nature of participants who already have a high baseline level of static balance ability, which makes it difficult to achieve measurable improvements over a relatively short intervention period, as eight weeks may not have been sufficient for notable changes. The findings of group C are in line with the study that investigated the effects of 12 weeks (Imai et al., 2014), and 7 weeks (Carpes et al., 2007), as well as the immediate effect (Kaji et al., 2010) of core stability training on static balance. However, when Nasser and Lee investigated the relationship between female soccer players' performance and core stability and strength, they found no correlation (Nesser& Lee, 2009). They ascribed their findings to two potential causes core strength is not correlated with strength and athletic performance, or the tests used to evaluate core strength are not specific to strength and athletic performance.

Concerning dynamic postural stability, the current results indicated that all mSEBT outcome variables, which include the composite mean values and %MAXD in all reach directions for both limbs in the three groups, had statistically significant improvement. The combined benefits of proprioceptive training and core stability exercises are responsible for the notable increase in all outcome measures in group A. These activities enhance the strength and patterns of muscular activation in the local and global core muscles (Barnes et al., 2014). Proprioceptive exercises can enhance the ability of the central processing system, sensory information system, effector, and body balance controller to adjust to environmental changes (Rejeki et al., 2018). Additionally, it develops vestibular skills, which improves general balance and coordination (Karakaya et al., 2015). This is consistent with Rahim et al., (2020) findings that core stability and ankle proprioceptive exercises impacted overweight young adults' dynamic balance. In addition, Barnes et al., (2014) concluded that the combination of these exercises can be one of the modifications of the exercise for improving dynamic balance. In group B, the significant improvements in dynamic postural stability observed after the proprioceptive program agreed with many previous studies (Noviana et al., 2022; Roşu & Cordun, 2022). They concluded that proprioception training significantly impacted dynamic postural control. However, when comparing the dynamic balance characteristics in a single-leg stance posture pre- and post-proprioceptive exercise training, no statistically significant change was detected ($p > 0.05$) (Beydagı & Talu, 2021). This might be because they employed different measurement techniques for the assessment. For dynamic balance evaluation, they used the KorebalanceTM balance assessment and training apparatus (Korebalance Premier-19 Systems Inc., USA). The significant improvement in the core exercise group (C) is in agreement with Szafraniec et al., 2018 and Shah& Varghese, 2014, they found that the %MAXD results are improved after the core stability exercise. Moreover, improvement in dynamic balance during core stability training exercises was also observed in girls with scoliosis (Imai et al., 2014). However, this contrasts with Sato and Mokha's evaluation of dynamic postural control and performance following a core stabilization training program in competitive and recreational runners (Sato & Mokha, 2009). This could be because the participants only practiced for a short duration of six weeks.

Regarding the anthropometric measurements, there was more improvement in group A, which may be attributed to a combination of a caloric restriction diet with proprioceptive and core stability exercises. This agreed with Kulkarni and Shinde (Kulkarni & Shinde, 2020), who revealed that physical exercise, including core and balance exercises and multicomponent exercises combined with nutritional guidance programs and dietary intervention, was effective in BMI reduction.

Strengths and Limitations

The strengths of this study are a randomized controlled design and a calculated sample size that significantly enhance the validity, reliability, and applicability of the study outcomes and long-term duration training. The study has the limitations of the absence of the participant's long-term follow-up duration after the end of the program, the study was restricted to young adult females only, so it is suggested to be done on males and females with different ages to determine if specific age group benefits more from interventions. In addition, using subjective measures for dynamic stability assessment requires additional research to confirm these results using objective measures.

This study has the potential to enhance both theoretical knowledge and practical applications concerning the relationship between core and proprioceptive training and postural stability in obese adult females the study can empower women's health providers with the knowledge, tools, and confidence needed to effectively address the challenges related to obesity in female patients. The findings can serve as a valuable resource for healthcare providers, enabling them to develop informed exercise and rehabilitation recommendations specifically tailored for obese adult females, addressing their unique needs and promoting better health outcomes. Outcomes from the study can be used to educate patients about the importance of core strength and balance training and how such exercises can improve their overall stability and reduce risks associated with obesity. Understanding how core and proprioceptive training can improve stability may highlight its role in enhancing self-efficacy and mental well-being in obese women. The findings could inform the development of new theoretical frameworks for designing interventions aimed at improving balance and stability in specific populations. This may include a combination of different physical training, education, and psychological support.

CONCLUSION

The current study's results suggested that the combination of core stability and proprioception training exercises significantly affects postural stability with greater clinical improvement than each exercise alone in obese adult females. However, further research is needed with long-term follow-up durations of the participants after the end of the program to assess the sustainability of improvements and any secondary benefits.

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AUTHOR CONTRIBUTIONS

A.G.E., K.S.A., H.H.K., R.M.E. and A.M.B. conducted the idea, research design, data gathering, statistical analysis, and data interpretation. They collaborated to write, revise, and accept the final manuscript before publication.

ETHICAL APPROVAL

This trial was accepted by the institutional review board at the Faculty of Physical Therapy, Cairo University (No. P.T.REC/012/004956). It was registered at the Pan African Clinical Trial Registry following WHO and ICMJE standards (PACTR202403583803304).

DATA AVAILABILITY

The authors are willing to provide raw data supporting this work's findings upon request without unnecessary restrictions.

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