Delta University Scientific Journal
Journal home page: https://dusj.journals.ekb.eg

The Relation between Different body weights and Center of Pressure Displacement in adolescents during quiet standing: a review

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ABSTRACT

Background: Obesity, overweight, and underweight conditions, particularly during adolescence, present significant health challenges. While obesity is widely recognized as a public health crisis, underweight individuals also face health risks. Given the critical role of postural stability in maintaining equilibrium and preventing falls.

Purpose: This review aimed to illustrate the relation between different body weights and center of pressure deviations throughout the direction of displacement and sway length and average velocity and oscillatory swing.

Methods: The published researches that studied the relation between body weight and center of pressure since 1990 were assessed according to CONSORT checklist. Fair to good quality researches were included, while low quality researches were excluded.

Results: The reviewed studies consistently demonstrate a significant association between increased body weight and impaired postural stability. Obese individuals exhibited larger sway parameters, including increased COP displacement and velocity, compared to normal-weight individuals. This impairment was particularly evident in conditions requiring greater postural control, such as during quiet standing with eyes closed or on unstable surfaces.

Conclusion: Obesity has been shown to compromise postural stability, characterized by increased sway and decreased balance control. Addressing weight-related issues is essential for improving balance and reducing fall risk, particularly in obese individuals.

Keywords: *obesity, underweight, postural stability, center of pressure, sway*.

1. Introduction

Adolescent obesity is classified according to the World Health Organization (WHO) criteria for ages 5-19 years: obese as a BMI-for-age percentile ≥95th, and overweight as a body mass index (BMI)-for-age percentile between the 85th and 95th percentiles **(Lob-Corzilius, 2007)**. Underweight can be defined in several ways. It may refer to low weight for height, defined as a BMI <18.5, or a weight that is 15-20% below the typical weight for a person's age **(WHO, 1995)**.

Healthy and normal weight in adolescents is an urgent public concern reflecting socio-economic and political conditions, since it determines the future of the country, its intellectual, economic, scientific potentials. Age-and-sex growth charts developed by the U.S. Centers for Disease Control and Prevention (CDC) were used to categorize each adolescent normal weight into (BMI ≥5th and <85th percentile), **(NCHS\CDC, 2014).**

World Health Organization defines underweight as a BMI below the 5^{th} percentile for age and gender CDC growth chart. Thinness, as per WHO-BMI for age criteria is the condition where the Z scores for BMI for age fall below 2 standard deviations (SD) of normal values (**Khasnutdinova and Grjibovski, 2010).**

Postural control is any action or reaction to maintain, achieve or restore the balance in any static or dynamic posture. While Balance is the state of equilibrium whereby the summation of forces, acting on the body is zero **(Pollock et al., 2000).** Complex interactions of the sensory, motor, vestibular, and visual systems aiming to balance maintenance or movements or center of gravity displacements, which also trigger the balance correction causing the body weight distribution to both lower extremities in a way that does not cause fall (**Taube et al., 2006**).

Center of gravity (COG) is an important component during evaluating balance and posture stability. It is often measured with center of pressure (COP) because COG is hardly to be quantified. According to **Lafage et al., (2008)** the COG located at the midpoint of the base of support (BOS) of an individual ideal posture. COP excursion and velocity are indicators of control COG and are key factors for identifying proper posture and balance keeping up. COP excursion is defined by **Pineda et al., (2020)** as displacement in the anterior/posterior and medial/lateral directions within the base of support (perimeter around the feet).

Posturographic analysis is an equipment to quantitatively measure body sways during quiet erect posture or during the performance of different tasks in the standing position (**Şimşek and Şimşek, 2020).** Commonly divided into static posturographic analysis, when the individual is quiet erect posture during the testing procedure, and dynamic postrugraphic analysis, when a response to a disturbance applied on the individual during testing procedure. The most common posturographic measure used in the assessment of postural control is the COP. The COP is the point of application of the resultant from the vertical force's action on the support's surface. The equipment most often used to evaluate the COP is the force plate (**Freitas et al, 2005).**

Static posturography is one of these methods, which contributes to the assessment of postural stability in an accurate and objective way. This method uses a platform that registers the force of the feet pressure and moment of this pressure force for the standing person during the testing procedure. Based on the reading, the computer software of the platform calculates the center of pressure (COP) coordination, when the person is standing freely (**Samson and Crowe, 1996; Carpenter et al., 2001).**

2. Material and methods

2.1. Design of the study

Narrative review

2.2 Participants

The published researches that studied the relation between body weight and center of pressure since 1990 were assessed according to CONSORT checklist (APPINDIX I). Fair to good quality researches were included, while low quality researches were excluded.

2.3 Materials and methods

The reviewed literature in this article were originated from google scholar and bumped and Elsevier database. Twenty three research paper were illustrated with detailed explanation and analyzed as represented in table (1). Further more research papers were deliberated in discussion section.

Discussion

A positive correlation between postural instability and BMI was reported by **Greve et al., (2007)** who observed greater shifts in both lateral and anteroposterior directions by obese subjects in order to maintain stability. Increased Overall Body Weight leading to greater AP and ML shifts during stance.

There are at least two reasons why postural stability is influenced by obesity. The first reason is related to the contribution made by an altered body geometry in obese individuals. In the present study, pelvic anterior tilt was significantly higher in the obese group. The degree of pelvic tilt is associated with lumbar posture, because the lumbar spine is connected to the pelvis and an increased anterior pelvic tilt can lead to excessive lumbar extension **Levine and Whittle (1996)**. The increased anterior pelvic tilt in obese individuals might be caused by an alteration of body geometry due to increased abdominal fat.

Onyemaechi et al., (2016) reported that obese individuals had a significantly higher mean lumbar lordosis angle. To demonstrate the mechanism whereby upright standing balance is achieved, the human body is often compared with an inverted pendulum model **Gage et al., (2004),** and because anterior tilts increased by adipose tissue accumulation in the abdominal area, body COG is displaced forward at the ankle joint **Corbeil et al., (2001) and Berrigan et al., (2006)**, which means that obese individuals need to adopt a larger corrective ankle torque in order to counter a greater gravitational torque**. Corbeil et al., (2001)** also suggested that obese individuals with abnormal amounts of abdominal body fat may be at greater risk of falling than normal-weight individuals.

The second reason of the relationship between postural stability and increased body weight is the contribution made by foot mechanoreceptors to balance control. Several studies reported that obese individuals have a larger plantar contact area and greater mean pressure values **(Birtane and Tuna, 2004; Gravante et al., 2003)**. For example**, Hills et al., (2001)** showed significantly greater pressure in the heels, midfoot, and metatarsal head in obese individuals. These results are important because desensitization of mechanoreceptor.

Generally, balance control in ML direction occurs at the hip and trunk of the body while the pelvis generates ML motion in the lateral direction **(Shumway-Cook and Woollacott, 2007)**. When descending response of the body segment takes place, head movement will occur first, followed by trunk and hip movements. The data revealed that there was significant increase in ML sway for the obese **(Blaszczyk et al., 2007).**

Menegoni et al., (2009) did not notice significant differences between obese and normal-weight women in ML COP displacements. Due to the reduction in body weight**, (Cieślińska-Świder and Błaszczyk, 2019)** applied (physical activity training with 60%-70% from maximum HR) he did not notice the influence of therapy on the COP total velocities during standing, average speed and maximal velocity in obese women before and after weight loss.

Also, the was no statistical significant difference between obese and healthy male in (AP and ML And MV mean velocity during applying static balance test in OE conditions reported by **Menegoni et al., (2011).** Throughout the evaluation for obese, overweight, normal weight and underweight for 26 adult women after 30 second of quit standing trial there were statistical significant different between overweight and normal weight in mean velocity and this against our statistical result that was not significant between both groups normal and overweight average velocity **(Sibella et al., 2024)**.

Hue et al., (2007) estimated the contribution of body weight to postural stability in conditions of vision and no vision. With eyes open, body weight accounted for 52% of variance in balance stability. With eyes closed, the contribution of body weight was 54% of variance. The study noted a strong correlation between increased body weight and decreased postural stability, as evidenced by increased COP speed to maintain stability, decreased mean peak stability times and increased mean distance between stable positions

It is clarified that obese persons are less responsive to perturbation than normal weight subjects. One potential explanation for this decreased sensitivity is the increase in mean pressure that the mechanoreceptors – the body's sensory receptor Structural and functional declines of the somatosensory systems occur with increase in body weight and these changes are associated by postural stability. Several studies observed an increase in plantar contact areas and pressure levels in the heel, midfoot and metatarsal areas **(Fabris et al., 2006; Birtane and Tuna, 2004; Hills et al., 2001)**. It is possible that this constant and elevated pressure interferes with the function of the mechanoreceptors that is necessary to inform the body's response to oscillation. Whatever the mechanism, it seems likely that obese individuals are challenged in recovering balance once a postural perturbation occurs.

Mean COP displacement speed, and range values in A/P and M/L and speed were significantly reduced in obese and morbid obese groups after hypocaloric diet and post bariatric due to weight loss reported by **Handrigan et al., (2010).**

For underweight an observational study done with 75 subjects from both genders, between 18-23 years were included in this study the participant assigned to 3 groups based on BMI calculation equation. Group A-underweight, group B-normal and group C-obese assessment was performed for both eyes conditions opened and closed, found that the sway increased to a maximum in AP direction and minimum sway in ML direction with no statistical significance difference for underweight individuals in comparison to normal and this could be due to localized plantar flexor fatigue that cause impairment to postural control in underweight young adult as developed by **Tharani and Kamatchi (2019).**

It is reported in the underweight individuals, the deficient body mass could have influenced foot morphology, could led to the development of greater neuromuscular imbalances. It is clear that reduced position sense in underweight individuals may lead to increased risk for falls and serious injuries during everyday activities parameters **(Paschalis et al., 2013).**

Changes in body mass index affect decreasing throughout the evaluation for obese, overweight, normal weight and underweight for 26 adult women after 30 second of quit standing trial there were statistical significant different between underweight and normal weight in mean velocity and the other group also except between (obese and underweight) expressed that there were a statically difference between both groups normal and underweight in average velocity **(Sibella et al., 2024)**.

The ability of muscle tone which also affects the balance of the human body Muscle strength is one of the factors that affect balance. A person with an ideal BMI category has better muscle strength than a person with a non-ideal BMI category because his body fat composition is relatively low and his muscle composition is relatively high (**Handayani et al., 2022)**. This is what makes the ability to maintain postural balance is also better malnutrition can cause reduce muscle strength (**Intan et al., 2020)**.

So, it can be concluded that individuals with non-ideal BMI tend to experience a decrease in muscle strength. Weak muscle conditions will have an impact on a decrease in postural balance because of increasing average speed indicated to impaired postural control so that underweight have a higher cop average velocity due to (reduced proprioception, coordination, muscle mass and tone, and strength **(Handayani et al., 2022; Azi et al., 2020).**

Obese subjects showed a longer length and a larger area of sway than lean and overweight subjects produced a larger increase of sway in obese subjects than in lean and overweight subjects (This finding supports that obese subjects may be more dependent on vision to control balance. In addition, obese subjects uses their somatosensorial to control posture differently than lean and overweight subjects **(Cruz-Gómez et al., 2011).**

Limited mobility in obese individuals accelerates physiological repercussions through increased adipose burden and intramuscular fat, reducing muscle quality and tone. Indeed, increased sway length and sway velocity about a COP are presumed identifiers of at-risk populations **(Wearing et al., 2014)**.

A significant increase in sway parameters (circular area, ellipse area, and path length) were also observed in obese fallers. Traditionally, greater COP displacements have been linked with less stability and, consequently, increased fall risk. This implies the motor system was unable to adjust to the demands inherent in obesity during stance, resulting in diminished adaptability and stability. In this context, the increase in sway area and path length may be a result of impaired feedback control or impaired proprioception/vision/vestibular system leading to a reduced adaptive capacity of the postural system **(Pagnotti et al., 2020; Manor et al., 2010).**

Also evaluated the effect of obesity on mean peaks and mean distance. The mean peaks correspond to the time in which the COP is relatively stable and the mean distance corresponds to the distance between stability zones. Consequently, shorter mean peaks (time) and larger mean distance between peaks, as observed in obese individuals, indicate a more instable COP. The discriminative power of these two COP sway parameters is greater than those of other global parameters to distinguish among sensory and pathological conditions in the general framework of balance control **(Dutil et al., 2013).**

The study noted a strong correlation between increased body weight and decreased postural stability, as evidenced by increased COP speed to maintain stability, decreased mean peak stability times and increased mean distance between stable positions. Also cog velocity and total sway distance were significantly greater in the obese group confirmed by **(Son, 2016).**

As the increased mass affects the mechanical and sensorial systems involved in postural control, the central nervous system has to adapt its control actions to maintain balance. Sensory system input dramatically reduced the postural balance of high weight children compared to normal children. In addition to the system that might be less effective in over weight and obese children is the somatosensory system. The excessive pressure on these children's feet might alter the activity of the plantar cutaneous sensory receptors; this may reduce the sensory feedback required to coordinate the body's position and to maintain postural balance also poor postural balance in obese and overweight children may be associated with more frequent falls and with a higher risk of fractures **(Steinberg et al., 2018).**

Mean speed is often considered to represent an overall amount of activity necessary to maintain stability. Mean peak corresponds to time instants in which the ankle torque and the associated motor commands are relatively stable and mean distance represents the distance between one relative stable region to another one. With the increase of body weight, the peaks decreased and the distance between stable regions increased significantly **(Baratto et al., 2006).** Overweight and obese children have better stability parameters such as ellipse area, AP, ML, total path length than children with normal body weight **(Rusek et al., 2021; Rezaeipour, 2018)**.

A study conducted on female collages age between 20-25 y old to illustrate the relation between BMI for (obese, overweight, normal and underweight) and static balance in the result was significant negative moderate-to-strong correlation between BMI and postural balance for static balance with eyes open and closed eye on different surfaces during test (**Almurdi, 2024).**

Melzer and Oddsson, (2016) used stabilogram-diffusion analysis to evaluate underlying mechanisms of postural control characteristics of obese older adults. The higher short-term scaling exponent values indicated an increase in persistence, meaning that body sway tends to continue moving in an ongoing direction when open-loop control dominates. Moreover, an increase in transition displacement and transition time interval values indicated that closed-loop control began to dominate behavior at longer time intervals and at higher amplitudes of sway in the obese group compared to the normal weight group increased risk of fall **(Melzer and Oddsson, 2016).**

Also**, Cieślińska-Świder and Błaszczyk, (2019)** reported that total maxima velocity in ML and AP summation) before and after weight loss in obese group in obese woman the result was that there was no Statistical significant difference**.**

The presence of higher oscillations in obese individuals with respect to controls, two hypotheses are proposed by literature: 1) the reduction of plantar sensitivity due to the hyperactivation of the plantar mechanoreceptors for the continuous pressure of supporting the large mass; and 2) the presence of high mechanical request in obese subjects due to a whole body center of mass further away from the axis of rotation causing a greater gravitational torque the obese individuals present larger excursions of COP, which are characterized by the same velocity of oscillation if compared non obese (**Capodaglio et al., 2012).**

Obese elderly females showed that their COP swing velocity (oscillation maximum and minimum) was lower than the normal weight group. Reasons for improved stability along ML direction could be of anatomical changes in response to obesity, such as more limitation of range of movement in the lower limbs and torso to the side due increasing adiposity in lower part of the body (**Rezaeipour and Apanasenko, 2018).** Higher values of

BMI and body mass components correlated with a shorter path length in both pre-pubertal and adolescent children **(Rusek et al., 2021)**.

A lot of epidemiological studies suggesting that a low BMI is a risk factor of fall and instable posture due to excess sway of COP because it is thought that BMI could offer a skeletal loading, increases osseous mass and padding that guards from fractures during falls which could explain why underweight people center of pressure is higher oscillatory amplitude (**Hue et al., 2007).**

Conclusion:

Obesity is associated with impaired postural stability, characterized by increased postural sway and reduced balance control. These findings highlight the importance of addressing weight-related issues to improve postural stability and reduce the risk of falls, particularly in individuals with obesity. Future research should investigate the underlying mechanisms linking obesity to postural instability and explore targeted interventions to enhance balance control in this population.

Acknowledgements:

The authors thank for Dr. Amira H. Mohammed and Dr. Mohamed N. Al Khouli assistant professors at department of Physical Therapy for Pediatrics and its Surgeries, Faculty of Physical Therapy, Delta University for Science and Technology for their support in the conduction of this study.

Funding support

This research received no specific grant from any funding agency in the public, commercial, or medical for-profit sectors.

Conflict of Interest:

The Authors declare that there is no conflict of interest

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APPENDIX I

Modified CONSORT checklist

Section	Checklist item
Abstract	**A** Structured summary of trial design, methods, results, and conclusions
Introduction	**B** Scientific background
	C Objectives and/or hypotheses
Methods	**D** The intervention for each group, with sufficient detail
	E How and when the primary and secondary measures are evaluated
	F Statistical methods used to compare groups for primary and secondary outcomes
Results	**G** For each primary and secondary outcome, results for each group, and the estimated size of the effect and its precision
Discussion	**H** Trial limitations, addressing sources of potential bias, imprecision, and, if relevant, multiplicity of analyses
Other information	**I** Sources of funding and other support
	J Where the full trial protocol can be accessed

Table (1): Analysis of the reviewed articles

	Author	Aim of the Study:	Method	Result
1.	Melzer and Oddsson (2016)	To assess the effect of obesity on balance control mechanisms in older adults.	COP displacements along the AP and ML directions in eyes open and eyes closed conditions were used to characterize postural control in 22 obese (30—<35 kg/m2), 26 overweight (25—<30 kg/m2), and 18 normal weight subjects (18.5—<25 kg/m2).	Obese group subjects demonstrated significantly greater transition displacement, transition time interval, and short-term scaling exponent in the ML-direction compared with the normal weight group (eyes open and closed). In the AP-direction the obese group showed greater transition displacement (eyes open) and short-term scaling exponent (eyes open and closed). Average AP-COP and ML-COP ranges of COP sway were higher in the obese group compared with the normal weight group (eyes open and closed).
2.	Błaszczyk., et al (2009)	To determine the impact of excessive body weight on postural control	The COP motion during quiet stance and a range of forward voluntary COP displacements were studied in 100 obese, and 33 lean women. Characteristics of postural sway were acquired while the subjects were standing quiet on a force plate with eyes open (EO) and with eyes closed (EC). Their anterior range of COP voluntary displacements was assessed upon a range of maximal whole-body leanings which were directed forward.	A substantial reduction of postural sway was observed in all patients which had increased body weight. Main postural sway parameters i.e., the total path length as well as its directional components were negatively correlated with the body mass and body mass index (BMI). The range of a whole body voluntary forward leaning, did not exhibit any significant change in patients with an obesity grade of I and II. Such a deficit was, however, found in subjects with a body mass index above 40.
3.	Sibella., et al (2024)	To examine of postural stability in obese subjects in comparison to normal subjects using a biomechanical approach.	A total number of 26 women (mean age 32.5) divided into 4 subgroups in relation to BMI value (BMI: Body Mass Index defined as weight [kg] / height^2[m^2]): i) underweight, mean BMI 19.81; ii) normal weight, mean BMI 22.33; iii) overweight, 26.21 and iv) obese mean BMI 38.94 were assessed using an optoelectronic motion measurement system for: 1) Total excursion index during open eye condition minimum of the COP trajectory vs. time	Results show a strong correlation between pathological BMI values and increasing imbalance during quiet standing in both AP direction and ML direction, confirming that normal BMI range gives the highest stability to the subject.

		(Etot max (COP)-min (COP)); it is calculated for both AP and ML direction; 2) Mean excursion velocity (vm) were assessed	
4. Son , (2016**)**	To determine whether obesity is associated with less postural stability in young adults, and whether it is influenced by anterior pelvic tilt angle and sensory dysfunction.	COG velocity and total sway distance with eyes open or eyes closed on firm or foam floors were determined in 12 obese individuals and 12 individuals with normal weight.	On firm and foam floors with eyes closed, COG velocity and total sway distance were significantly greater in the obese group than in the normal-weight group. However, on firm and foam floors with eyes open, center of gravity velocity and total sway distance were not significantly different in the two groups.
5. Cruz-Gómez .,et al (2011)	To assess the influence of BMI group (lean/overweight/obese) and gender on the postural sway of adults and adolescents during quiet upright stance.	90 women and 90 men, aged 12 to 67 years old, MI (lean, overweight and obese). The COP during quiet upright stance was recorded using a force platform, during 4 conditions (eyes open/closed on hard/soft surface).	During recordings on hard surface, closing the eyes produced a larger increase of sway on obese subjects than on lean and overweight subjects, with a larger increase on the length and the area of sway. Although gender differences were found during the four sensory conditions, no interaction was observed between the BMI group and the gender.
6. Cieślińska-Świder, and Błaszczyk, (2019).	To determine the impact of body weight on quiet standing postural sway characteristics in young women	Compared spontaneous oscillations of the COP between 32 obese (BMI: 36.4 ± 5.2 kg/m2), and 26 normal-weight (BMI: 21.4 ±1.5 kg/m2) women and assessed the influence of obesity treatment and body weight reduction on postural sway. Trajectories of the COP were assessed while the subjects were standing quietly with eyes open (EO) and closed (EC). Both in the sagittal (AP) and frontal (ML) planes the sway range, average velocity, and maximal velocity of COP were calculated. Moreover, the total average and maximal velocities were computed.	The results indicate that young obese women in the habitual standing position are characterized by the destabilizing influence of mass in the sagittal plane only in the absence of a visual control. This effect is dominated by the stabilizing mass effect in the frontal plane, which affects overall postural stability when standing. The reduction of body mass enables a decrease in ML static stability, likely due to natural changes in the base of support while standing
7. Singh., et al (2009)	To examine the effects of obesity level, standing time and their interaction on postural sway	Ten extremely obese (BMI 4 40 kg/m2) and 10 non-obese (18.5 kg/m2 5 BMI 5 24.9 kg/m2) participants performed quiet upright standing on a	The results suggest that obesity may impair postural control and may be a risk factor of balance loss and falls, especially during prolonged physical work activities. The research findings are

	during a prolonged quiet upright standing task.	force plate for over 18 min. Eleven postural sway measures were computed for each 1-min time interval based on the center-of-pressure data from the force plate.	relevant to identifying and reducing risks of balance loss and falls in various work place settings for a wide variety of workers.
8. Hue., et al (2007)	To determine the contribution of body weight to predict balance stability	59 male subjects with BMI ranging from 17.4 to 63.8 kg/m2 was assessed using a force platform. The subjects were tested with and without vision. A stepwise multiple regression analysis was used to determine the independent effect of body weight, age, body height and foot length on balance stability (i.e., mean speed of the center of foot pressure). With vision, the stepwise multiple regression revealed that body weight accounted for 52% of the variance of balance stability. The final model explained 63% of the variance.	A decrease in balance stability is strongly correlated to an increase in body weight. This suggests that body weight may be an important risk factor for falling. Future studies should examine more closely the combined effect of aging and obesity on falling and injuries and the impact of obesity on the diverse range of activities of daily living
9. Emara and Amira, (2020)	To study the computerized dynamic posturography (CDP) static and dynamic tests among healthy adults according to their BMI classification (underweight/ normal weight/ overweight/ obese).	Control group: consisted of 15 adult persons with normal body weight with their BMI between 18.5 and 24.99 kg/m^2; Study group: was classified according to body mass index (BMI) into three subgroups: Subgroup (1) (underweight): consisted of 15 subjects with their BMI < 18.5 kg/m^2; Subgroup (2) (overweight): consisted of 15 subjects with their BMI between 25 and 29.99 kg/m$^{2;}$ Subgroup (3) (obese): consisted of 15 subjects with their BMI > 30 kg/m^2. The study included adult persons with normal hearing aged 18–60.	A significant difference between studied groups among the different scores recorded from sensory organization test and rhythmic weight shift test, which means the presence of an effect of increased body mass index on the different sensory systems required to maintain balance control and the motor strategy used to maintain balance. In obese elderly subjects, there was increased reliance on vestibular system to maintaining balance. With increasing BMI, there was decrease in visual dependence in maintaining balance.
10. Teasdale et al. 2007	To investigate the effect of weight loss on balance control in obese and morbid obese men.	Control (n = 16) BMI < 25kg; Obese (n = 14) BMI < 39.9 and Morbid Obese (n = 14) >40 kg	Obese groups significantly reduced COP speed with increasing weight loss

		-Assessment for Mean COP displacement speed, and RMS in A/P and M/L directions - Quiet stance eyes open/eyes closed (14 trials of 35 sec)	
11. Rezaeipour, (2018).	To evaluate the postural stability in a natural stance in overweight and obese men	A total number of 111 men categorized according to body mass index (BMI) into normal weight, overweight, and obese categories underwent a measurement of quiet standing with eyes open (EO) and with eyes closed (EC). Postural stability was assessed using a force platform. The average of COP velocity was assessed in the two directions.	In the AP direction under EO and EC conditions, obese men swayed significantly quicker than men with normal weight. In the ML direction under EO and EC conditions, a higher velocity of COP was seen in normal weight men than in obese men.
12. Handrigan et al. 2010	To investigate the Weight loss and muscular strength affect static balance control	Force (isometric knee extension) and balance control (center of pressure speed and range) were studied in three groups; normal weight (BMI o25 kg m2), obese (30 kg m2 BMI 40 kg m2) and excess obese (BMI 440 kg m2) Caucasian male individuals.	Result suggests, in overweight individuals, weight loss is more efficient at improving balance control than increasing, or even maintaining muscle strength. In these individuals, training programs aimed at improving balance control should primarily target weight loss
13. Riach and Starkes (1994).	To investigate the velocity of center of pressure excursions as an indicator of postural control systems in children	Children (n = 81) aged 4-13 years and adults (n = 26) stood quietly on a force plate to determine velocity of center of pressure of ground reaction forces.	The results show a distinct age-related change in postural velocity in both feet together and feet heel-to-toe stances (eyes open and eyes closed). The authors suggest a development from predominantly fast open-loop control (4-7 years) to closed-loop control at 8 years.
14. Bonnet et al., (2014)	To examine the contribution of body weight distribution and center of pressure location in the control of mediolateral stance	Investigating the mediolateral control of upright stance in 16 healthy, young adults. The model analyzed the body weight distribution and center of pressure location mechanisms under three stances width conditions (feet close, under standard condition, and apart). Our first objective was to discuss some methodological requirements to investigate the contribution of both mechanisms by means of two platforms	The result was important because this mechanism is known to be secondary, weaker than the body weight distribution mechanism to control mediolateral stance. In practical terms, these findings may explain why the mediolateral variability of center of pressure displacement was significantly higher in narrow stance but not lower in wide stance.

15. Simoneau and Teasdale (2015)	To study balance control impairment in obese individuals is caused by larger balance motor commands variability	To simulate body sway of normal weight, obese and morbid obese individuals, three different body model parameter sets were calculated according to participant's characteristics (weight: 71.1 7.9 kg, 101.5 14 kg and153.3 23.7 kg; height: 177 5.6 cm, 175 6.8 cm and174 6.1 cm; age: 38.6 9.4 years, 37.9 7.7 years and44.4 8.9 years, for control (n = 16), obese (n = 14) and morbid obese (n = 14) groups respectively). These data were taken from a previously published manuscript investigating the effect of weight loss on balance control in obese and morbidly obese Caucasian men. Participants stood barefoot on a force platform with feet together for 35 s (14 trials). Although participants performed 7 trials with their eyes closed (at 5 s a computer-generated tone indicated to close their eyes; only the last 30 s served for computing the COP displacement), only the data with eyes open are considered in the modeling approach.	Overall, this study revealed that faster COP speed observed in obese individuals is related to larger balance motor commands variability. As a result, to improve balance control in this population, it is suggested that the benefit of a balance control improvement training program aiming at increasing ankle muscles strength would have limited influence in the absence of weight loss. Following weight loss, the gravitational torque decreases. Therefore, the corrective torque amplitude is reduced as well leading to less variability in the balance motor commands. Future work needs to determine if obese individuals, in weight bearing position, have higher plantar sole mechanoreceptor threshold. This would allow assessing the contribution of sensory and motor variability to explain their larger COP speed compared to lean individuals.
16. Geldhof et al., (2006)	To study the static and dynamic standing balance: test-retest reliability and reference values in 9 to 10 year old children	Twenty children participated in the reproducibility study (mean age 10.1±0.7) including test and retest measurement with a one-week interval. The modified clinical test of sensory interaction on balance (mCTSIB) quantified children's static standing balance. The test for the limits of stability (LOS) measured dynamic standing balance. The study sample to determine reference values consisted of	The ICCs for inter-item reliability of the four sensory conditions of the mCTSIB showed fair to excellent reliability (ICCs between 0.62 and 0.80). The reproducibility between test and retest was non-significant for the condition 'firm surface with eyes closed' (ICC of 0.37), fair to good for the three other sensory conditions (ICCs between 0.59and 0.68), and excellent for the composite sway velocity (ICC of 0.77). For all LOS parameters, the significant ICCs showed fair to good reproducibility (ICCs between 0.44 and0.62), with the exception of the non-significant ICC for

		99 children (mean age 9.8±0.5).	the composite reaction time. The ICCs for the separate LOS parameters showed fair to good and excellent reliability for nine parameters (ICCs between 0.46 and 0.81), while 11 separate LOS scores did not demonstrate significant ICCs, girls performed better on all the composite balance parameters compared to boys, with the exception of reaction time and movement velocity. No differences were found on standing balance scores between 9 and 10 year olds.
17. Hasan et al., (1990)	The goal of this paper to study Effect Of Loss of Balance on Biomechanics Platform Measures of Sway: Influence Of Stance And a Method for Adjustment	This paper describes a method for adjusting biomechanics platform measures of sway for loss of balance. Area and velocity measures of sway were determined in forty-seven elderly women, in double and single leg stance, first with their eyes open, then closed. Subjects were rarely able to complete IO s trials during single leg stances. Therefore, a method was developed for eliminating data associated with loss of balance. Monitoring changes in vertical force and velocity by computer, those points exceeding trial specific thresholds associated with loss of balance were truncated.	This study shows the effect that losses of balance have on biomechanics platform measures of sway. We suggest that loss of balance data should be separated from stance data obtained from tasks, such as single balance is high. Such adjustments will render sway measures better suited for examining the changes in postural control that are associated with advanced Age
18. Innocenti, (2018)	To study correlations between static balance and body mass composition,	Forty-four participants, which were 23 obese (group OB) and 21 normal-weights (group CONT). The mean ± SD age, height and body mass of subject were between the normal-weight group and the obese group, respectively: 37.5 ± 15.9 and 45.2 ± 13.2 years, 21.2 ± 1.6 and 38.1 ± 4.4 BMI, 24.5 ± 5.2 and 46.7 ± 5.0 %Fat-mass. Open eye single standing test was assessed	This preliminary study shows that static balance capacity have significate differences between a normal-weight and an obese population. This study suggests investigating in general populations such as elderly and adolescents/children in both sexes.
19. Tharani and Kamatchi (2019)	To analyze the correlation between body weight and	This is an observational study done with 75 participants. Both male and female healthy	On comparing mean values of groups, A, B and C there was a positive association and strong correlation between body

	postural control in healthy individuals using sway meter	individuals between 18-23 years were included in this study. Individuals with any musculoskeletal injuries, neurological conditions, peripheral artery disease and pregnant women were excluded from the study. BMI of each participant was calculated and assigned into three groups. Group A-lean, group B-normal and group C-obese. Postural control was analyzed for each group by using sway meter; level of postural sway was compared between groups A, B & C	mass index and postural control with eye open and eye closed in anterior, posterior and postural sway towards left between the groups at ($P \leq 0.05$). However, there was a negative association and weak correlation between BMI and postural control with eye open & eye closed in postural sway towards right between the groups at ($P \geq 0.05$).
20. Paschalis et al., (2013).	To study the effects of eccentric exercise on muscle function and proprioception of individuals being overweight and underweight	Twelve lean, 12 overweight, and 8 underweight female participants performed an eccentric exercise session using the knee extensor muscles of the dominant leg. Muscle damage indices and proprioception were assessed up to 3 days post exercise	The results indicated that proprioception at baseline of the lean individuals was superior to that of the other 2 groups. The overweight individuals exhibited a smaller knee joint reaction angle to release than did the lean group, whereas the underweight individuals exhibited a larger reaction angle to release than did the lean group. After eccentric exercise, proprioception was affected more in the overweight and the underweight groups than in the lean group. The greater exercise-induced muscle damage appeared in the overweight group, and the deficient muscle mass of the underweight participants could explain in part the greater disturbances that appeared in proprioception in these 2 groups than for the lean counterparts.
21. Handayani et al., 2022	To study the relationship between body mass index and postural balance among student of the martial arts club malikussaleh university	The sample of this study used total sampling with 49 respondents. Data collection was carried out by measuring body weight, height, static balance with a standing stork test and dynamic balance with a modified bass test of dynamic balance. The results of this study obtained BMI with the highest proportion is normal category, with 31 people (63.3%), while the static	This study concludes that there is a relationship between BMI and postural balance among students of Martial Arts Club Malikussaleh University.

		balance commonly found in the very good category with 11 people (22.4%), and dynamic balance commonly found in the balanced category with 29 people (59.2 %)	
22. Pagnotti et al., 2020	To study postural stability in obese preoperative bariatric patients using static and dynamic evaluation	Traditional force plate measurements and stabilograms are gold standards employed when measuring center of pressure (COP) and postural sway. To quantify the extent of postural instability in subjects with obesity before bariatric surgery, we assessed 17 obese subjects with an average BMI of 40 kg/m2 in contrast to 13 nonobese subjects with an average BMI of 30 kg/m2. COP and postural sway were measured from static and dynamic tasks. Involuntary movements were measured when patients performed static stances, with eyes either opened or closed. Two additional voluntary movements were measured when subjects performed dynamic, upper torso tasks with eyes opened	Mean body weight was 85% ($p < 0.001$) greater in obese than nonobese subjects. Following static balance assessments, we observed greater sway displacement in the AP direction in obese subjects with eyes open (87%, $p < 0.002$) and eyes closed (76%, $p = 0.04$) versus nonobese subjects. Obese subjects also exhibited a higher COP velocity in static tests when subjects' eyes were open (47%, $p = 0.04$). Dynamic tests demonstrated no differences between groups in sway displacement in either direction; however, COP velocity in the ML direction was reduced (31%, $p < 0.02$) in obese subjects while voluntarily swaying in the AP direction, but increased in the same cohort when swaying in the ML direction (40%, $p < 0.04$)
23. Capodaglio et al., 2012).	To Investigate balance control and balance recovery in obesity	Platform stabilometry consists of the measurement of forces exerted against a platform during quiet stance. The force platform quantifies the body sways of an individual in a standing position. It is widely used in clinical settings to obtain functional markers on fine competencies and their development and a large number of posturographic measures are sensitive to testing condition (ie, eyes open vs eyes closed, feet position, and presence of external stimuli). Static posturography	the result concluded that high mechanical request in obese subjects due to a whole body center of mass further away from the axis of rotation causing a greater gravitational torque the obese individuals present larger excursions of COP, which are characterized by the same velocity of oscillation if compared non obese

		is user-friendly and typically in everyday practice focuses on the properties of the COP trajectory using time series (length, surface, maximal amplitude of the displacement, speed, and frequency analysis).	