Original Article

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Physiotherapy Section

Impact of Body Mass Index on Coordination, Static and Dynamic Balance in Young Adults: A Case-control Study

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ABSTRACT

Introduction: Abnormal Body Mass Index (BMI), characterised by a higher percentage of fat mass, has notable effects on postural control, leading to a forward shift in posture that exceeds the Base Of Support (BOS) boundary due to increased segmental mass and a compromised ability to regain stability after a disruption caused by excess adiposity.

Aim: To investigate the potential impact of BMI on the coordination, static balance and dynamic balance of young adults.

Materials and Methods: The present case-control study was conducted in the Department of Physiotherapy, School of Healthcare and Allied Sciences (SoHAS), G D Goenka University, Gurugram, Haryana, India from November 2023 to April 2024. Study was conducted among 90 subjects from the Delhi-NCR region, aged between 18 years and 30 years and including both genders, were recruited. They were categorised into three groups based on Asian Pacific BMI classifications: 29 subjects in the normal weight group (BMI 18.5-22.9 kg/m^2), 26 subjects in the overweight group (BMI 23-24.9 kg/m^2), and 35 subjects in the obese group (BMI >25 kg/m^2). Body composition, balance tests and coordination tests were assessed for all subjects. The p-value and F-values were calculated to assess group differences using the One-way Analysis of Variance (ANOVA) method, indicating significant results (p-value<0.01) for static and dynamic balance as well as coordination tests. Subsequently, post-hoc tests were conducted to explore specific differences among the groups.

Results: The mean ages of the normal weight, overweight and obese groups were 22.10±2.38 years, 21.77±2.90 years and 21.91±2.38 years, respectively. The mean BMI of the normal weight, overweight and obese groups were 20.23±1.30 kg/m^2, 23.99±0.68 kg/m^2 and 29.69±3.09 kg/m^2, respectively. The ANOVA single factor test showed a significant difference between the normal weight, overweight and obese groups in the Single Leg Standing (SLS) test with opened and closed eyes on each leg for static balance; in the Timed Up and Go (TUG) test for dynamic balance; and in sidewalking, tandem walking, and heel walking for coordination at p-value<0.05. The post-hoc test showed a significant difference in all the parameters for overweight and obese groups in comparison to the normal weight group at p-value<0.016.

Conclusion: Abnormal BMI affects both static and dynamic balance along with coordination in young adults. Therefore, preventive measures should be considered to normalize BMI to prevent coordination and balance issues in overweight and obese young adults.

Keywords: Base of support, Body composition, Motor skills, Obesity, Overweight

INTRODUCTION

Obesity is the disproportion between energy consumption and expenditure, leading to an abnormal accumulation of fat in the body [1]. Worldwide, 1.9 billion adults aged 18 years and older are identified as overweight with 650 million of them classified as obese [2]. Approximately 2.8 million deaths worldwide have been attributed to the consequences of overweight and obesity [3]. Body composition measures fat mass percentage and Fat-free Mass percentage (FFM%)-including water, bone, muscle, proteins and minerals and a Body Composition Analyser (BCA) machine uses Bio-electrical Impedance Analysis (BIA) to assess these metrics by measuring electrical impedance and calculating mass and water distribution, with changes indicating obesity and overweight [4]. Deviations in body composition affect BMI and Waist-hip Ratio (WHR), both of which are used to define body composition precisely, with BMI being a simple weight-for-height ratio commonly used to classify overweight and obesity in adults [5]. A sedentary lifestyle combined with high-fat and high-calorie dietary habits contributes to an increase in BMI [6].

A purposeful biophysical correlation of the Centre of Gravity (COG), Line of Gravity (LOG) and Base of Support (BOS) is required to maintain the safe functionality of daily life through efficient and integrated biomechanics of coordination, static and dynamic balance [7]. Coordination is characterised by accurate, smooth, rhythmical and purposeful body movement due to normal neuromuscular integration and the correction of movements by comparison with their respective engrammed patterns [8]. Differences in bodily characteristics are believed to affect an individual's ability to maintain postural stability. These variations may impact the motor strategies individuals use to maintain their balance while standing [9]. Abnormal fat accumulation surrounding the upper trunk and chest area causes reduced Total Lung Capacity (TLC) for the following reasons: abnormal inflationary and deflationary pressure on the lungs due to excess adipose tissue, and limited downward movement of the diaphragm due to unnecessary adipose tissue in the abdominal space [10]. Psychological problems such as lack of self-esteem, self-confidence, self-acceptance, depression and anxiety can also stem from obesity and its stigma in society, degrading the overall quality of life [11].

Research regarding the impact of BMI on coordination, as well as, static and dynamic balance, in the young adult population is currently limited. The present study was aimed to highlight the necessity of assessing deviations from the norm in body composition, and the outcomes will also aid in formulating proactive and remedial approaches to mitigate the detrimental effects of irregular body composition on coordination and balance.

The null hypothesis of the study asserts that there is no significant impact of BMI on coordination, static balance and dynamic balance in young adults. Conversely, the alternative hypothesis proposes that there is a significant impact of BMI on these factors. Thus, the present study was aimed to investigate how BMI influences coordination, static balance and dynamic balance among young adults.

MATERIALS AND METHODS

The present case-control study was conducted in the Department of Physiotherapy, School of Healthcare and Allied Sciences (SoHAS), G D Goenka University, Gurugram, Haryana, India from November 2023 to April 2024. After obtaining ethical clearance from the Institutional Ethics Committee (IEC) (IEC/MPTNEURO/35-36), subjects who met the inclusion and exclusion criteria were selected.

Sample size calculation: The sample size of 66 for the present study was calculated using G-Power 3.1.9.4 software, with a significance level of 5%, a power (1-beta) of 80% and an effect size of 0.4 across three groups. To account for a 20% dropout rate, the final sample size was adjusted to 80.

Inclusion criteria: Individuals aged 18-30 years, comprising both males and females across all groups were included in the study. For the normal weight group (control), participants had a BMI ranging from 18.5-22.9 kg/m^2. The overweight group (case) included individuals with a BMI of 22.9-24.9 kg/m^2, while the obese group (case) consisted of participants with a BMI exceeding 25 kg/m^2.

Exclusion criteria (for cases and controls): Participants in both the control and overweight/obese groups (cases) were excluded if they had any of the following: recent trauma (e.g., fractures, injuries to the upper or lower extremities, traumatic brain injury, or traumatic spinal cord injury), a history of neurological disorders (such as epilepsy, multiple sclerosis, etc.), psychological disorders (such as major depression, anxiety, etc.), congenital disorders (e.g., kyphosis, scoliosis, Marfan syndrome, etc.), recent surgical history, cardiovascular diseases (e.g., hypertension, coronary artery disease, etc.), systemic diseases (e.g., diabetes mellitus, chronic kidney disease, etc.), severe low back pain, disorders affecting special senses (e.g., vision or hearing impairments, etc.), or congenital/acquired lower limb deformities (e.g., flat feet or other lower limb deformities).

Study Procedure

The informed consent was obtained from all participants, who were thoroughly briefed about the procedure. The participants were categorised into three groups, ensuring that age and gender were matched, according to the Asian Pacific BMI classifications: 29 participants with normal weight (BMI 18.5-22.9 kg/m^2), 26 participants with overweight (BMI 23-24.9 kg/m^2), and 35 participants with obesity (BMI >25 kg/m^2). BMI was measured as BMI=weight (in kilograms) / height (in meters squared) [12].

Body composition, the Single Leg Standing (SLS) test, the Timed Up and Go (TUG) test, sidewalking, tandem walking and heel walking were used as outcome measures. A BCA machine was used for body composition measurement, and a floor marker was utilised for measuring the distance during the balance and coordination tests. The specified outcome measures were evaluated for all participants, and subsequently, data were collected, gathered, and analysed both manually and digitally to evaluate the effect of BMI on coordination, static balance, and dynamic balance in young adults.

The BCA machine (Tanita Corp., Tokyo, Japan), abbreviated as BCA, analysed body composition using the bioelectrical impedance analysis method to measure the bioelectrical impedance of various parts of the human body. It calculated the body composition through algorithms based on the difference in conductivity of different components of the human body. The BC-418 8-contact electrode system (Tanita Corp., Tokyo, Japan) took all measurements at 50 kHz and 0.8 mA sine wave constant current. A total of five segments were measured: each arm, each leg and the remainder (trunk and head), with the whole body measured as the foot-hand electrical pathway. Lean soft tissue and percentage of fat for each region were provided, and the percentage of fat of the whole body was based on foot-hand impedance measurement [13].

The SLS test was used to assess and evaluate static balance. In this test, the subject was instructed to stand on one leg for 30 seconds with a hand by the side of the trunk. This test was repeated the same way for the other leg, both with eyes open and closed. Three measurements for each side and each state were taken in seconds, and the best of the three was considered as the result. The TUG test was used to assess and evaluate dynamic balance. In this test, the subject was asked to get up from a standard chair, walk straight for 3 meters, return, and then sit back down in the same chair, all at maximum speed without running. Three measurements of this entire process were taken in seconds, and the best of the three was considered as the test result [14].

A total of three tests were used to evaluate coordination skills: sideways walking, tandem walking and heel walking. Each test was conducted over a distance of 10 meters, with the starting position of both hands placed on the Anterior Superior Iliac Spine (ASIS). The command given was 'Get Set Go,' and the walking was done at a comfortable speed. The total time was recorded, and three readings were taken, with the mean value of the three considered as the result.

For sideways walking, the subject was instructed to walk sideways by placing the governing leg into abduction and the subordinate leg into adduction. The medial line of both feet was to touch and remain in contact with each other. Both the step count and the total time taken were recorded.

For tandem walking, the subject was instructed to make contact between the toe of one foot and the heel of the preceding foot, walking straight in this manner. The same process was repeated with the rear foot placed in front of the front foot.

For heel walking, the subject was asked to walk on their heels while lifting the forefoot off the ground and pointing the toes outward. Initially, the subject was instructed to place the left foot ahead of the right foot, and the same repetition was done for the right foot [15].

STATISTICAL ANALYSIS

Data analysis was conducted using the Statistical Package for the Social Sciences (SPSS) software version 25.0 (International Business Machines (IBM), US. Descriptive statistics were employed to analyse and determine the mean and standard deviation of the demographic and anthropometric profiles, as well as, the outcome measures of the subjects. Each measure was normally distributed, as assessed by the Shapiro-Wilk test. The p-value and F-values were generated for group differences using the one-way ANOVA method. Post-hoc tests were utilised to evaluate the differences among specific groups, with significance set at p-value<0.016.

RESULTS

There were 29 subjects in normal weight group, 26 subjects in overweight group and 35 subjects in obese group. The demographic profile of the study participants, as shown in [Table/Fig-1], reveals that the mean ages of the normal weight, overweight and obese groups were 22.10±2.38 years, 21.77±2.90 years and 21.91±2.38 years, respectively. The mean heights of the normal weight, overweight and obese groups were 162.63±10.71 cm, 163.04±11.57 cm and 156.26±27.11 cm, respectively. The mean weights of the normal weight, overweight and obese groups were 53.90±8.33 kg, 64.25±9.14 kg and 77.16±13.01 kg, respectively. The mean BMI of the normal weight, overweight and obese groups were 20.23±1.30 kg/m^2, 23.99±0.68 kg/m^2 and 29.69±3.09 kg/m^2, respectively, as shown in [Table/Fig-1]. The data comprised nearly equal numbers of males and females across all three groups: the normal weight group included 16 males and 13 females, the overweight group had 14 males and 12 females, and the obese group consisted of 19 males and 16 females. The body composition of the study participants indicated that the mean fat mass of the normal, overweight and obese groups was 24.26±6.19%, 27.82±6.60%, and 32.83±6.96%, respectively, while the mean Fat-free Mass (FFM) of the normal, overweight and obese groups was 75.74±6.19%, 72.18±6.60% and 67.17±6.96%, respectively.

Parameters	Normal weight subjects (n=29) Mean±SD	Overweight subjects (n=26) Mean±SD	Obese subjects (n=35) Mean±SD	F-value	p-value
Age (in years)	22.10±2.38	21.77±2.9	21.91±2.38	0.10	0.90
Height (cm)	162.63± 10.71	163.04± 11.57	156.26± 27.11	1.27	0.28
Weight (kg)	53.90±8.33	64.25±9.14	77.16±13.01	38.61	<0.001*
BMI (kg/m²)	20.23±1.3	23.99±0.68	29.69±3.09	161.35	<0.001*
Fat-mass (%)	24.26±6.19	27.82±6.6	32.83±6.96	13.35	<0.001*
Fat-free Mass (FFM) (%)	75.74±6.19	72.18±6.6	67.17±6.963	13.55	<0.001*

[Table/Fig-1]: Demographic and anthropometric characteristics of study subjects in all three groups.
BMI: Body mass index; One-way ANOVA test; **Significant difference: p-value<0.01

The static and dynamic balance profiles of the study participants are illustrated in [Table/Fig-2]. The mean SLS test timing with open eyes on the left and right legs for the normal, overweight and obese groups were 28.86±3.85, 25.96±7.97 and 24.47±7.94 seconds, respectively. The mean SLS test timing with closed eyes on the right leg were 15.79±6.33, 10.65±4.24 and 6.69±4.65 seconds, respectively; the mean SLS test timing with closed eyes on the left leg were 17.93±6.19, 11.38±4.14 and 6.74±3.71 seconds, respectively. Lastly, the mean Timed Up and Go (TUG) test timing for the normal, overweight and obese groups were 9.07±1.39, 11.88±3.25 and 16.74±3.65 seconds, respectively.

Parameters	Normal weight subjects (n=29) Mean±SD	Overweight subjects (n=26) Mean±SD	Obese subjects (n=35) Mean±SD	F-value	p-value
Static balance tests (seconds)					
SLS with eyes open L and R	28.86±3.85	25.96±7.97	24.47±7.94	3.250	0.043*
SLS with eye closed on right leg	15.79±6.33	10.65±4.24	6.69±4.65	24.77	<0.001*
SLS with eye closed on left leg	17.93±6.19	11.38±4.14	6.74±3.71	43.93	<0.001*
Dynamic balance test (seconds)					
Timed Up and Go (TUG) test	9.07±1.39	11.88±3.25	16.74±3.65	54.66	<0.001*
Coordination tests (seconds)					
Sidewalking	32.17±4.79	39.54±4.81	44.86±8.60	29.74	<0.001*
Tandem walking	30±6.34	39.3±11.07	50.31±11.84	32.05	<0.001*
Heel walking	26±4.98	32.7±6.18	43.71±7.75	60.52	<0.001*

[Table/Fig-2]: Comparison between the groups for balance and coordination tests in subjects with different BMIs.
**Significant difference: p-value<0.01; *Significant difference: p-value<0.05; One-way ANOVA test

The coordination profile of the study subjects across all three groups shows that the mean timing for sidewalking for normal weight, overweight and obese individuals were 32.17±4.79 seconds, 39.54±4.81 seconds and 44.86±8.60 seconds, respectively. The mean timing for tandem walking for the normal, overweight and obese groups were 30±6.34 seconds, 39.30±11.07 seconds and 50.31±11.84 seconds, respectively. The mean timing for heel walking for normal weight, overweight and obese groups were 26±4.98 seconds, 32.70±6.18 seconds and 43.71±7.75 seconds, respectively.

The one-way ANOVA test indicated a significant difference in the static and dynamic balance of normal, overweight and obese subjects, with F-value=3.20, p-value=0.043 for the SLS test with open eyes on the left and right legs; F-value=24.77, p-value<0.001 for the SLS test with closed eyes on the right leg; F-value=43.93, p-value<0.001 for the SLS test with closed eyes on the left leg; and F-value=54.66, p-value<0.001 for the TUG test, with $F_{critical}$=3.101.

There was a significant difference in coordination among normal weight, overweight and obese subjects, with F-value=29.74; p-value<0.001 for sidewalking, F-value=32.05; p-value<0.001 for tandem walking, and F-value=60.52; p-value<0.001 for heel walking.

In the post-hoc analysis, the Bonferroni method was applied for multiple comparisons to adjust the alpha level, which was determined by dividing the original alpha level by the number of comparisons, resulting in 0.05/3 ≈ 0.016. The analysis of Single Leg Stance (SLS) with open eyes on the right and left legs showed significant differences between the normal and overweight groups, as well as between the obese and normal weight groups, with p-values <0.001. These results are significant given the Bonferroni-adjusted alpha level of 0.016. However, there was no significant difference between the overweight and obese groups [Table/Fig-3].

The post-hoc analysis for SLS with closed eyes on the right leg revealed significant differences between normal and overweight (p-value<0.001), overweight and obese (p-value=0.001), and obese and normal weight (p-value<0.001). For the left leg, significant differences were observed among the normal weight, overweight and obese groups, all with p-value<0.001.

The Timed Up and Go (TUG) post-hoc test showed significant differences between normal and overweight overweight and obese, and obese and normal weight, all with p-value<0.001. Similarly, the sidewalk post-hoc test revealed significant differences between normal and overweight overweight and obese, and obese and normal weight, all at p-value<0.001. The tandem walking and heel walking post-hoc tests also indicated significant differences among the groups, with p-values <0.001 for all comparisons [Table/Fig-3].

Parameters	Normal vs overweight	Overweight vs obese	Obese Vs. normal weight
Static balance tests			
SLS test with open eyes on both legs	-0.087*	0.471	0.008*
SLS test with closed eyes on right leg	<0.001*	0.001*	<0.001*
SLS test with closed eyes on left leg	<0.001*	<0.001*	<0.001*
Dynamic balance test			
Timed Up and Go (TUG) test	<0.001*	<0.001*	<0.001*
Coordination tests			
Sidewalking	<0.001*	<0.001*	<0.001*
Tandem walking	<0.001*	<0.001*	<0.001*
Heel walking	<0.001*	<0.001*	<0.001*

[Table/Fig-3]: Post-hoc test for balance and coordination tests.
L: Left leg; R: Right leg; *Significant difference: p-value<0.016

DISCUSSION

The results of the present study clearly show that changes in body composition, specifically increased fat mass, can influence BMI and WHR proportionately and have an inverse association with coordination, as well as, static and dynamic balance, accepting alternative hypothesis. The statistics presented in the study indicate significant differences in coordination, static balance and dynamic balance among different BMI groups when inter group comparisons were made. Increased fat mass, BMI and WHR have detrimental effects, as evidenced by decreased scores in the SLS test with open eyes on both legs, the SLS test on the right leg, and the SLS test on the left leg; as well as, increased scores in the TUG test, sidewalking, tandem walking and heel walking.

A study by Kumar M and Arya P has pointed out through their research that an elevated BMI can be associated with excess fat accumulation around the abdominal area, leading to weakened abdominal muscles and consequently changing the alignment of the body's Centre Of Gravity (COG) by increasing lumbar lordosis [16]. Further, the study by Mohebi Rad Z and Norasteh AA aligns with the present research and supports the idea that core muscles play a vital role in regulating limb movement, stabilising the trunk and lumbopelvic regions, distributing stress, and supporting body weight during various activities. Increased fat mass, particularly in the abdominal area, diminishes the core muscles' ability to manage postural fluctuations, leading to a higher risk of falls in obese and overweight individuals. This occurs due to a disproportion between the COG, the Line of Gravity (LOG) and the Base of Support (BOS), caused by impaired core muscle biokinetics. Increased fat mass is inversely related to balance capability due to greater COG displacement [17]. Another study by Kumar M et al., found a correlation between flat feet and obesity in middle-aged individuals, which disrupts the kinematic chain and is associated with structural changes in the feet. This supports the study's rationale that obesity can lead to structural alterations in the feet, resulting in flat feet and potentially affecting balance through kinematic chain disruption [18].

Body composition also adversely affects coordination, as increased fat mass, BMI and WHR collectively increase the time required to complete tests designed to evaluate coordination in all three groups. A study by D'Hondt V et al., has aligned the same pathology behind poorer coordination with increasing BMI and WHR. The probable reason given is that greater abdominal fat mass diminishes core muscle capacity for dynamic postural control, challenging coordination amidst increased body mass, movement and gravitational forces, which require enhanced strength, endurance and explosiveness. The present study has shown that having a higher fat mass percentage negatively impacts both static and dynamic balance [19].

Another study by Mocanu GD and Murariu G stated that children aged 12-15 years with elevated BMI values, particularly those classified as overweight and obese, exhibited diminished balance capability in the anterior reach direction compared to their peers with normal weight. Variations in muscle strength, particularly in the flexors and extensors of the lower limbs, were evident between obese and normal weight individuals. Greater abdominal fat mass challenges coordination due to reduced core muscle capacity for dynamic postural control. Additionally, the study highlighted the adverse effects of excess weight on postural control and a reduction in upper limb movement efficiency. However, the study recognised limitations, such as the absence of underweight participants in the sample, which is also a limitation of the current study [20].

Results from a study by Türker A and Yüksel O showed statistically significant developmental variances in metrics such as Maximal Oxygen Consumption (VO2) estimate (mg/kg/min), Metabolic Equivalent (MET) fat percentage and the left foot lateral balance test, which were achieved by providing classical and functional strength training. From the present study, it can be inferred that classical and functional strength training has reduced fat mass percentage, which, in turn, significantly improved balance capability, supporting the findings of the current research [21].

The clinical implications of the present study not only highlights the variations in neuromuscular biomechanics, such as coordination and static and dynamic balance, based on body composition, but also emphasise the physiotherapeutic impact in the assessment, evaluation, treatment and prevention of metabolic pathologies such as obesity.

Limitation(s)

The present study had limitations in that it did not assess the amount and type of physical activity in which participants engaged, which could influence balance and coordination. Additionally, nutritional habits and deficiencies, which can impact physical performance-including balance and coordination were not evaluated through dietary intake assessments.

CONCLUSION(S)

The findings of the present study suggest that there are significant differences in balance and coordination among young adults based on their BMI categories. Specifically, the study indicates that individuals of normal weight, those who are overweight and those who are obese exhibit clear and statistically significant distinctions in their balance and coordination abilities. Changes in body composition and proportional alterations in BMI inversely impact coordination, as well as, static and dynamic balance. This implies that as BMI increases, there is a corresponding decrease in balance and coordination abilities. Overall, the present study underscores that higher BMI levels adversely affect balance and coordination in young adults. This finding could have important implications for interventions aimed at improving physical health outcomes, particularly in addressing the impact of weight management on motor skills and overall functional abilities.

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