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Original research papers

AGE, SEX AND BMI IN DYNAMIC BALANCE CONTROL: A CROSS-SECTIONAL STUDY

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Abstract

Introduction. Sex and anthropometric parameters have a significant impact on balance performance, emphasizing the necessity of considering these factors in dynamic balance studies. Therefore, this study aims to explore independent and interactive effects of age, sex, and BMI on dynamic balance control in healthy adults. ***Material and Methods.*** A total of 227 healthy participants (aged 20-70 years), volunteered to take part in the study. Dynamic balance values were assessed using the Y-Balance Test (YBT), including anterior (ANT), posteromedial (PM), and posterolateral (PL) directions. The values were normalized based on leg length, and the average of the right and left leg scores were calculated to determine the total score (TotalScore). A covariance analysis method was used to model the effects of sex, BMI, and age on YBT. ***Results.*** Sex had a significant effect on all YBT variables. BMI showed statistically significant effects on TopPM, TopPL, and TotalScore, but no significant effect on TopANT. The interaction between sex and BMI was not statistically significant across all variables. The effect of age as a covariate on balance showed a negative correlation across all variables. ***Conclusions.*** These results indicate that sex is directly related to YBT measurements, age has a negative effect, and BMI particularly influences TopPM and TopPL, but not TopANT. The effects of sex and BMI on balance performance were found to be independent and did not interact with each other. In conclusion, controlling these factors in balance assessments may help obtain more reliable results.

Key words: anthropometric factors, adult individuals, postural control, Y-balance test

Introduction

Dynamic balance, a key component of motor control that helps individuals maintain stability during movement, is a complex sensorimotor skill essential for daily life [1]. Impairments in dynamic balance and postural control impact postural stability across diverse populations, from athletes [2] to elderly individuals [3]. Such impairments increase the risk of falls, disability, and healthcare costs, ultimately compromising independence and quality of life [4]. Sell [5] noted that dynamic balance performance in healthy and athletic populations may be a significant predictor of lower extremity injury risk. Furthermore, a meta-analysis of 16 prospective and retrospective studies in adults aged 60 and over demonstrated that deficits in lower extremity balance and gait were associated with an increased risk of falls [6]. Despite its critical role in functional movement, balance is often overlooked until it declines, leading to negative consequences for motor skill execution across all age groups [7].

Previous studies have indicated that both sexes [8, 9] and anthropometric parameters significantly effect balance [10, 11, 12, 13]. However, more research is needed to explore the interaction between these factors and their impact on balance. For example, while some studies on athletes have found no significant sex differences in dynamic balance performance [14], others have reported that males exhibit shorter reach distances and greater asymmetry in the YBT [15]. In the research on healthy adults, Wu et al. [16] found that from the ages of 65-75, both males and females exhibited similar patterns of decline in general balance abilities. Therefore, independent and interactive effects of sex on balance should be further investigated.

Additionally, studies have also demonstrated the negative effects of increased body weight [13, 17] and aging [12, 18] on balance. An increase in BMI can negatively affect dynamic balance by altering the biomechanical distribution of body weight [13]. With aging, vestibular sensitivity decreases, reflexes and motor reactions slow, muscle strength and mass are lost, and the receptors responsible for balance decrease [19]. This decline can severely affect daily life activities and increase the prevalence of falls and injuries, negatively impacting individual independence and placing substantial economic and health burdens on society [20]. However, the exact mechanisms behind the decline in balance performance with age are not fully understood [3].

Despite these insights, there remains a need to explore balance across different age groups, including younger and middle-aged populations, who may also experience early neuromuscular adaptations that influence dynamic balance. Understanding the factors affecting balance in healthy adults is crucial not only for advancing motor control research but also for guiding fall prevention strategies and informing health policies. Therefore, this study aims to investigate independent and interactive effects of age, sex, and BMI on dynamic balance control in healthy adults. We hypothesize that aging, sex differences, and increased BMI will negatively affect dynamic postural control, resulting in limitations in balance performance.

Material and Methods

A total of 227 healthy participants (112 female, 115 male; age = 37.6 ± 15.3 years, 40.1 ± 17.1 years; height = 161.5 ± 6.48 cm; 173.4 ± 6.9 cm; weight= 61.8 ± 10.7 kg; 79.0 ± 12 kg; BMI= 23.8

± 4.63 kg/m2, 26.3 ± 3.85 kg/m2; leg length = 85.6 ± 5.66 cm; 91.6 ± 6.35 cm, respectively) volunteered to take part in the present study. The inclusion criteria required participants to have no history of neurological, psychiatric, orthopedic, vestibular, or systemic conditions that could affect balance control, no participation in a regular exercise program in the past six months, no medical issues that would prevent them from safely completing the balance assessments, and a BMI of 18.5 or higher. Sample size estimation using G*Power [21] indicated that 196 participants were required for analysis of covariance (ANCOVA) and standard error of measurement (SEM) analysis, based on an effect size of 0.3, α = 0.05, and power (1-β) = 0.80. For SEM, 200 participants were sufficient with an effect size of 0.1. To account for potential dropouts, 227 participants were recruited, and no data were missing as all participants completed the protocol. The study was approved by the Uşak University Ethics Committee (Approval No: 150-150-07) and conducted in accordance with the Helsinki Declaration.

The participants completed a dynamic balance assessment using the YBT. Previous research findings indicate that the inter-rater reliability of the YBT test is quite high [22]. The leg length of each participant was measured bilaterally in a supine position and recorded in centimeters, from the anterior superior iliac spine to the distal end of the medial malleolus. The ANT reach was defined as the distance from the tip of the toes of the stance foot to the furthest point reached, while PL and PM reaches were defined as the distance from the heel to the furthest point reached. The test required participants to be barefoot, with one foot placed at the intersection point, allowing the free limb to reach as far as possible. During the trial, participants were instructed to keep their hands on their iliac crests and their heel of the stance leg on the ground, and to lightly touch the furthest point they could reach with the toes of the reaching limb. Prior to the measurement, a brief demonstration of the test was provided by an experienced researcher, and participants were allowed at least six practice trials in each direction [23]. After completing the practice trials, participants were given a 5-minute rest period, followed by three test trials in each direction. During the measurement, if participants shifted body weight onto the reaching limb, lifted the heel of the stance foot off the ground, or removed their hands from the hips, the trial was considered invalid. In such cases, participants were verbally informed of the error and asked to repeat the trial to ensure proper performance. All reach distances were recorded in centimeters. After data collection, the best reach scores for each direction were normalized to leg length using the formula: (best reach distance/leg length) × 100 = %Max [24]. The normalized scores were expressed as a percentage of the stance leg length (%LL). The average of the normalized ANT, PL, and PM scores was calculated to determine a total score. Before testing, participants underwent a warm-up session consisting of 5 minutes of light jogging followed by dynamic stretching exercises to ensure optimal neuromuscular activation. Participants were instructed to maintain their balance while reaching as far as possible with the free limb without touching the ground, losing stability, or compensatory movements.

Body weight and height were measured using an integrated stadiometer scale (Seca, model 709, Germany) with an accuracy of 0.1 kg and 0.1 cm, and body mass index was calculated.

Statistical analysis

Statistical analyses were performed using ANCOVA to assess the effects of sex, BMI, their interaction (Sex*BMI), and age on balance outcomes. Prior to the analyses, the assumptions of the ANCOVA were evaluated. The normality of residuals, homogeneity of variances, and homogeneity of regression slopes were assessed using both graphical methods and statistical tests. The residuals were found to be normally distributed, variances were homogeneous across groups, and the regression slopes were parallel. Accordingly, it was concluded that the analyses performed using the PROC MIXED procedure satisfied the fundamental assumptions of ANCOVA. Each model included sex, BMI, their interaction, and age as a covariate (slope coefficient γ). Data were analyzed using SAS software with a significance level set at 0.05. Least squares means and Tukey's adjusted p-values were used for group comparisons.

Results

The results of the analysis evaluate the effects of sex, BMI, and age on balance performance (Tab. 1). Sex was found to have a highly significant effect on all balance variables (TopANT, TopPM, TopPL, and TotalScore) ($p < 0.0001$). BMI showed statistically significant effects on TopPM, TopPL, and TotalScore ($p = 0.0092$, $p = 0.0152$, and $p = 0.0156$, respectively), but did not show a significant effect on TopANT ($p = 0.4606$). The interaction between sex and BMI was not statistically significant for any of the balance variables (TopANT, TopPM, TopPL, and TotalScore) (p-values: 0.2652, 0.308, 0.4511, and 0.3159, respectively). The effect of age as a covariate on balance performance showed a negative correlation across all balance variables ($p < 0.0001$). The estimated effects of age on TopANT, TopPM, TopPL, and TotalScore were found to be -0.12 ± 0.03, -0.40 ± 0.06, -0.46 ± 0.06, and -0.32 ± 0.05, respectively.

Table 1. ANCOVA results for balance variables

Effects	p-values for variables			
	TopANT	TopPM	TopPL	TotalScore
Sex	<0.0001	<0.0001	<0.0001	<0.0001
BMI	0.4606	0.0092	0.0152	0.0156
Sex*BMI	0.2652	0.3080	0.4511	0.3159
Covariate	β ± S.E.	β ± S.E.	β ± S.E.	β ± S.E.
Age	-0.12 ± 0.03	-0.40 ± 0.06	-0.46 ± 0.06	-0.32 ± 0.05
p-values	0.0001	<0.0001	<0.0001	<0.0001

LSmeans represent means adjusted for all variables included in the statistical model. The means and p-values related to the effects of BMI and Sex on the ANT variable (Fig. 1). In the BMI range of 18.5-24.9, there is no statistically significant difference between males and females in terms of ANT scores ($p = 0.0959$). However, in the BMI ranges of 25-29.9 and 30 and above, statistically significant differences between sexes were observed ($p = 0.0091$ and $p = 0.0102$, respectively). On the other hand, there was no statistically significant change in ANT balance scores across BMI categories within each sex ($p > 0.05$). However, it is noteworthy that, especially in females, the ANT balance score decreased from 50.01 ± 0.70 in the 18.5-24.9 BMI range to 46.80 ± 1.46 in the 30+ BMI range.

Figure 2 shows the LSmean averages of total PM balance scores and the p-values between the groups. In all BMI categories, men have higher and statistically significant PM scores compared to women. As BMI increases, PM scores decrease, but this decrease is not significant in men. In women, a significant

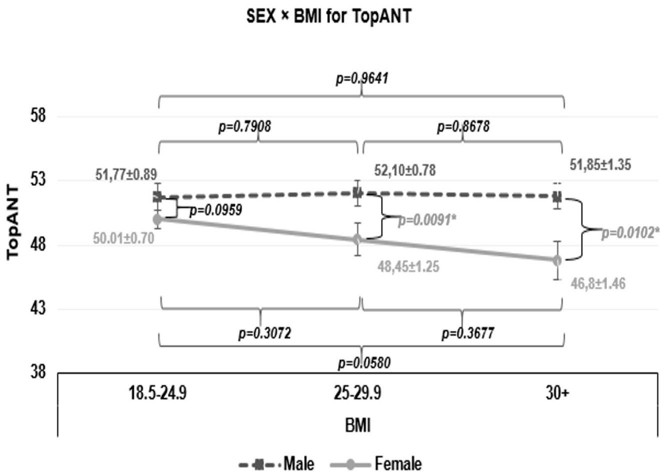

Fig. 1. LSmeans ± standard error for Total ANT balance scores and p-values for the comparison groups

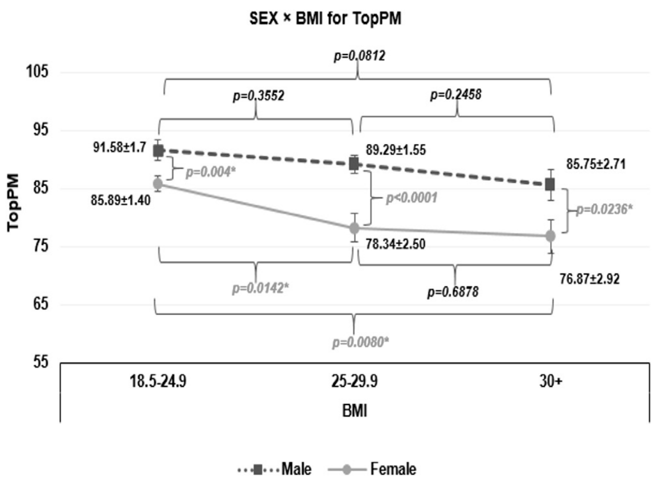

Fig. 2. LSmeans ± standard error for Total PM balance scores and p-values for the comparison groups

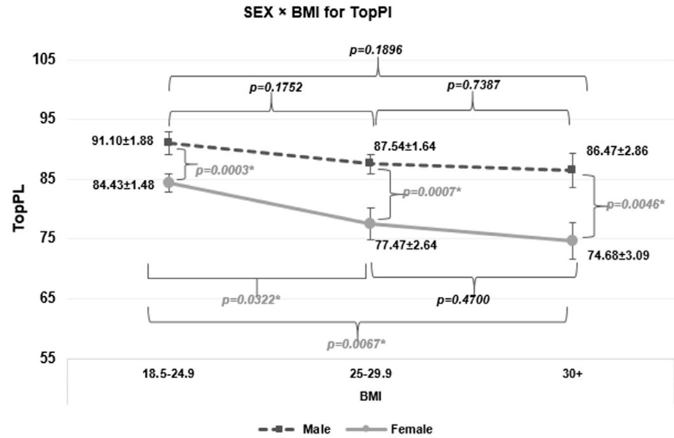

Fig. 3. LSmeans ± standard error for Total PL balance scores and p-values for the comparison groups

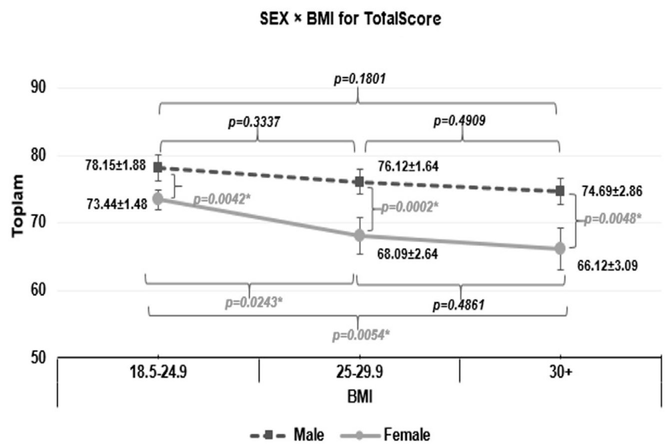

Fig. 4. LSmeans ± standard error for Total balance scores and p-values for the comparison groups

decrease in PM scores ($p < 0.01$) is observed when transitioning from the normal weight to the overweight category, but no significant difference is found between the overweight and obese categories. The difference between normal BMI and obese is significant ($p < 0.01$).

The LSmean averages of total PL balance scores and the p-values between the groups are shown in Figure 3. Significant differences in PL balance scores were found between men and women in all three BMI categories. The smallest difference was observed with men at 91.10 ± 1.88 and women at 84.43 ± 1.48. The difference in PL balance scores between sexes reached approximately 12 points at the obesity level and was statistically significant. While a decrease in PL balance was observed in both sexes as BMI increased, this decrease was not significant in men. In women, a significant difference was found between the normal BMI and overweight categories, but no significant difference was observed between the overweight and obese categories ($p > 0.05$).

The LSmean averages of total balance scores and the p-values between the groups are shown (Fig. 4). Significant differences in total balance scores were found between men and women in all three BMI categories. The smallest difference was observed in the normal BMI category, with men having an average of 78.15 ± 1.88 and women 73.44 ± 1.48. At the obesity level, the difference between sexes reached approximately 8 points and was statistically significant. While both sexes showed a decrease in total balance scores as BMI increased, this decrease was not significant in men. In women, a significant difference was found between the normal BMI and overweight categories, but no significant difference was observed between the overweight and obese categories ($p > 0.05$).

Discussion

In this study, we analyzed how sex, BMI, and age independently and interactively affect dynamic balance control based on dynamic balance scores. Our results indicate that sex, BMI, and age significantly influence balance performance, with men exhibiting higher balance scores than women across all BMI categories. While increased BMI generally impairs balance, this effect is more pronounced in women, and age serves as a negative predictor of balance across all measures.

Sex has been reported as a confounding factor in performance assessments during YBT, as highlighted in previous studies [25]. However, there is no consensus regarding the influence of sex on dynamic balance abilities. Contrary to the findings of previous studies [8, 9, 26, 27], our study found that sex had a significant effect on all normalized balance variables (TopANT, TopPM, TopPL, and TotalScore). These results suggest that sex plays a critical role in balance performance, with this effect being consistent across all balance variables. Higher balance performance observed in males across all BMI categories supports previously reported biomechanical and neuromuscular differences [24]. In line with our findings, Nascimento et al. [28] reported higher balance performance in male participants compared to females in a large sample of older adults. Similarly, a study by Wu et al. [16] in older adults found no significant overall difference between males and females, but did observe that at certain ages, males performed better in specific balance areas, with declines in balance performance occurring in both sexes with aging. This may be due to women generally having lower health and physical fitness levels than men as they age [29]. A common theme in some studies is that sex does not directly affect balance, but rather influences it through other factors, such as muscle strength and maturation [4]. Thus, sex-related differences in balance may be influenced by age and body composition.

Consistent with previous studies [10, 13, 17], our study also found that an increase in BMI negatively affects balance. A study by Abdolahi et al. [30] involving construction workers reported a statistically significant relationship between body weight and YBT, indicating that increased body weight impairs dynamic balance. In our study, BMI was found to play a significant role in determining YBT performance, particularly in TopPM, TopPL, and TotalScore reach. However, the lack of an effect on the TopANT parameter suggests that this balance measure may be influenced by different biomechanical factors. The absence of BMI's effect on TopANT could be explained by the importance of ankle dorsiflexion range of motion (ROM) in affecting TopANT reach. This parameter may be more related to ankle ROM and body posture [31]. In conclusion, increased body mass requires more movement from the body's center of mass to maintain an upright posture [32].

The findings of our study show that sex and BMI are independent factors that affect balance performance and do not significantly influence each other. Although the interaction between sex and BMI was not statistically significant, it is still important to interpret this result in context. The lack of interaction suggests that the effect of BMI on balance is consistent across sexes – in other words, BMI influences balance independently of sex. This may indicate that while sex and BMI both affect balance, they do so through distinct and non-overlapping physiological mechanisms. It is also possible that sample size limitations or uneven group distributions in certain BMI categories reduced the power to detect subtle interaction effects. Nonetheless, the consistency of the main effects across groups underscores their individual importance in balance performance.

A decline in balance performance was observed with an increase in BMI, but this decrease was particularly significant and statistically meaningful in women. The significant difference in balance performance between women with normal weight (18.5-24.9 kg/m^2) and overweight women (25-29.9 kg/m^2) indicates that increased body mass has substantial negative effects on balance control. This finding parallels previous results suggesting that increased fat mass and changing body composition in women may reduce the effectiveness of balance strategies [33]. In our study, although an increase in BMI also negatively affected balance performance in men, the decrease was not statistically significant. This suggests that different compensatory mechanisms may be involved in balance control between sexes. Mocanu and Murariu [7], in their study on university students, examined the interaction between sex and BMI, emphasizing that the effects on balance performance were generally independent. They also noted that the effects of BMI on balance performance did not significantly affect each other. Similarly, Menegoni et al. [34] studied the impact of sex and BMI on balance performance and found that the influence of sex on balance performance continued independently of BMI. These findings are consistent with the results of our study and further highlight that these factors should be considered independently.

In the literature, it has been emphasized that with age, performance in multidimensional dynamic balance tasks decreases more significantly, and the risk of falls increases [3, 11, 12, 27]. Therefore, the finding of a decline in balance associated with age in our study is consistent with the existing literature and is considered an expected result. Notably, the more pronounced decrease in balance in the PM and PL directions with age suggests that multidirectional balance movements become more challenging as individuals age. This finding parallels previous studies that have demonstrated the negative effects of aging on multiple systems, such as proprioceptive senses, muscle strength, balance strategies, and the vestibular system [27]. Specifically, the decrease in the efficiency of the postural control system with age, the weakening of reactive and proactive balance strategies, and the decline in musculoskeletal system function contribute to the inevitable decline in balance performance [31]. A recent study involving 82 healthy participants aged 20-85, using an Inertial Measurement Unit (IMU) based dynamic balance test, found that younger participants (18-20 years) demonstrated lower angular velocities in body segments compared to both middle-aged (40-60 years) and older adults (60+ years) [12]. In two studies using YBT, Freund et al. [11] and Lee et al. [18] showed that younger groups achieved better balance performance compared to older individuals. These studies collectively suggest that dynamic balance abilities decline with age.

Conclusions

Age, sex, and BMI have significant effects on YBT measurements. Although the results indicate that the effects of sex and BMI on YBT measurements are independent, they also highlight the need for further investigation of these interactions. Consequently, the independent effects of sex and BMI suggest that specialized training and rehabilitation programs may be necessary for each factor.

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