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Neural Control of Movement

Postural control performance of active and inactive older adults assessed through postural tasks with different levels of difficulty

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Abstract - Aim: To investigate postural control between active (AOA) and inactive (IOA) older adults and active young adults (YA) due to the difficulty level of the postural task. **Methods:** 25 active YA, 31 AOA, and 30 IOA were invited to perform postural tasks with eyes open and closed: bipedal stance on a rigid surface, bipedal stance on an unstable surface, semi-tandem stance on a rigid surface, and semi-tandem stance on an unstable surface. **Results:** IOA (0.74 cm) presented higher COP displacement amplitude in the mediolateral direction than AOA (0.64 cm) only in bipedal stance on an unstable surface with eyes closed condition ($p \leq 0.0001$). In relation to frequency variables, IOA (0.37 Hz) presented a greater frequency band with 50% of the spectral power in the mediolateral direction than AOA (0.28 Hz) in all experimental conditions, except for semi-tandem stance on a rigid surface ($p \leq .0001$). AOA (0.62 cm | 0.28 Hz) and IOA (0.67 cm | 0.37 Hz) presented an increase in time/frequency variables in both directions (anterior-posterior and mediolateral) than YA (0.52 cm | 0.17 Hz) ($p \leq 0.0001$) that indicates a worse performance of postural control as the level of task difficulty increased, such as unstable base with eyes open and closed. **Conclusion:** Older adults tend to present greater COP sway and velocity when subjected to complex tasks compared with younger, which is more evident in older adults physically inactive. This could be considered an adaptive strategy by older adults to minimize the risk of losing balance and, consequently, falling.

Keywords: postural control, aging, physical exercise, posturographic variables.

Introduction

The aging process is characterized by functional and structural changes that are cumulative, progressive, intrinsic, and deleterious[1]. This process usually impacts all body systems and is commonly associated with functional changes in the neuromuscular, somatosensory, vestibular, and visual systems[2]. Moreover, it influences the ability to maintain postural stability due to impaired control systems[3].

One of the most alarming losses that affect older adults is the decline in postural balance, which is related to high rates of falls and can lead to loss of mobility and reduction of functional independence[4]. This decline in postural balance can be explained by deterioration in sensory, musculoskeletal, and neuromuscular systems and the coordination between them[3], impaired cognitive function, and weakened motor responses[5]. Furthermore, deterioration in the visual and vestibular systems decreases the sense of orientation and awareness of the body, which affects movement coordination and increases the motor reaction time3. These factors, combined with age-related lower physical activity levels, lead to postural instability and an increased risk of falls[4].

Postural control has two main goals: postural orientation and postural equilibrium[6]. Postural orientation involves the active control of body alignment in relation to gravity, support surface, visual environment, and internal references[6]. In addition, postural equilibrium involves the coordination of sensorimotor strategies to stabilize the center of mass during self-initiated and external disturbance movements[6]. Some studies have shown that older adults have a greater, more rapid, and more varied postural sway compared to young adults[7-9]. For example, Degani et al. (2017)[8] investigated the effects of aging on postural sway in two tasks: 1) functional limits of stability and 2) unperturbed stance for 120 s. In both tasks, these authors found that older adults presented a larger, faster, and shakier body sway in the anteroposterior and mediolateral directions than young adults. These results indicate that these changes in older adult posture can be interpreted as a compensatory mechanism in function of the age-related decline of sensory, neural, and motor systems. However, Gotardi et al. (2018)[9] investigated the effect of horizontal and vertical saccadic eye movements on the performance of postural control in young and older adults during the maintenance of the standing posture in different support bases (bipedal and semi tandem). They found that older adults had greater body sway velocity than young adults in a semi-tandem task. These results suggest that older adults were not able to perform postural adjustments necessary for visual tasks involving saccadic movements, contributing to greater postural instability than young adults. Moreover, it is believed that the deterioration of proprioceptive information is the one that most interferes with postural control performance, leading to increased COP sway and increased weight assigned to other sensory information when comparing older and young adults[10]. Yet, it is also observed that the losses in postural control and cognitive resources are also related to physical inactivity and muscle atrophy due to disuse[11].

Studies show that physical inactivity favors the deterioration of the musculoskeletal, neuronal, and sensory systems that act in the maintenance of postural control[11,12]. Thus, by physical exercise, it is possible to preserve and/or improve functional, neuromotor, and coordination capacity[13]. The benefits of physical exercise are decreased total sway path length/velocity, area, and postural sway in the anteroposterior direction in both eyes open and closed in bipedal stance[11,14], and increased step speed and length[12], indicating an improvement in postural and locomotor stability.

The focus of this research is to understand the changes in postural control performance as a function of the aging process and level of physical activity. Postural stability has been studied and measured under static conditions with different foot positions, on a stable surface, with and without visual restriction[15,16]. A study has also measured it in the bipedal stance, on an unstable surface, with and without visual restriction[17], in order to make the task more challenging. The literature shows that body sway amplitude and velocity in the mediolateral and anteroposterior directions are COP variables commonly reported in investigations[14,15], and those sway frequency parameters posturographic variables are capable of evaluating balance control performance[18]. For example, Delmas et al. (2021)[19] investigated frequency variables related to postural control in older adults during a lean forward task. They found that the age-associated increase in postural variability relates to greater COP oscillations below 0.5 Hz. However, more studies are warranted to investigate the frequency variables in a postural context with eyes open and closed and different bases of support (semi-tandem and bipedal) in older adults. Thus, frequency variables may also provide additional information about the underlying causes of balance deficits due to aging. Therefore, postural balance assessment for older and young adults must include different COP sway variables in terms of both time and frequency[19].

In this study, we analyze time variables such as 1) mean COP displacement velocity; 2) COP displacement amplitude. In relation to the frequency domain, the variables calculated are 1) frequency band with 50% (representing the mean of the signal) and frequency band with 80% of the spectral power (this variable best characterizes some changes in postural control) (Baratto et al. 2002)[20]. Both time and frequency parameters were calculated in the anteroposterior (AP) and mediolateral directions. These variables were chosen to evaluate possible changes in postural control due to aging, physical activity level, and different postural tasks. Thus, an increase in the parameters cited above indicates poor balance control; consequently, greater values are associated with fall risk in the aging population (Howcroft et al., 2017)[21].

Based on these considerations, this study presents the following research questions: What are the changes in the time/frequency variables of postural control in older adults (active and inactive) compared to young adults? Is there any difference in the time/frequency variables of postural control between active and inactive older adults? Do these changes occur as a function of postural task difficulty?

This study aims to investigate postural balance using time and frequency variables in active and inactive older individuals, as well as in young adults, as a function of the difficulty level of the postural task. We considered the difficult crescent level as follows: bipedal stance on a rigid surface, bipedal stance on an unstable surface, semi-tandem stance on a rigid surface, and semi-tandem stance on an unstable surface with eyes open and closed.

We expected that a) active older adults would present a better postural control performance than inactive older adults in all postural tasks; b) inactive and active older adults would present an increase in time/frequency variables (mean COP displacement velocity, COP displacement amplitude, 50% and 80% of the spectral power in the AP and ML directions) of postural control when compared to young adults, indicating poor postural control performance; and c) older adults presented a worse performance of postural control than young adults as the level of task difficulty increases. In semi tandem an unstable base with eyes closed task, we expected that older adults present an increase in mean COP displacement velocity, COP displacement amplitude, 50%, 80% of the spectral power in AP and ML directions than young adults.

Methods

Participants

Eighty-six individuals participated in this study and were divided into three groups: 1) Active Young Adults

(YA) (n = 25), consisting of young adults who performed 150 min of physical exercise per week in the last 3 months[22]; 2) Active Older Adults (AOA) (n = 31), consisting of older adults who regularly participated in the Exercise Orientation Service Program (EOS) - Vitória/ES (sessions of approximately 60 min twice weekly including balance, strength, and flexibility exercises) and 30 min of other physical activity (e.g., walking and dancing); 3) Inactive Older Adults (IOA) (n = 30), consisting of older adults who did not perform 150 min of physical exercise per week in the last 3 months[22]. Based on the sample calculation, a minimum sample size of 21 participants in each group was required for a power of 90% and an alpha error of 0.05 in MANOVAs analyses. The Human Research Ethics of the Federal University of Espirito Santo (CAAE: 67639417.0.0000.5542) approved all the procedures of this study, and participants signed an informed consent form before the start of the data collection.

All participants had a normal or corrected-to-normal vision and no neurological/musculoskeletal disorders that would affect the experimental task. Furthermore, participants were excluded if they had cognitive impairment (< 26 points in the MiniMental), vestibular dysfunction, obesity above grade I (BMI $\geq$ 35), and/or if they were unable to walk without assistance.

Of the total number of older adults who agreed to participate in the study (68 older adults), there were three dropouts and four exclusions: one because of diagnosis of Parkinson's disease, one for having grade 2 for obesity, one for present episodes of cramps, and one due to chronic low back pain during data collection.

Experimental design

Data were collected over two days. On the first day, it was done at EOS Modules and/or Basic Health Units, and on the second day, at the Strength and Conditioning Laboratory (LAFEC) of the Center for Physical Education and Sports of the Federal University of Espirito Santo (CEFD/UFES).

On the first day, an anamnesis was initially conducted to check the general health status of the participants, check the inclusion and exclusion criteria of the study, and check whether they were eligible to participate. Afterward, an anthropometric assessment was performed using a Filizola scale with an attached stadiometer to measure body mass and height. The Body Mass Index (BMI) was calculated by dividing the body mass in kilograms by the squared height in meters (BMI = kg/m^2), with the classification being: normal (BMI between 18.5 and 24.9 kg/m^2), overweight (BMI between 25 and 29.9 kg/m^2), grade I obesity (BMI between 30.0 and 34.9 kg/m^2), grade II obesity (BMI between 35 and 39.9 kg/m^2), and grade III obesity (BMI greater than or equal to 40 kg/m^2)[23]. The level of physical activity was measured using the Modified Baecke Questionnaire for older adults, covering three basic areas: occupational, sports, and leisure activities[24]. According to Ueno (2013)[25], a Baecke score of more than 9 is considered to be active for older adults. Notably, this cutoff of 9 (Baecke score) is only applied to older adults. For the young adult group, we applied the standard Baecke Questionnaire to investigate the level of physical activity[26].

In addition, the following scales were applied for clinical assessment: the Mini-Mental State Exam (maximum score - 30 points) for cognitive-function assessment[27] and the MiniBEST (maximum score - 28 points), to assess static and dynamic balance[28]. Higher scores on the Mini-Mental and MiniBEST indicate that older adults have greater cognition and balance conditions, respectively. In relation to MiniMental, a score below 26 points indicates a risk of developing dementia (Santana et al., 2016)[29].

On the second day, plantar skin sensitivity and postural balance were assessed at the LAFEC. Plantar skin sensitivity was assessed using the Semmes-Weinstein test (SORRI Bauru), which consists of a set of six nylon monofilaments with different colors and diameters that exert pressure on the skin according to the thickness of the filament, which varies from 0.05 at 300 g[9]. Ten points were analyzed from different regions of both feet in random order, where each region received a score according to the monofilament color (green = 1, blue = 2, violet = 3, red = 4, orange = 5, and pink = 6). The total sensitivity score of the foot was obtained from the sum of all points evaluated on each foot. A higher total score indicates worse plantar skin sensitivity[30]. The assessment was conducted in a silent environment, with the participants in the supine position and with their eyes blindfolded. A force platform was used for postural balance assessment (Biomech 400, EMGSystem do Brasil, SP, LTDA), with a signal acquisition frequency of 100 Hz. For postural balance evaluation on an unstable surface, a viscoelastic foam (RM Produtos) was placed on the force platform.

Postural control was assessed with the subject standing barefoot on the force plate, focusing on the visual target placed 1 m at eye level. They were invited to perform four postural tasks: Condition 1 (BSR): bipedal stance on a rigid surface, Condition 2 (BSU): bipedal stance on an unstable surface (viscoelastic foam), Condition 3 (STR): semi-tandem stance on a rigid surface, and Condition 4 (STU): semi-tandem stance on an unstable surface. These four conditions were performed with eyes open (EO) and closed (EC).

Under the bipedal stance conditions, the feet were positioned in parallel and aligned approximately shoulder-width apart, while in the semi-tandem stance conditions, the feet were positioned one in front of the other, with the dominant foot ahead and with the hallux touching the medial edge of the heel of the contralateral foot. For each condition, three trials were made, lasting 30 s, with the eyes open and closed, and with a 1-minute break between each trial, totaling 24 trials. The sequence of conditions was randomized for each participant.

Data analysis

The center of pressure (COP) data from the force platform were filtered digitally with a low-pass filter and a 10 Hz cut-off frequency. The variables calculated based on the COP data were the mean COP displacement velocity in the anteroposterior (VEL_AP) and mediolateral (VEL_ML) directions; COP displacement amplitude in the anteroposterior (MSA_AP) and mediolateral (MSA_ML) directions; frequency band with 50% and 80% of the spectral power in the anteroposterior (FREQ50_AP, FREQ80_AP) and mediolateral (FREQ50_ML, FREQ80_ML) directions.

Statistical analysis

All statistical analyses were performed using SPSS software (Statistical Package for the Social Sciences), version 20 (SPSS Inc., Chicago, USA). One-way analysis of variance (ANOVA) was used to compare age, anthropometric (height, body mass, and body mass index), and clinical characteristics (MiniMental, MiniBESTest, Baecke scores, and right/left skin sensitivity) between the groups. Multivariate Analysis of Covariance (MANCOVA) and repeated measures were performed to analyze variables related to postural control. The body mass index and plantar skin sensitivity were used as a covariate to eliminate their effect on the dependent variables. Three-way multivariate analyses of covariance (MANCOVAs) were performed (group [YA, AOA, IOA] x condition [BSR, BSU, STR, STU] x vision [eyes open and closed]) for the following set of dependent variables: VEL, MSA, FREQ50, FREQ80, for both AP and ML directions.

The results of the statistical analyses are presented in tables. When MANCOVAs revealed the main interaction effect, only the triple-interaction effect was described. In addition, post hoc tests with Bonferroni adjustment were performed when necessary, and for all analyses, a significance level of $p \leq 0.05$ was adopted.

Results

The results are presented separately in sub-items, and the characteristics of the study sample are highlighted, followed by the results of the postural balance assessment.

Sample characterization

Table 1 presents the anthropometric and clinical characteristics of the entire sample. The YA group comprised 14 young adult women (56%) and 11 young adult men (44%). The AOA group comprised 27 (87%) older adult women, and 4 (13%) older adult men, while the IOA group comprised 26 (86.66%) older adult women, and 4 (13.33%) older adult men.

ANOVA revealed differences between young adults, and active and inactive older adults in terms of age ($F_{2,82}$ = 849.08, p = 0.001), height ($F_{2,82}$ = 26.08, p = 0.001), body index mass ($F_{2,82}$ = 13.05, p = 0.001), and right ($F_{2,82}$ = 12.76, p = 0.001) and left ($F_{2,82}$ = 12.80, p = 0.001) skin sensitivity. Moreover, ANOVA revealed differences between active and inactive older adults for Baecke ($F_{2,82}$ = 98.28, p = 0.001) and MiniBESTest ($F_{1,58}$ = 13.2, p = 0.001). Active and inactive older adults presented higher age (IOA = 66.7 | AOA = 65.1 | YA = 23.1), Body Mass Index (IOA = 27.5 | AOA = 26.8 | YA = 23.4), and right (IOA = 25.1 | AOA = 25.8 | YA = 18.9)/left (IOA = 25.2 | AOA = 25.5 | YA = 18.6)

Table 1 - Mean and standard deviation (in parenthesis) for the age and anthropometric and clinical characteristics of active older adults (AOA), inactive older adults (IOA), and young adults (YA). P-values indicate significant effects.

	Groups			
Variables	**IOA (N = 31)**	**AOA (N = 30)**	**YA (N = 25)**	**p-value**
Age (years)	66.7 (± 4.4)[a]	65.1 (± 4.2)[a]	23.1 (± 4.4)	0.001
Body mass (kg)	68.2 (±10.5)	66.47 (± 9.6)	67.38 (± 14.1)	0.894
Height (m)	1.6 (± 0.1)[a]	1.6 (± 0.1)[a]	1.7 (± 0.1)	0.001
BMI (kg/m^2)	27.5 (± 3.6)[a]	26.8 (± 3.1)[a]	23.4 (± 2.8)	0.001
Mini-Mental State Exam (points)	27.8 (±1.4)	27.9 (± 1.7)	-	0.804
Baecke Questionnaire (points)	3.8 (± 1.1)[a,b]	13.9 (± 4.3)[a]	8.9 (± 1.4)	0.000
MiniBESTest (points)	22.1 (± 3.9)[a,b]	25.1 (± 2.1)	-	0.001
Right plantar skin sensitivity score (points)	25.1 (± 4.9)[a]	25.8 (± 5.2)	18.9 (± 6.7)	0.001
Left plantar skin sensitivity score (points)	25.2 (± 5.1)[a]	25.5 (± 5.2)[a]	18.6 (± 6.8)	0.001

Legend: IOA (inactive older adults); AOA (active older adults); YA (young adults); N (number of sample participants); kg (kilogram); m (meters); BMI (Body Mass Index); kg/m^2 (kilogram per square meter).
[a]Different from young adults.
[b]Different from active older adults.

sensitivity, and lower height than young adults. These results indicate that older adults have decreased plantar skin sensitivity and increased body mass. Thus, active older adults presented a higher level of physical activity (IOA = 3.8 | AOA = 13.9 | YA = 8.9) than inactive and young adults. Finally, active older adults had a greater score in MiniBESTest (IOA = 22.1 | AOA = 25.1) than inactive older adults, which indicates greater balance and mobility. In addition, older adults showed a preserved cognitive status according to the MiniMental scale.

Postural balance assessment

Variables in the time domain

The MANCOVAs revealed a triple-interaction effect. The ANCOVAs showed this effect for the "mean COP sway amplitude (MSA)" and "mean COP velocity (VEL)" variables, in the mediolateral (ML) direction, and for the "mean COP velocity (VEL)" variable, in the anteroposterior (AP) direction (Table 2). However, MANCOVAs did not reveal the main effect on body mass index (Wilks' λ = 0.946, $F_{2,81}$ = 2.30, p = 1.06) and plantar skin sensitivity (Wilks' λ = 0.976, $F_{2,81}$ = 1.05, p = 0.35) for MSA in AP and ML directions. Moreover, MANCOVAs did not revealed main effect of body mass index (Wilks' λ = 0.985, $F_{2,81}$ = 0.63, p = 0.533) and plantar skin sensitivity (Wilks' λ = 0.988, $F_{2,81}$ = 0.50, p = 0.61) for VEL in AP and ML directions.

Post hoc analyses revealed that IOA (0.891 cm) had higher MSA in the mediolateral direction than AOA (0.760 cm) under the BSUEC condition. The IOA also presented greater MSA in the mediolateral direction than the YA, under the following conditions: BSREO (0.258 cm | 0.168 cm, respectively), BSREC (0.283 cm | 0.187 cm), BSUEO (0.589 cm | 0.382 cm), BSUEC (0.891 cm) cm | 0.576 cm), STREO (0.555 cm | 0.459 cm), and STUEO (0.753 cm | 0.547 cm) (Figure 1). Finally, AOA also presented higher MSA in the mediolateral direction than YA under the following conditions: BSREO (0.208 cm | 0.168 cm, respectively), BSUEO (0.524 cm | 0.382 cm), BSUEC (0.760 cm | 0.576 cm), and STUEO (0.677 cm | 0.547 cm) (Figure 1).

Moreover, AOA and IOA presented higher VEL in the anteroposterior direction than YA, under the following experimental conditions: BSREO (AOA: 0.891 cm/s | IOA: 0.944 cm/s | YA: 0.642 cm/s), BSREC (AOA: 1.203 cm/s | IOA: 1.225 cm/s | YA: 0.792 cm/s), BSUEO (AOA: 1.780 cm/s | IOA: 1.920 cm/s | YA: 1.078 cm/s), BSUEC (AOA: 3.225 cm/s | IOA: 3.205 cm/s | YA: 1.926 cm/s), STREC (AOA: 1.835 cm/s | IOA: 1.952 cm/s | YA: 1.559 cm/s), and STUEO (AOA: 2.013 cm/s | IOA: 2.169 cm/s | YA: 1.400 cm/s). For the STREO condition, we found that IOA presented a greater VEL than YA (IOA: 1.310 cm/s | YA: 1.077 cm/s). However, AOA and IOA presented higher VEL in the mediolateral direction than the YA group under the following conditions: BSREO (AOA: 0.586 cm/s | IOA: 0.645 cm/s | YA: 0.492 cm/s), BSREC (AOA: 0.769 cm/s | IOA: 0.808 cm/s | YA: 0.576 cm/s), BSUEO (AOA: 1220 cm/s | IOA: 1.356 cm/s | YA: 0.832 cm/s), BSUEC (AOA: 1.964 cm/s | IOA: 2.147 cm/s | YA: 1.417 cm/s), STREC (AOA: 2.274 cm/s | IOA: 2.324 cm/s | YA: 1.900 cm/s), and STUEO (AOA: 2.115 cm/s | IOA: 2.226 cm/s | YA: 1.502 cm/s). Furthermore, for the STREO condition, we also found that IOA presented a greater VEL than YA (IOA: 1.474 cm/s | YA: 1.153 cm/s).

Table 2 - F, p, and η_p^2 values for the main effect and triple interaction between factors (group, condition, vision, and group*condition*vision) of MANCOVAs and ANCOVAs for time variables: mean sway amplitude (MSA) and mean displacement velocity (VEL) of the center of pressure (COP) in the anteroposterior (AP) and mediolateral (ML) directions.

Variables	Groups	Condition	Vision	Group*Condition *Vision
MANCOVA	Wilk's lambda = 0.719, $F_{4,164}$ = 7.337, p ≤0.0001, η_p^2 = 0.152	Wilk's lambda = 0.036, $F_{6,78}$ = 344.258, p ≤ 0.0001, η_p^2 = 0.964	Wilk's lambda = 0.118, $F_{6,78}$ = 305.343, p ≤ 0.0001, η_p^2 = 0.882	Wilk's lambda = 0.737, $F_{12,156}$ = 2.14, p = 0.017, η_p^2 = 0.141
ANCOVA				
MSA_AP	$F_{2,83}$ = 15.071, p ≤ 0.0001, η_p^2 = 0.266	$F_{3,249}$ = 699.200, p ≤ 0.0001, η_p^2 = 0.894	$F_{1,83}$ = 494.291, p ≤ 0.0001, η_p^2 = 0.856	$F_{6,249}$ = 1.651, p = 0.134, η_p^2 = 0.038
MSA_ML	$F_{2,83}$ = 14.778, p ≤ 0.0001, η_p^2 = 0.263	$F_{3,249}$ = 617.850, p ≤ 0.0001, η_p^2 = 0.882	$F_{1,83}$ = 544.760, p ≤ 0.0001, η_p^2 = 0.868	$F_{6,249}$ = 4.060, p ≤ 0.0001, η_p^2 = 0.089
MANCOVA	Wilk's lambda = 0.758, $F_{4,164}$ = 6.099, p ≤ 0.0001, η_p^2 = 0.129	Wilk's lambda = 0.078, $F_{6,78}$ = 152.767, p ≤ 0.0001, η_p^2 = 0.922	Wilk's lambda = 0.159, $F_{2,82}$ = 217.263, p ≤ 0.0001, η_p^2 = 0.841	Wilk's lambda = 0.684, $F_{12,156}$ = 2.720, p = 0.002, η_p^2 = 0,173
ANCOVA				
VEL_AP	$F_{2,83}$ = 12.572, p ≤ 0.0001, η_p^2 = 0.233	$F_{3,249}$ = 295.685, p ≤ 0.0001, η_p^2 = 0.781	$F_{1,83}$ = 244.245, p ≤ 0.0001, η_p^2 = 0.746	$F_{6,249}$ = 2.926, p = 0.009, η_p^2 = 0.066
VEL_ML	$F_{2,83}$ = 9.332, p ≤ 0.0001, η_p^2 = 0.184	$F_{3,249}$ = 450.881, p ≤ 0.0001, η_p^2 = 0.845	$F_{1,83}$ = 439.084, p ≤ 0.0001, η_p^2 = 0.841	$F_{6,249}$ = 5.257, p ≤ 0.0001, η_p^2 = 0.112

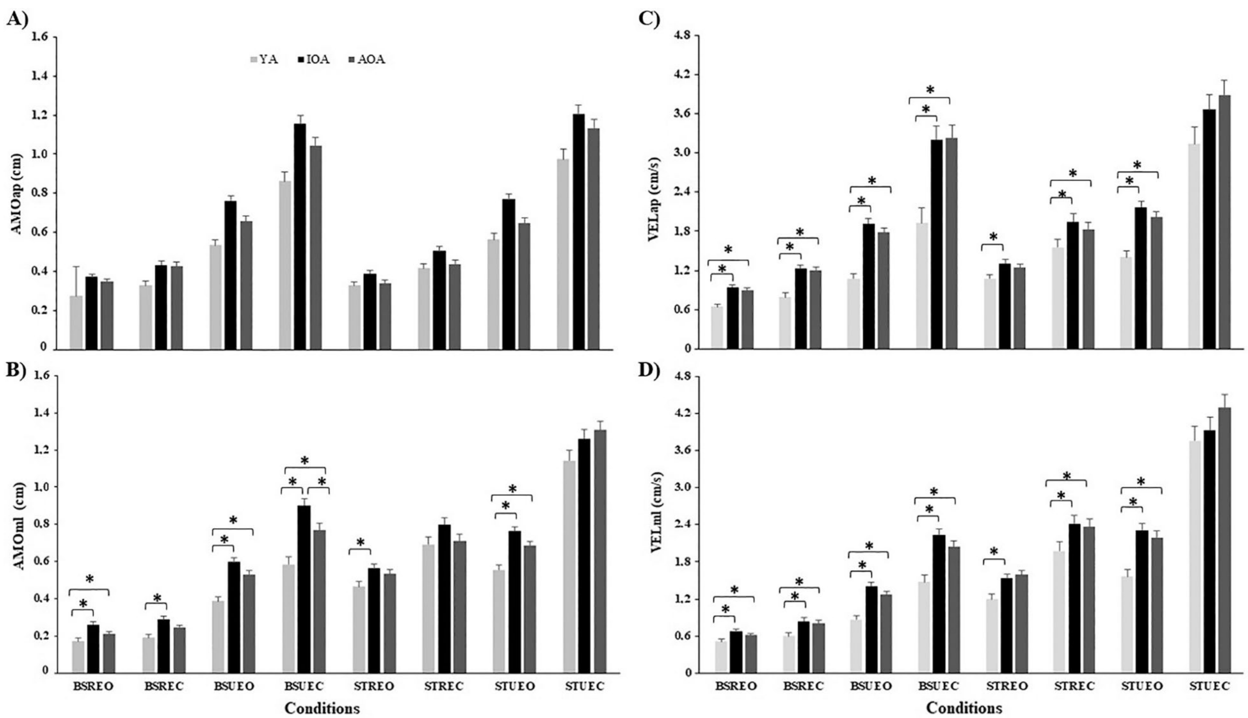

Figure 1 - Mean and standard deviation of the MSA_AP (A), MSA_ML (B), VEL_AP (C), and VEL_ML (D) variables for the YA, AOA, and IOA groups under experimental conditions.

Variables in the frequency domain

The MANCOVAs revealed a triple-interaction effect. The ANCOVAs showed an effect for the "50% and 80% total power spectral density (PSD)" frequency variables in the mediolateral direction (ML) (Table 3). MANCOVAs did not revealed main effect of body mass index (Wilks' $\lambda = 0.955$, $F_{2,81} = 1.89$, $p = 0.16$) and plantar skin sensitivity (Wilks' $\lambda = 0.984$, $F_{2,81} = 0.63$, $p = 0.53$) for FREQ50 in AP and ML directions. Furthermore, MANCOVAs did not revealed main effect of body mass index (Wilks' $\lambda = 0.994$, $F_{2,81} = 0.25$, $p = 0.77$) and plantar skin sensitivity (Wilks' $\lambda = 0.996$, $F_{2,81} = 0.15$, $p = 0.86$) for FREQ80 in AP and ML directions.

Post hoc analyses revealed that the IOA group presented higher FREQ50 in the mediolateral direction than the AOA group, under the following conditions: BSREO (0.074 Hz | 0.047 Hz, respectively), BSREC (0.092 Hz | 0.063 Hz), BSUEO (0.345 Hz | 0.278 Hz, respectively), BSUEC (0.813 Hz | 0.594 Hz), STREO (0.314 Hz | 0.274 Hz), and STUEO (0.590 Hz | 0.464 Hz) (Figure 2). In addition, IOA presented higher FREQ50 in the mediolateral direction than YA under the following conditions: BSREO (0.074 Hz | 0.028 Hz, respectively), BSREC (0.092 Hz | 0.035 Hz), BSUEO (0.345 Hz | 0.150 Hz), BSUEC (0.813 Hz | 0.336 Hz), STREO (0.314 Hz | 0.205 Hz), and STUEO (0.590 Hz | 0.290 Hz). Finally, AOA presented higher FREQ50 in the mediolateral direction than YA under the following conditions: BSUEO (0.278 Hz | 0.150 Hz, respectively), BSUEC (0.594 Hz | 0.336 Hz), and STUEO (0.464 Hz | 0.290 Hz). For the FREQ80 variable, in the mediolateral direction, IOA presented a higher COP sway frequency compared to YA under the following conditions: BSUEO (1,132 Hz | 0.885 Hz) and BSUEC (1.195 Hz | 0.920 Hz) (Figure 2). AOA also presented higher FREQ80 in the mediolateral direction than YA under the following conditions: BSREC (1.238 Hz | 1.058 Hz, respectively), BSUEO (1.201 Hz | 0.885 Hz), BSUEC (1.317 Hz | 0.920 Hz), and STUEO (1.382 Hz | 1.105 Hz) (Figure 2).

Discussion

This study aimed to investigate postural control performance in active and inactive older adults, as well as in young adults, using time and frequency variables as a function of the difficulty level of the postural task. These three hypotheses were partially supported. IOA presented higher MSA in the mediolateral direction than AOA only in bipedal stance on an unstable surface with eyes closed condition. In relation to frequency variables, IOA presented greater FREQ50 in the mediolateral direction than AOA in all experimental conditions, except for a semi-tandem stance on a rigid surface. AOA and IOA presented an increase in time/frequency variables in both directions (anterior-posterior and medio-lateral) than YA that indicates a worse performance in postural control as the level

Table 3 - F, p, and η_p^2 values for the main effect and triple interaction between factors (group, condition, vision, and group*condition*vision) of MANCOVAs and ANCOVAs for variables in the frequency domain: frequency 50% (FREQ50) and frequency 80% (FREQ80) of the total spectral density (PSD) in the anteroposterior (AP) and mediolateral (ML) directions.

Variables	Group	Condition	Vision	Group*Condition*Vision
MANCOVA	Wilk's lambda = 0.705, $F_{4,164} = 7.842$, $p \leq 0.0001$, $\eta_p^2 = 0.161$	Wilk's lambda = 0.085, $F_{6,78} = 139.832$, $p \leq 0.0001$, $\eta_p^2 = 0.910$	Wilk's lambda = 0.223, $F_{2,82} = 142.534$, $p \leq 0.0001$, $\eta_p^2 = 0.777$	Wilk's lambda = 0.733, $F_{12,156} = 2.184$, $p = 0.015$, $\eta_p^2 = 0.144$
ANCOVA				
FREQ50_AP	$F_{2,83} = 6.776$, $p = 0.0002$, $\eta_p^2 = 0.140$	$F_{3,249} = 124.163$, $p \leq 0.0001$, $\eta_p^2 = 0.599$	$F_{1,83} = 35.516$, $p \leq 0.0001$, $\eta_p^2 = 0.300$	$F_{6,249} = 0.907$, $p = 0.49$, $\eta_p^2 = 0.021$
FREQ50_ML	$F_{2,83} = 8.896$, $p \leq 0.0001$, $\eta_p^2 = 0.177$	$F_{3,249} = 244.465$, $p \leq 0.0001$, $\eta_p^2 = 0.747$	$F_{1,83} = 263.045$, $p \leq 0.0001$, $\eta_p^2 = 0.760$	$F_{6,249} = 2.191$, $p = 0.044$, $\eta_p^2 = 0.050$
MANCOVA	Wilk's lambda = 0.894, $F_{4,164} = 2.352$, $p = 0.056$, $\eta_p^2 = 0.054$	Wilk's lambda = 0.109, $F_{6,78} = 106.723$, $p \leq 0.0001$, $\eta_p^2 = 0.891$	Wilk's lambda = 0.649, $F_{2,82} = 22.152$, $p \leq 0.0001$, $\eta_p^2 = 0.351$	Wilk's lambda = 0.719, $F_{12,156} = 2.329$, $p = 0.009$, $\eta_p^2 = 0.152$
ANCOVA				
FREQ80_AP	$F_{2,83} = 4.338$, $p = 0.016$, $\eta_p^2 = 0.095$	$F_{3,249} = 30.657$, $p \leq 0.0001$, $\eta_p^2 = 0.270$	$F_{1,83} = 30.054$, $p \leq 0.0001$, $\eta_p^2 = 0.266$	$F_{6,249} = 1.636$, $p = .138$, $\eta_p^2 = 0.038$
FREQ80_ML	$F_{2,83} = 2.744$, $p = 0.070$, $\eta_p^2 = 0.062$	$F_{3,249} = 140.745$, $p \leq 0.0001$, $\eta_p^2 = 0.629$	$F_{1,83} = 0.323$, $p \leq 0.0001$, $\eta_p^2 = 0.266$	$F_{6,249} = 2.882$, $p = 0.010$, $\eta_p^2 = 0.065$

of task difficulty increased, such as unstable base with eyes open and closed.

Behavior of time and frequency variables in active and inactive older adults assessed through postural tasks with different levels of complexity

Active older adults presented a lower mean COP sway amplitude when subjected to the bipedal stance on an unstable surface with eyes closed in the mediolateral direction than inactive older adults. They also presented a lower 50% COP sway frequency under bipedal stance with a stable surface and with their eyes open, bipedal stance on an unstable surface with eyes closed, and semi-tandem stance on an unstable surface with eyes open. These results show the benefit of physical exercise on postural control in older adults, favoring their better performance as a function of the difficulty level of the postural task. Another study[29] evidence that physical exercise improves older adults' cognitive and motor aspects, helping in balance when they are subjected to more challenging tasks. Moreover, the difference between older and younger adults was more evident in the inactive older adult groups. This shows that physical exercise can reduce the deterioration in balance[15] and facilitate physiological adaptations, thus preserving and improving the older adults' functional, neuromotor, and coordination capacity[13].

Due to changes in the sensorimotor system accelerated by physical inactivity, inactive older adults have less mobility and postural balance[31], which generates unstable postural control[9] that increases the risk of falling[7]. Moreover, physical inactivity deteriorates the systems responsible for maintaining postural control[12], which explains why inactive older adults present greater COP sway than active older adults.

In the bipedal stance on an unstable surface with eyes closed, active older adults also presented a better postural performance for the MSA variable in the mediolateral direction than inactive older adults. This result shows that physical exercise can promote less dependence on the somatosensory system in balance control. It also influences the maintenance of the vestibular system and, consequently, better postural control and stability inactive older adults. Thus, physical exercise allows repetitive stimuli that provide new information to the nervous and vestibular systems, improving the perception of information[32]. Furthermore, it improves proprioceptive feedback from older adults and restores vestibular orientation[33]. In addition, physical exercise provides the necessary stimuli for reorganization and sensory physical integrity, thus improving postural control, visual stability, and vestibulo-visual interaction, allowing postural stability in situations with challenging sensory information[34].

Consistent with the results of this investigation, some studies[35-37] have also reported that physical exercise directly influences postural control in older adults and allows active older adults to have better balance and postural control, with a lower mean COP sway amplitude in the mediolateral direction compared to inactive ones. Thus, it can be stated that the impairments in the postural control system are due to not only the aging process but also factors related to physical inactivity[12]. Victor et al. (2014)[38] compared balance in the unipedal stance with eyes open between IOAs and AOAs, finding that IOAs had a higher mean COP sway frequency in the mediolateral direction, which is reflected in lower levels of

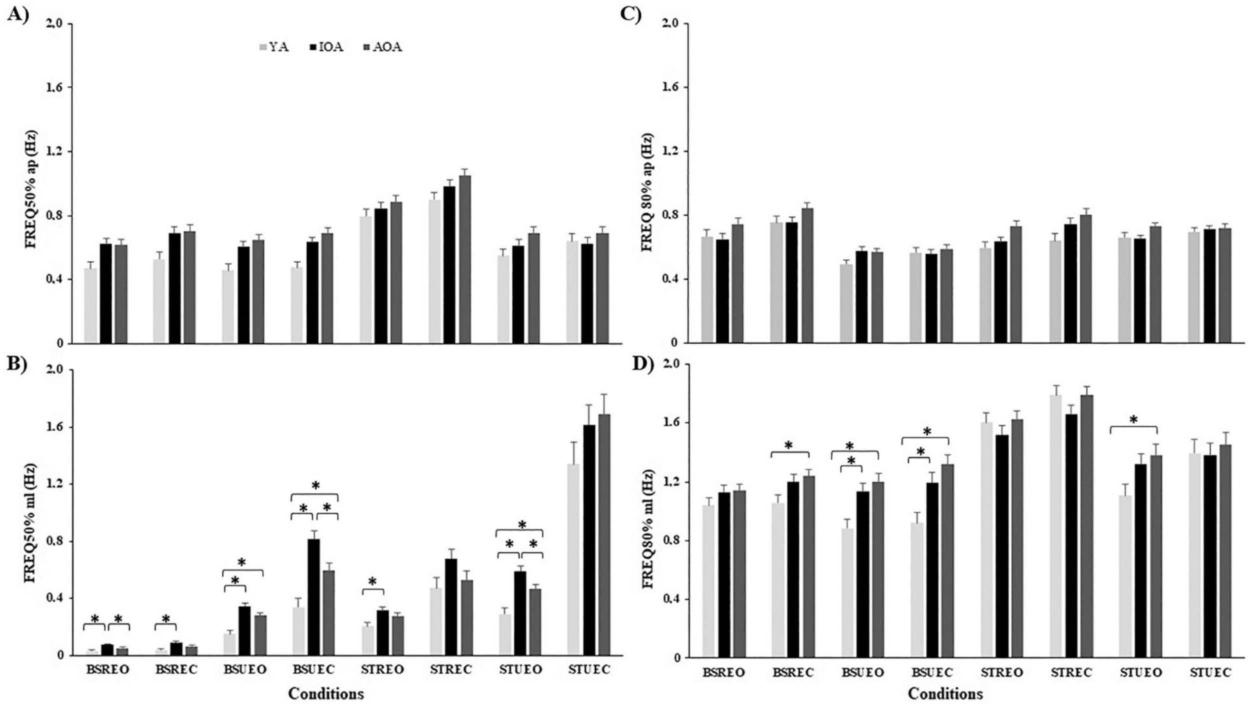

Figure 2 - Mean and standard deviation of the FREQ50_AP (A), FREQ50_ML (B), FREQ80_AP (C), and FREQ80_ML (D) variables for the YA, AOA, and IOA groups under experimental conditions.

stability and worse postural control on unipedal support, even without visual disturbance - this is consistent with and partially explains this study's results. In the present study, we found that in the eyes closed condition, AOAs presented a lower COP sway frequency than IOAs. The same happens when the task difficulty level is changed, such as a bipedal stance on an unstable surface with eyes open, or closed, and a semi-tandem stance on an unstable surface with eyes open, emphasizing a greater deficit in postural balance and susceptibility to falls among IOAs.

Unlike studies that evaluated balance in older adults only under stable conditions[35-37] and with unipedal support[34,37], this study examined postural control through time and frequency variables in active and inactive older adults through different postural tasks. Therefore, it adds to the literature the finding that aging and the level of physical activity influence the postural behavior and performance of older adults, in accordance with the level of challenging postural tasks present in everyday life.

Behavior of time and frequency variables in older and young adults were assessed through postural tasks with different levels of complexity

Compared to young adults, older adult participants presented higher COP velocity in the mediolateral direction for all bipedal support conditions, as well as in the semi-tandem stance on a rigid surface with eyes closed and on an unstable surface with eyes open. Older adults also showed greater mean COP sway amplitude and 50% sway frequency in the mediolateral direction for all bipedal stances and semi-tandem stances on an unstable surface with eyes open. Finally, a greater sway in the 80% frequency was also found among the older adults in the mediolateral direction on the bipedal stance on a rigid surface with eyes closed, bipedal stance on an unstable surface with eyes open, and bipedal stance on an unstable surface with eyes closed, as well as for the semi-tandem stance on an unstable surface with eyes open.

These results show that aging causes neurodegenerative changes and acts directly on postural control performance, promoting a decline in functional capacity and lower efficiency of the systems responsible for postural adjustments. Studies[34,38] have shown that deterioration of postural control is not only related to the reduced capacity of the central nervous system in efficiently integrating vestibular, visual, and proprioceptive commands responsible for maintaining postural balance, but also to the incidence rates of sensory impairments (visual, somatosensory, and vestibular) that increase with aging. The increase in body sway is associated with an age-related decline in postural control[39]. This could be considered a strategy for optimizing the performance of postural control and decreasing the risk of falling[7].

These results suggest that postural control changes due to aging, which may be more evident when older adults are exposed to unstable surfaces and/or deprived of visual information. The literature shows that increased sway velocity is a strong indicator of postural deterioration[40] and the ability to perform postural adjustments necessary for a complex task is reduced due to aging, contributing to a more unstable postural control[9]. Tavares et al. (2017)[7] evaluated the postural balance of older adult women and young adult women on a force platform (with foam) with the eyes open and closed. They found that older adults showed greater body sway than young adults as a function of task complexity. Furthermore, higher values were found when the complexity of the task increased, for example, in foam, semi-tandem, and eyes closed conditions, which corroborates the findings of this study. Similar changes in postural control as a function of the support base were also reported by Gotardi et al. (2018)[9], who found that older adults had a greater COP displacement velocity than young adults, and sway velocity was greater for the older adults on the semi-tandem support base in the mediolateral direction. This study's results confirm that older adults have sensory and motor deficits that lead to increased postural instability in the semi-tandem stance compared to the bipedal stance[41].

For the experimental conditions on bipedal support and semi-tandem support, with and without sensory change on an unstable surface and stable surface, older adults presented greater mean COP sway amplitude in the mediolateral direction than young adults. This shows that older adults have impaired postural performance and less balance control with or without manipulation of the support base or on an unstable surface. The analysis of the performance of older individuals on bipedal support[8] and semi-tandem support base[42] obtains similar results. In this studies[8,42], older adults showed a greater mean sway amplitude in the mediolateral direction in bipedal and semi-tandem support than younger adults. When older adults were submitted to a more unstable base of support, they presented a lower capacity to maintain postural stability, which corroborates this study's results. The maintenance of postural balance becomes a more complex process for older adults, as they present a decline in somatosensory and motor skills. As a strategy to recover posture and maintain stability in challenging situations, older adults have greater COP oscillation, which can be considered a compensatory adaptive strategy.

For the 50% COP frequency variable, older adults showed greater mediolateral sway than young adults for all bipedal support conditions and in the semi-tandem on a rigid surface and unstable surface with eyes open conditions. These results indicate that older adults tend to make postural adjustments in an attempt to minimize postural imbalance and make the task more secure and stable. Previous studies[8,32], comparing the COP sway FREQ50 between young and older people in the bipedal stance on the force platform, also identified that older participants had a higher 50% sway frequency in the mediolateral direction than young adults. Regarding the semi-tandem support base, the literature[9,43] shows that a smaller support base for older adults results in lower postural stability and greater center of pressure sway. This explains the results presented by the older adults in this study, showing greater difficulty in maintaining balance and postural control than young adults.

Finally, for the COP FREQ80 variable, the results obtained were similar. Compared to young adults, older adults presented greater sway in the mediolateral direction, bipedal stance on a rigid surface with eyes closed, bipedal stance on an unstable surface with eyes open and eyes closed, as well as for the semi-tandem stance on an unstable surface with eyes open. These results show that older adults, when subjected to tasks with different levels of complexity, even if minimal, have greater difficulties in performing them, with evident postural changes, which are identified by the greater COP sway at 80% frequency.

Furthermore, higher physiological levels of body sway are commonly found in older adults when they are subjected to more complex situations[42], because they have limited functioning of sensory systems[32], which impairs performance in tasks as the difficulty level increases, for example, on the semi-tandem base of support[44]. In addition, there is a reduced ability to make postural adjustments necessary for the visual task, which contributes to a more unstable postural control when they are subjected to this type of disturbance[9]. Therefore, it is possible to identify from the results reported here that older adult participants presented worse balance control, and those physical and sensorimotor strategies tend to be less effective, reflecting in a greater COP FREQ80 when in a semi-tandem stance, as a conservative and adaptive way to avoid falling, under complex conditions. Moreover, we also found that older adults presented higher Body Mass Index and plantar skin sensitivity than young adults. Some studies have shown that both variables may influence the balance[45,46]. However, our results showed that plantar skin sensitivity and Body Mass Index did not influence the postural control variables. Thus, the difference between older and younger adults for postural control performance is due to aging and physical activity level.

Although there was a difference in the composition of the sexes between the groups, in this study, gender was not included in the analysis. Recent studies[47-49] have shown that there is no difference between genders in terms of postural stability. Thus, balance disturbance is associated with aging and low physical activity levels, which increase the risk of falling.

A possible limitation of this study is that we did not divide the younger adults into similar groups (active and inactive), because we could not recruit a sufficient number of young adult participants. For future studies, it would be interesting to investigate the effect of training with balance exercises on the time and frequency variables of postural control with different levels of postural task difficulty in young and older adults.

Conclusion

Based on this study's results, it was possible to identify that older adults tend to present greater COP sway and velocity when subjected to tasks with different levels of complexity, compared to young adults, which is even more evident in inactive older adults, independently of body mass index and plantar skin sensitivity. For this behavior, the CoP is considered an adaptation strategy in an attempt to minimize the risk of losing balance and, consequently, falling. Postural control performance as a function of tasks that are similar to daily activities among older adults identifies their motor behavior and allows for better planning for fall prevention programs targeting older people and for the rehabilitation of those with a history of falls. Furthermore, this study contributed to addressing the gap that existed so far concerning the behavior of time-related posturographic variables and, mainly, frequency variables that have not been elucidated in the literature.

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