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Postural balance and body mass index in older adults; a descriptive and associative study testing traditional risk factors

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Background: *There is a scarcity of information about how much the postural balance parameters, as the area and mean velocity of the center of pressure (CoP), can be modified by traditionally adiposity markers in older adults.* ***Objectives:*** *To describe and associate postural balance parameters in Chilean older adults with different BMI. A second objective was to associate the area of balance with weight.* ***Methods:*** *In a descriptive study, Chilean older adults (mean age; 70 ± 1.0, BMI 29.0 ± 0.4 kg/m²) were categorized by a normoweight control group (CG, n = 7, BMI; 23.1 ± 0.5), overweight (OvW, n = 41, BMI; 27.6 ± 0.2), and obesity (Ob, n = 23, BMI; 34.2 ± 0.5). The subjects were evaluated on a stable/hard [HS]/soft [SS] surface, and under open [OE]/closed [CE] eyes. Secondary outcomes were weight, height, BMI, and functional health. Univariate test and linear regression were applied.* ***Results:*** *CoP mean velocity on the HS and CE, showed significant differences between CG vs. OvW groups (24.9 ± 7.4 mm/s vs. 12.1 ± 0.97 mm/s, p < 0.0001). There were significant differences in Romberg index between CG vs. OvW group (176.7 ± 16.4% vs. 132.4 ± 7.1%, p = 0.002), and between CG vs. Ob group (176.7 ± 16.4% vs. 129.4 ± 17.2%, p = 0.005). On the SS with OE, there were significant differences between CG vs. OvW groups (29.8 ± 4.8 mm/s vs. 18.6 ± 1.2 mm/s, p < 0.003), and, on the SS, with CE, between CG vs. OvW groups (41.5 ± 31.2 mm/s vs. 24.6 ± 15.2 mm/s, p = 0.015).* ***Conclusions:*** *At higher BMI such as at overweight or obesity conditions, older adults show a reduced 'CoP mean velocity' than control normoweight peers', being 'weight' a traditional adiposity risk factor predictor of balance performance.*

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Key words: *Body Mass Index; Aging; Postural Balance.*

Balance postural e índice de masa corporal en adultos mayores; un estudio descriptivo y asociativo con los factores de riesgo tradicionales

Introducción: *Existe escaza información acerca de cómo los parámetros del balance postural, como el área y velocidad media del centro de presión (CoP), pueden ser modificados por marcadores tradicionales de adiposidad en personas mayores.* ***Objetivos:*** *Describir y asociar parámetros del balance postural en*

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personas mayores con diferente IMC. Un segundo objetivo fue asociar el área de balance con el peso. ***Métodos:*** *Estudio descriptivo con personas mayores chilenas (Edad; 70 ± 1.0, IMC 29,0 ± 0,4 kg/m^2) fueron categorizadas en un grupo normopeso o control (CG, n = 7, IMC; 23,1 ± 0,5), sobrepeso (OvW, n = 41, IMC; 27,6 ± 0,2) y obesidad (Ob, n = 23, IMC; 34,2 ± 0,5). Los sujetos fueron evaluados en una superficie estable/dura [HS]/ e inestable o blanda [SS], y bajo ojos abiertos [OE]/y cerrados [CE]. Fueron variables secundarias el peso, talla, IMC y la salud funcional. Test univariado y regresión lineal fueron aplicados.* ***Resultados:*** *La velocidad media del CoP en HS con CE, mostró diferencias significativas entre los grupos CG vs OvW (24.9 ± 7.4 mm/s vs 12,1 ± 0,97 mm/s, p < 0,0001). Existieron diferencias significativas entre el Índice de Romberg entre CG vs OvW (176,7 ± 132,4% vs 121,3 ± 7,1%, p = 0,002) y entre CG vs Ob group (176,7 ± 16,4% vs. 129,4 ± 17,2%, p = 0,005). En SS con OE, existieron diferencias significativas entre CG vs OvW (29,8 ± 4,8 mm/s vs 18,6 ± 1,2 mm/s, p < 0,003), y sobre SS, con CE, entre CG vs OvW (41,5 ± 31,2 mm/s vs 24,6 ± 15,2 mm/s, p = 0,015).* ***Conclusiones:*** *A un elevado IMC, como en condiciones de sobrepeso u obesidad, personas mayores muestran una reducida velocidad media CoP en relación a sus pares normopeso, siendo el peso un factor de adiposidad tradicional predictor del balance.*

Palabras clave: *Envejecimiento, Índice de Masa Corporal; Equilibrio Postural.*

The condition of higher adiposity, commonly known as overweight/obesity, is strongly related to a worsening in the ability to carry out activities of daily living such as walking, and climbing stairs, where older adults (OA) receive a major impact under these limitations[1]. This cohort frequently shows more risk of falls and tripping during walking compared to normal weight controls[2], leading to more hospitalizations and dependency. In this sense, a systematic review recently pointed out that nutritional status and body mass index (BMI) would be associated with the risk of suffering falls in OA[3].

Maintaining balance while standing or in dynamic postures requires adequate postural control, which is based on the use of strategies to counteract different external forces to prevent falls, which can be altered by different conditions, such as greater body mass[4]. Higher BMI was reported to show a strong association with poor balance and gait performance[5,6], and worryingly this association is exacerbated for OA[7]. On the other hand, in body composition, a sedentary lifestyle and physical inactivity decrease lean mass, and increase body fat in older populations[6], which are associated with muscle weakness and thus promote detrimental changes in normal gait and postural balance[8]. In this sense, the worsening of walking performance has been attributed to the worsening of the muscular capacity to recover postural balance immediately after a disturbance to prevent a fall[8].

Postural balance is usually assessed while standing through standardized instrumental methods that record the center of pressure (CoP) obtained on a force platform. CoP area and mean velocity in the standing position are two frequently used outcomes related to fall risk[9] and have been useful as markers for fall prevention[10]. For example, physically active OA show better performance in the 'CoP area' than their inactive peers[11]. Although there is abundant information on the effect of obesity on postural balance, its behavior in OA categorized according to their BMI is still being discussed. Recent reports have shown that OA with obesity, reported a significant association between the reduced postural balance on unstable conditions and increased risk of falls in these cohorts[12]. Interestingly, other studies report obesity as a protective state, in which obese older adults reported a significant association with a reduced risk of falls and hip fractures[13].

Understanding the importance that postural balance in the OA is considered a complex sensorimotor skill[14] and that the increase in body mass would imply a greater demand for control to maintain stability safely and thus avoid risks of falls, the objective of this study was to describe and associate the postural balance parameters, as the area and mean velocity of the CoP, of Chilean OA with different BMI. A second aim consisted of associating the results of the area of balance and mean velocity with 'adiposity' marker such as weight and BMI.

Material and Methods

Study design

This descriptive study was carried out between the 2018 and 2019 years. The participants were older adults (OA) between 60 and 80 years of age, recruited from different social clubs of Talca city, Chile.

All participants recruited participated in the Functional Examination of the older adult (EFAM), which is an instrument applied by the Chilean Ministry of Health for predicting the functionality independence loss of the OA[15].

The inclusion criteria, were as follows; a) to be classified as self-sufficient with or without risk of dependence' by the EFAM test, b) to present 'independent gait' and 'without supportive assistance', c) controlled chronic pathologies and without a history of frequent falls. The exclusion criteria were; a) the presence of vestibular disorders, b) central or peripheral neurological disease, c) uncorrected visual impairment, and d) musculoskeletal disorders involving significant functional impairments. The study adhered to the Declaration of Helsinki, all participants gave their written informed consent, and was approved by the Scientific Ethic Committee of the University of Talca (Number: 1A-2018).

Postural balance protocol

The postural balance was measured with a force platform (Bertec, USA) with an area of 50 x 43 cm. A data acquisition frequency was set at 100 Hz and stored with Digital Acquire-4 software (Bertec, USA). The postural balance test[17,18] consisted of 4 stages: (1) open_eyes (OE) on a hard_surface (HS), (2) closed_eyes (CE) on a HS, (3) OE on a medium density foam (soft_surface: SS), and (4) CE on a SS. Each stage lasted 30 s and a 1 min rest was allowed between each trial. For the SS, a medium density foam (20-30 kg/m^3) was used, located on the platform. The CoP data obtained from the force plate were low-pass filtered with a fourth-order Butterworth filter and a cutoff frequency of 10 Hz, and the offset of the CoP data was also removed. Each participant stood barefoot on the platform, with a comfortable posture and with their feet separated at shoulder width, and the position of the feet was marked to reproduce it in each of the tests.

Outcomes

Of the CoPs outcomes obtained during each test, a) the value of the area (mm^2) was obtained by calculating the ellipse of 95% of the dispersion measurements of the CoP signal, b) the mean velocity (mm/s) of the CoP was calculated by dividing the total oscillation of the CoP in both directions by the total duration of the test. In each test, the Romberg Index (RI) was applied, defined as the percentage (%) of the eyes closed/eyes open ratio. The analysis was performed with MATLAB® V15a software (MathWorks, USA). Thus, the main outcomes were; i) Area of Balance oe-HS, ii) Area of Balance ce-HS, iii) Romberg index-HS; iv) Area of Balance oe-SS, v) Area of Balance ce-SS, vi) Romberg index-SS; vii) Mean velocity oe-HS, viii) Mean velocity ce-HS, the ix) Romberg index-HS, x) Mean velocity oe-SS, xi) Mean velocity ce-SS, and xii) Romberg index-SS. Secondary outcomes were weight, height, BMI, and EFAM score. The CoP area and mean velocity were compared by BMI groups from Ob and OvW groups versus those at the normoweight state of the CG.

Anthropometric measurements protocol

Weight and height were measured with the participant in light clothing and barefoot, in a private and tempered room (22 ± 1°C). A standardized scale calibrated to a precision of 0.1 kg was used to determine body weight (Webb City, USA). A stadiometer with 0.1 cm precision was used to record the height (m). BMI was calculated as body mass/(height^2) for all subjects, and all participants were categorized by a control group, who were in normoweight (CG, BMI; 23.1 ± 0.5 kg/m^2), overweight (OvW, BMI; 27.6 ± 0.2 kg/m^2), or obesity (Ob, BMI; 34.2 ± 0.5 kg/m^2).

Statistical analyses

Data are presented as the mean ± standard error mean (SEM). Normality and homoscedasticity assumptions were analyzed using the Kolmogorov-Smirnov and the F Levene's test, respectively. To normal distribution outcomes, a Univariant test was applied using Sidak's post hoc for group comparisons. To nonparametric comparisons among groups, the Games-Howell post hoc test was applied. A trend analysis (ptrend) was also applied to test trend across the BMI categories in each outcome. Additionally, the effect size partial squared for interaction was assessed by η^2 obtained and reported by small (η^2 = 0.01), medium (η^2 = 0.06), and large (η^2 = 0.14) effect size defined according to Cohen J.[16]. Linear regression showing βeta coefficient (β), and predictive percentage (%) from R^2 was applied to the associations expressed in natural log with weight. All statistical analyses were performed with SPSS software V28.0 (SPSSTM Inc., IL, USA), and the Graphs and Figures were carried out in GraphPad Prism V8.0 (USA). The alpha level was set at $p < 0.05$ for statistical significance.

Results

At baseline, there were no significant interaction among groups in age, height, and at functional condition (Table 1). There were significant interaction in weight among groups (F(21.0), p = 0.001, 0.38), particularly between CG vs. OvW (58.1 ± 2.2 kg vs. 72.6 ± 1.5 kg, $p < 0.05$), between CG vs. Ob (58.1 ± 2.2 kg vs. 85.2 ± 2.9 kg, $p < 0.05$), and between OvW vs. Ob (72.6 ± 1.5 kg vs. 85.2 ± 2.9 kg, $p < 0.05$), (Table 1). There were significant interaction in BMI among groups (F(134.4), p = 0.001, 0.79), particularly between CG vs. OvW (23.1 ± 0.5 kg/m^2 vs. 27.6 ± 0.2 kg/m^2, $p < 0.05$), between CG vs. Ob group (23.1 ± 0.5 kg/m^2 vs. 34.2 ± 0.5 kg/m^2, $p < 0.05$), and between OvW vs. Ob (27.6 ± 0.2 kg/m^2 vs. 34.2 ± 0.5 kg/m^2, $p < 0.05$), (Table 1).

Considering the three BMI groups, there was no significant interaction in the area of balance, and no significant trend was detected (Figure 1A–F).

On the ce-HS, there was significant interaction among groups (F(4.14), p = 0.009, η^2 = 0.15), particularly between CG vs. OvW (24.9 ± 7.4 mm/s vs. 12.1 ± 0.97 mm/s, $p < 0.0001$) (Figure 2B). At HS, there were significant interaction among groups (F(4.97), p = 0.004, η^2 = 0.18), particularly at Romberg index-HS between CG vs. OvW (176.7 ± 16.4 % vs. 132.4 ± 7.1%, p = 0.002) (Figure 2C), and Romberg index-HS between CG vs. Ob (176.7 ± 16.4% vs. 129.4 ± 17.2%, p = 0.005) (Figure 2C). Similarly, at the oe-SS, there was significant

Table 1. General characteristics of Chilean older adults under three different body mass index categories

Outcomes	CG[a]	Overweight[b]	Obesity[c]	F test, p value[¥], Effect Size (η^2)
(n =)	7	41	23	
Age (y)	70.0 ± 2.0	69.0 ± 1.0	71.5 ± 1.5	F(0.63), p = 0.535[¥], 0.01
Anthropometric				
Weight (kg)	58.1 ± 2.2	72.6 ± 1.5[a]	85.2 ± 2.9[ab]	F(21.0), p = 0.001[¥], 0.38
Height (m)	1.59 ± 0.04	1.62 ± 0.02	1.57 ± 0.03	F(1.35), p = 0.265[¥], 0.03
Body mass index (kg/m^2)	23.1 ± 0.5	27.6 ± 0.2[ac]	34.2 ± 0.5[ab]	F(134.4), p = 0.001[¥], 0.79
[&]Functional condition (by EFAM test)				
Self-sufficient without risk (n = / %)	6 (12.8)	27 (57.4)	14 (29.8)	p = 0.476†
Self-sufficient with risk (n = / %)	1 (4.2)	14 (58.3)	9 (37.5)	

(¥) Denotes continuous data analyzed by Univariant test. (†) Denotes data analyzed by ordinal Tau-b de Kendall test. (EFAM test). (&) Ordinal variables are described as frequency (n =), and percentage (%).

General characteristics of Chilean older adults under three different body mass index categories.

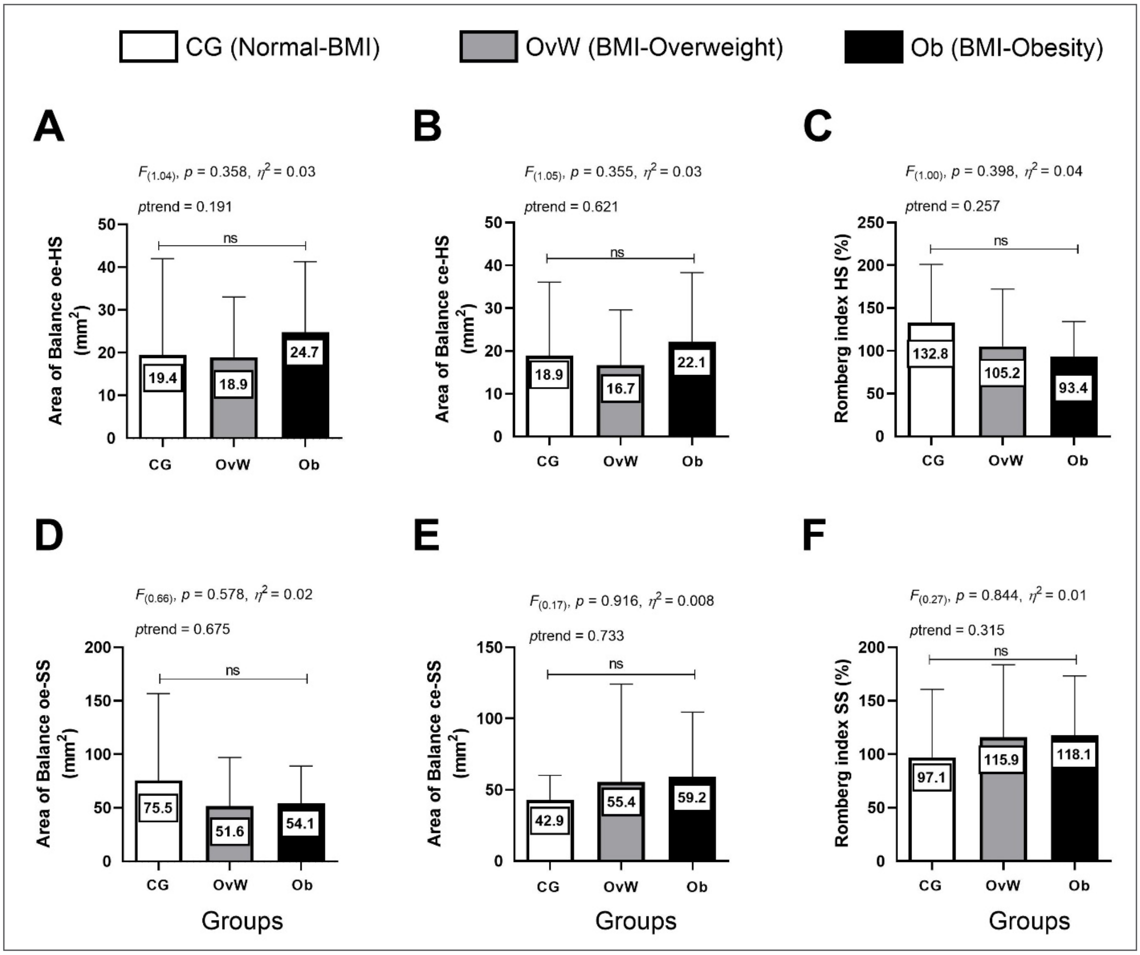

Figure 1. Area of balance (mm^2) in three BMI groups of Chilean older adults participants of the study. Panels A,B show the CoP area in open and closed eyes at hard surfaces, and panels D,E show the CoP area at open and closed eyes at the condition of soft surfaces. Panels C,F shows the Romberg index in (%), at hard and soft surfaces conditions. Groups of BMI are described as; (CG) Control group who were participants at normoweight, (OvW) Overweight, and (Ob) Obesity group classification. The interaction was tested by Univariant nonparametric Sidak's *post hoc* at $p < 0.05$. (η^2) Denotes Cohen d effect size. (ns) Denotes no significant differences between-groups among groups.

interaction among groups ($F(3.53)$, $p = 0.019$, $\eta^2 = 0.13$), particularly between CG vs. OvW (29.8 ± 4.8 mm/s vs. 18.6 ± 1.2 mm/s, $p < 0.003$) (Figure 2D). Additionally, on the ce-SS, there were significant differences between CG vs. OvW (41.5 ± 31.2 mm/s vs. 24.6 ± 15.2 mm/s, $p = 0.015$) (Figure 2E).

Lineal regression analyses revealed significant association between 'weight' with the Area of balance oe-HS ($\beta = 0.026$; $R^2 = 0.198$ (19.8% prediction), $p < 0.001$) (Figure 3, panel A); 'weight' with the Area of balance ce-HS ($\beta = 0.028$; $R^2 = 0.235$ (23.5% prediction), $p < 0.001$) (Figure 3, panel B), and 'weight' with Area of balance ce-SS ($\beta = 0.020$; $R^2 = 0.110$ (11.0% prediction), $p = 0.005$) (Figure 3, panel D).

No significant association between 'Mean velocity' with weight was detected (Figure 4).

Discussion

The present study has three main findings: i) there was no significant interaction and trends in the 'Area of balance' across different BMI categories, ii) the 'Mean velocity' in both surfaces (HS and SS), and oe and ce conditions (Figure 2 panels

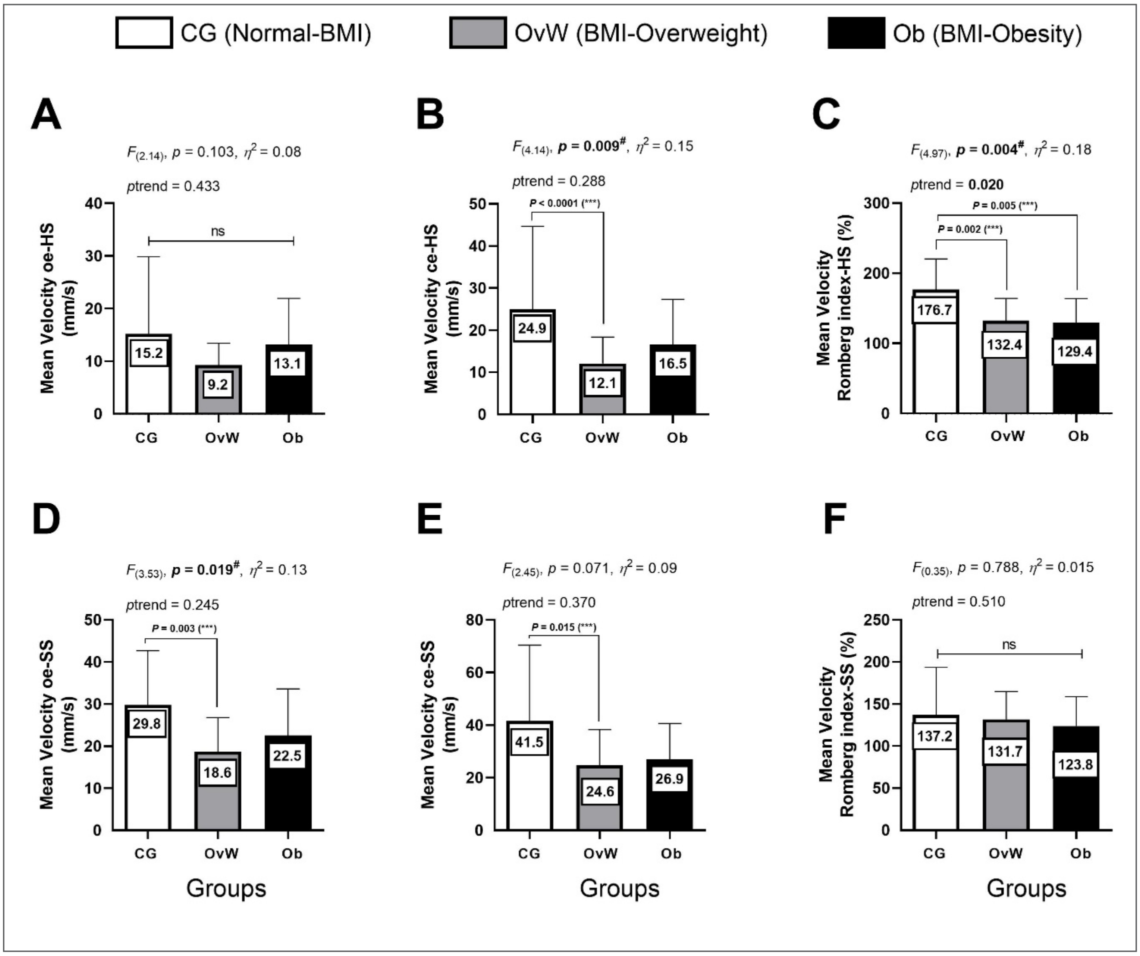

Figure 2. Mean velocity in mm/s (of the centre od pressure) in three BMI groups of Chilean older adults participants of the study. Panels A,B show the mean velocity, open and closed eyes at the condition of hard surface, and panels D,E show the mean velocity, open and closed eyes at the condition of soft surface. Panels C,F show the balance by the Romberg index (in %) at each respective hard and soft surface. Groups of BMI are described as; (CG) Control group who are participants in normoweight BMI, (OvW) Overweight, (Ob) Obesity group classification. (η^2) Denotes Cohen d effect size. (ns) Denotes no significant interaction among groups. The interaction was tested by Univariant nonparametric Sidak's *post hoc* at $p < 0.05$. (***) Denotes significant differences by unpaired t-test at $p < 0.05$. (#) Denotes significant interaction-group at $p < 0.05$ or less.

B,D,E), as well as Romberg index (Figure 3, panels C,F), showed lower values in OA with higher BMI in comparison with control normoweight peers, and iii) traditional adiposity markers as 'weight' is able to predict the Area of balance oe (19.8%), and ce-HS (23.5%), and ce-SS (11%) (Figure 4, panel A,B,D).

Literature frequently reports that OA have a lower capacity for static postural balance than young subjects and that this ability is worsened when subject change when visual input is restricted, as is the situation of performing balance test from the open to closed eyes, as well as when these trials are from a HS (i.e., stably) to another SS (i.e., unstably)[17,18].

The postural balance was previously reported in obese people under different complexities of the task, where there was observed that the mean velocity performance was lower and inversely associated with the middle-side position and displacement velocity of the CoP[19,20]. Interestingly, these results show that in obese OA there are limitations for a rapid/fast and coordinated response of movements multiple joints, showing

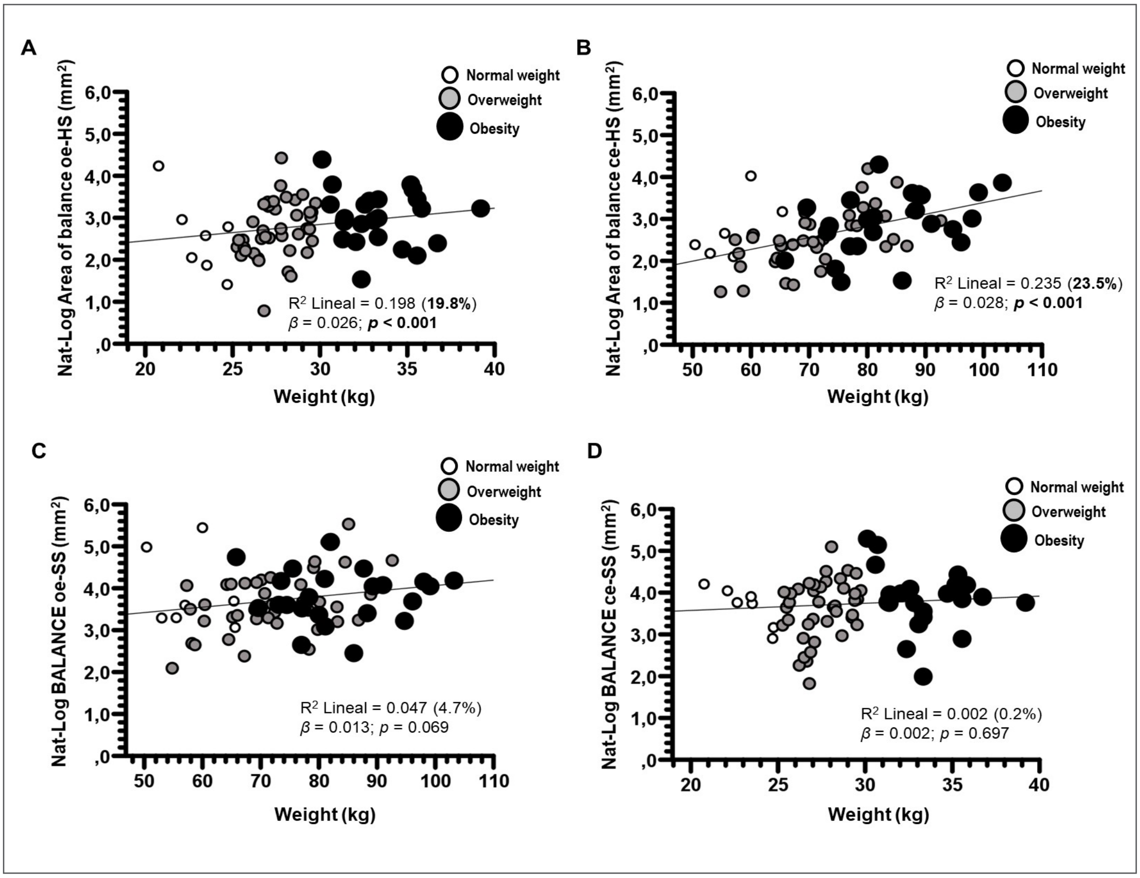

Figure 3. Association between different Areas of balance outcomes (mm^2) with 'weight' (kg) in older adults under normal weight, overweight, or obesity condition. Outcomes are described as; (Nat-Log BALANCE oe-HS) Area of balance measured at open eyes in hard surface (panel A), (Nat-Log BALANCE ce-HS) Area of balance measured at closed eyes in hard surface (panel B), (Nat-Log BALANCE oe-SS) Area of balance measured at open eyes in soft surface (panel C), and (Nat-Log BALANCE ce-SS) CoP area of balance measured at closed eyes in soft surface, all expressed in natural logarithm (panel D). Categories of different adiposity are expressed by body mass index [BMI], as (Normal) BMI 18-24.9 kg/m^2, green color, (Overweight) BMI 25.0-29.9 kg/m^2, yellow color, and (Obesity) BMI ≥ 30.0 kg/m^2, red color markers. Linear regression analyses are shown as; (ß) Beta coefficient. Bold values denote significant association at p < 0.05.

these cohorts a superior stiffness and a low range of movement that affect postural stability[21].

The balance test at a standing position in OA has shown a high oscillation at CoP at both in anterior-posterior and mid-lateral directions[22]. Previously, there was described that the changes over the postural balance attributed to obesity were related with a disruption in the distribution of mass, modifying the position and oscillation of center of mass (CoM), and the size of the support base[23]. By contrast, a wide area of balance is not always associated with postural instability, and more when adults are assessed under the BMI as adiposity marker[24]. For example, Cieślińska-Świder et al[24], found that the postural balance of women was more dependent on the anatomical place in which the adipose tissue was located, being this phenomenon potentially associated with i.e., CoM alteration, and indirectly modifying the balance test. Previously, Teasdale et al[25], show that obese people move the CoM to a forward position under a balance test, concerning the knee joint, causing a decrease in postural sway, which is in coherence with our findings.

There is limited information regarding the CoP velocity and its relationship with obesity. In this regard, some authors have previously reported that the Mean velocity of CoP is highly

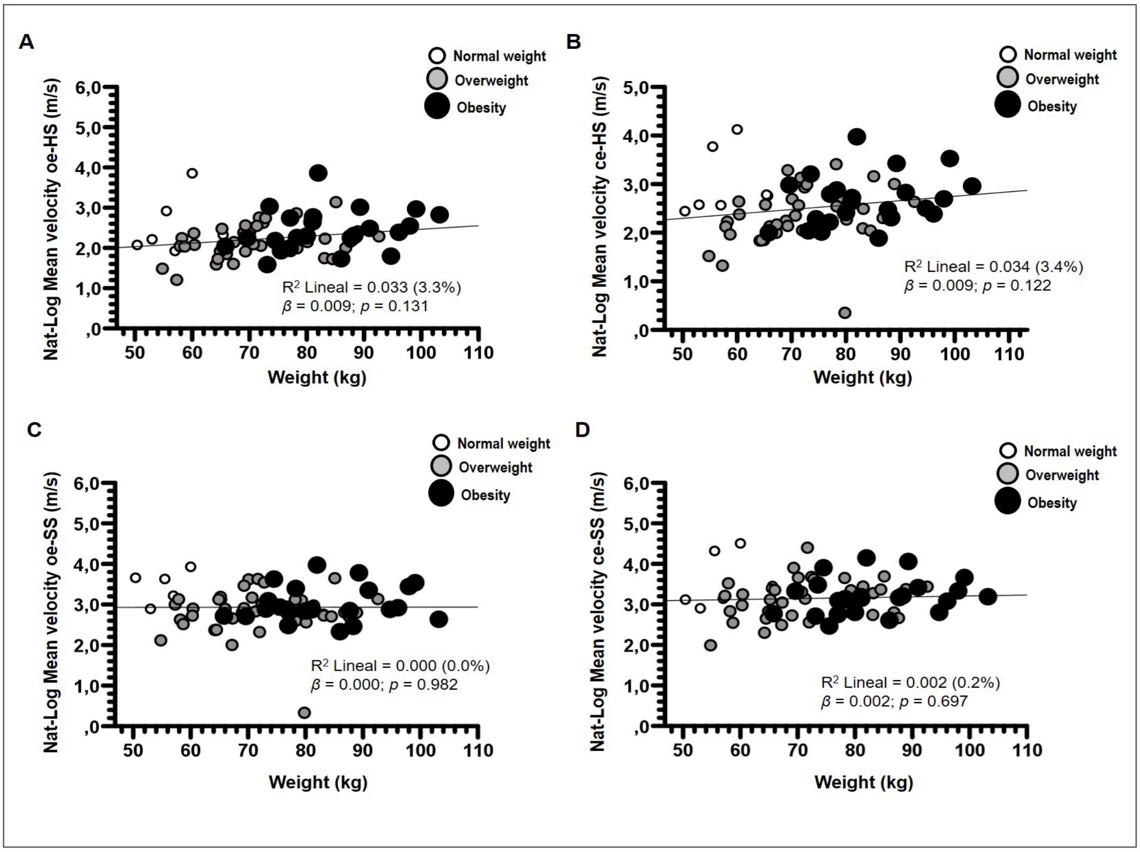

Figure 4. Association between different Mean velocity outcomes (mm/s) with 'weight' (kg) in older adults under normal weight, overweight, or obesity condition. Outcomes are described as; (Nat-Log VELOCITY oe-HS) Mean velocity measured at open eyes in hard surface (panel A), (Nat-Log VELOCITY ce-HS) Mean velocity measured at closed eyes in hard surface (panel B), (Nat-Log VELOCITY oe-SS) Mean velocity measured at open eyes in soft surface (panel C), and (Nat-Log VELOCITY ce-SS) Mean velocity measured at closed eyes in soft surface, all expressed in natural logarithm (panel D). Categories of different adiposity are expressed by body mass index [BMI], as (Normal) BMI 18-24.9 kg/m^2, green color, (Overweight) BMI 25.0-29.9 kg/m^2, yellow color, and (Obesity) BMI ≥ 30.0 kg/m^2, red color markers. Linear regression analyses are shown as; (ß) Beta coefficient.

sensitive to changes in the body inertia that is promoted by a wide distribution of the adiposity in the population with higher BMI as the obesity condition[24,26]. Thus, in subjects with higher BMI, there is an increase in the inertial body due to the adipose tissue accumulation, for example, the major body fat at the level of the lower limbs, modifying thus the size (i.e., area) of the support base and indirectly reducing the oscillation during the balance test[27]. It has been reported that the increased inertia of the segments in obese people would be associated with relative muscle weakness resulting from the non-uniform distribution of the adipose tissue, which would not allow adequate control of balance by the muscle mass[28]. In this sense, this point has been highlighted as important in the risk of falling that obese people would present, where the failure of balance control seems to be related to the velocity of control for regaining balance after disturbances[29-31].

Regarding the RI, although it is a widely known and used clinical test for balance, the literature in obese older people is limited. For example, it has been observed that the CE condition presents a greater balance oscillation in comparison with OE, being also highly noted this situation in older than young people[32]. Other studies do not find differences in the RI evaluating obese adults with normoweight peers, attributing the results to the increase in body mass would not imply a sensorial deterioration, due to there is an increase in plantar pressure with more body weight[33]. Considering our OA sample, we speculate that our results at the RI can be attributed to sensorial alterations not shown by the RI, but apparently altered by the higher BMI condition that is strongly associated with higher inertia of the segments, changes in COM position, and muscle weakness[6].

On the other hand, it is relevant to mention that the changes associated with the aging processes cause a progressive loss of skeletal muscle mass and strength that are both associated with sarcopenia state[34]. Additionally, the obesity prevalence is also increasing in the older population[2]. The presence of both sarcopenia and obesity conditions in OA, commonly known as sarcopenic-obesity, promotes several mechanical, and metabolic alterations of which postural balance is part[35].

Limitations

In addition, our study contains some limitations, such as a) this study categorized the adiposity using the BMI, which is a compound of both weight plus height, being not far from bias in the results and data interpretation, b) our study does not include the measurement of adiposity distribution according to anatomical segments (i.e., upper, or lower limbs), where we recommend to include this point for future studies, c) we do not include other categories as those OS in the underweight situation, and d) our CG was in minor sample size. However, part of the strength of our study are that a) we used high-quality and precise equipment for the postural balance measurement as was the force platform used, b) we apply different surface and vision conditions to consider the different systems that control posture, c) the ages of OA were representative of the OA condition (i.e., ~70 y).

Conclusion

At higher BMI such as at overweight or obesity conditions, older adults show a reduced 'CoP Mean velocity' than control normoweight peers', being 'weight' a traditional adiposity risk factor predictor of the postural balance test performance.

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