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Effects of body composition on postural balance in sedentary Spanish adult males: a cross-sectional study
Efectos de la composición corporal sobre el equilibrio postural en varones adultos españoles sedentarios: un estudio transversal

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Abstract. The aim of this study was to analyze the influence of anthropometric variables, body composition variables and fat distribution on the postural control of sedentary Spanish males. 39 males aged between 25 and 60 years old, with a body mass index between 18 and 35 kg/m^2, a stable body weight (no weight gain or loss of 2 kg or more in the last 3 months), and a level of physical activity classified as sedentary or low active (PAL <1.6 via accelerometer) were included in the study. Anthropometric variables (weight, height, body mass index and waist and hip perimeters), body composition variables (fat mass, lean mass and bone mass), body mass distribution (legs, android and total) and postural control were evaluated. A correlation was found between most of the anthropometric and body composition variables, assessed via the Somatosensory ratio of the Sensory Organization Test. Furthermore, individuals with a low percentage of leg and android fat mass presented improved scores when compared to those with higher percentages (97.05±2.66 vs. 95.84±1.64 and 97.00±2.61vs 95.83±1.69, respectively; p<0.05). Sedentary males with a greater body mass index and a higher percentage of leg fat mass and android fat mass are more proprioceptively challenged for maintaining balance.
Key words: Body composition; Postural control; Sedentary lifestyle; Body fat distribution.

Resumen. El objetivo de este estudio fue analizar la influencia de las variables antropométricas, de composición corporal y de distribución de la grasa en el control postural de varones españoles sedentarios. Se incluyeron en el estudio 39 varones de entre 25 y 60 años, con un índice de masa corporal entre 18 y 35 kg/m2, un peso corporal estable (sin ganancia o pérdida de peso igual o superior a 2 kg en los últimos 3 meses) y un nivel de actividad física clasificado como sedentario o poco activo (PAL <1,6 mediante acelerómetro). Se evaluaron variables antropométricas (peso, altura, índice de masa corporal y perímetros de cintura y cadera), variables de composición corporal (masa grasa, masa magra y masa ósea), distribución de la masa corporal (piernas, androide y total) y control postural. Se encontró una correlación entre la mayoría de las variables antropométricas y de composición corporal, evaluadas a través de la ratio Somatosensorial del Test de Organización Sensorial. Además, los individuos con un bajo porcentaje de masa grasa en piernas y androides presentaron mejores puntuaciones en comparación con aquellos con porcentajes más elevados (97,05±2,66 vs. 95,84±1,64 y 97,00±2,61vs 95,83±1,69, respectivamente; p<0,05). Los varones sedentarios con un mayor índice de masa corporal y un mayor porcentaje de masa grasa en las piernas y masa grasa androide tienen más dificultades propioceptivas para mantener el equilibrio.
Palabras clave: Composición corporal; Control postural; Sedentarismo; Distribución de la grasa corporal.

Introduction

Postural control is the ability to maintain equilibrium and orientation in a gravitational environment. Balance or postural stability is achieved by maintaining the center of body mass over the base of support provided by the feet (Delfa-de la Morena et al., 2021). This is essential for maintaining balance of the body during standing, movement and any activity requiring a high degree of balance (Hofgaard et al., 2019). In order to maintain balance, postural control is necessary to process the visual, vestibular and proprioceptive stimuli in charge of generating appropriate motor responses (Aydog et al., 2006; Buatois et al., 2007; Strobel et al., 2011).

Problems and illnesses affecting these systems, such as obesity and sedentary lifestyle, can provoke disorders of balance and posture (Buatois et al., 2007; Hita-Contreras et al., 2013; King, 2012) which can, in turn, increase the risk of falling (Hita-Contreras et al., 2013; Neri et al., 2020; Hue et al., 2007; Singh et al., 2009). A number of factors are known to affect postural con-

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trol, such as age (Ochi et al., 2010; Waters, 2010), sex (Greve et al., 2013; Pereira et al., 2013), muscle strength (Waters et al., 2010; Handrigan et al., 2010), physical activity (Maktouf et al., 2018), body mass index (BMI) (Aydog et al., 2006; Hue et al., 2007; Handrigan et al., 2010; Maktouf, 2018; Blaszczyk et al., 2009; Menegoni et al., 2009) or body composition (Delfa-de la Morena et al., 2021; Greve et al., 2013; Misic et al., 2007; Valentine, 2009).

To date, no studies have described the relationships between body composition and the distribution of body mass with the postural control of sedentary subjects. Thus, this study sought to analyze the influence of anthropometric variables, together with body composition and the distribution of body fat on the postural control of Spanish sedentary male adults.

Methods

Design

An observational, cross-sectional, descriptive study was performed using non-probabilistic consecutive sampling.

Subjects

Volunteer subjects were recruited via email from the Nutritional and Physical Activity Program for the Control of Obesity project (PRONAF) project (Hita-Contreras et al., 2013). From the total of participants from the project, 131 individuals expressed interest in being included in this study. 41 Spanish males aged between 25 and 60 years old, with a BMI between 18 and 35 kg/m^2, a stable body weight (no weight gain or loss of 2 kg or more during the past 3 months), and with a level of physical activity classified as sedentary or low active: PAL <1.6 measured via accelerometry, were included in the study. Those subjects suffering from serious illnesses, smokers or recent ex-smokers (abstinent for less than 6 months), consumers of alcohol, subjects diagnosed with balance disorders, subjects with knee or hip replacements, suffering from arthritis or other sever inflammatory diseases affecting the lower limbs, or who had suffered from trauma to the lower limbs in the previous 6 months were excluded from the study. During data collection, 2 subjects dropped out due to personal motives. Finally, 39 subjects completed the study. All participants were provided with written information detailing the nature and purpose of the study. The protocol was approved by the institutional ethics committee at Universidad Rey Juan Carlos and was in accordance with the Declaration of Helsinki for Human Research.

Measurements

The anthropometric variables measured were body weight, height and waist and hip perimeters of all subjects. Body weight was assessed using a TANITA BC-420MA balance scale (Bio Lógica Tecnología Médica S.L, Barcelona, Spain), and height was measured by a SECA stadiometer (range 80-200cm, Valencia, Spain). Waist and hip perimeters, assessed following the recommendations of the International Society for the Advancement of Kinanthropometry (ISAK) (Stewart et al., 2011), were calculated using a SECA 201 steel tape (Quirumed, Valencia, Spain). From these measurements, the waist-to-hip ratios were calculated (RCC) together with the BMI. Individuals with a BMI e»30 kg/m^2 were considered obese, those with a BMI between 25 and 29.9 kg/m^2 were categorized as overweight, and those with a BMI <25 kg/m^2 were classified as normal weight.

Body composition variables were measured by Dual X-ray absorptiometry (DXA) (Hita-Contreras et al., 2013; Valentine et al., 2009), using a GE Lunar Prodigy apparatus densitometer (GE Healthcare, Madison, Wisconsin, USA). Body composition parameters were: leg, android and total fat mass percentage; leg, android and total fat mass; leg, android and total lean mass; leg, android and total bone mineral quantity. In order to classify the subjects into either low or high percentage of fat mass and enable the comparison of results, the median of leg (26.1%), android (43.3%) and total (32.9%) fat mass percentages were used.

Postural control was assessed via posturography (Alonso et al., 2012). Specifically, balance was assessed using the SMART EquiTest® computerized dynamic posturographic system (Neurocom® International Inc., Clackamas, Oregon USA). This apparatus consists of a forceplate and a visual surround that can be either fixed or mobile (the system rotates around the ankle joints in response to the individual's postural adjustments). Sensory Organization Test (SOT) was performed by subjects for the measurement of balance. The SOT involves a sequence of six sensorial conditions: (1) eyes open, visual surround and fixed support; (2) eyes closed, fixed support; (3) mobile visual surround and fixed support; (4) fixed visual surround and mobile support; (5) eyes closed, mobile support; (6) eyes open, visual surround and mobile support (see figure 1) and provides the individual with information on a somatosensory, visual and vestibular level. Three 20-second measurements were taken in each condition. The SMART EquiTest® is described in detail elsewhere (Nashner et al., 1989). Based on these 6 conditions, the values of the SOT test were obtained to quantify the somatosensory organization test (SOT-SOM): the ability of the subject to use the somatosensory stimulus to maintain balance; the visual sensory organization test (SOT-VIS): the ability of the subject to use the visual stimulus to maintain balance; the vestibular sensory organization test (SOT-VEST): the ability of the subject to use input from the vestibular system to maintain balance; the preferential sensory organization test (SOT-PREF): the degree to which a subject relies on the visual information to maintain balance, even when the information is incorrect and the Composite Equilibrium Score (SOT-CES): the global ability of subject to maintain balance.

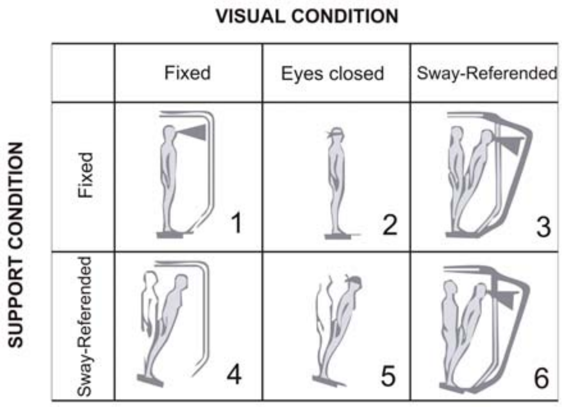

Figure 1. Sensory organization test in posturography.

Statistical analyses

The statistical analysis of the data was carried out using the Statistical Program for Social Science (SPSS) version 17 (SPSS Inc., Chicago, Illinois, USA). The significance level was set at á < 0.05. Mean (standard deviation) and percentiles of variables are shown. A descriptive analysis was performed for the characterization variables. The Shapiro-Wilk test confirmed the non-normal distribution of the data; therefore non parametric tests were used. The Spearman's correlation was used for assessing the relation between the body composition and balance variables. The Mann-Whitney U test was used for comparing between individuals classified as high or as low when compared to the median.

Results

Thirty-nine Spanish males participated in the study. Subjects had a mean age of 43.41±6.18 years (range: 28-54 years) with a mean weight of 89.05 Kg (±11.08), a mean height of 1.75 m (±0.07), a BMI of 29.18±3.01 kg/m² and a mean total fat mass percentage of 31.14±6.77 %. The characteristics of the study sample are shown in table 1.

Table 1.
Characteristics of the study sample (n=39)

Variables	Mean (SD)	Percentiles (25-75)
Anthropometric data		
Weight (kg)	89.05 ± 11.08	82.70 – 96.50
Height (m)	1.75 ± 0.07	1.68 – 1.79
Body Mass Index (kg/m²)	29.18 ± 3.01	27.25 – 31.07
Waist-to-hip ratio	0.92 ± 0.06	0.85 – 0.97
Waist perimeter (cm)	97.69 ± 9.58	91.40 – 105.85
Body composition		
% Fat Mass Legs	27.24 ± 6.38	22.20 – 31.40
% Android Fat Mass	41.22 ± 8.17	35.00 – 46.90
% Total Fat Mass	31.14 ± 6.77	25.40 – 36.10
Fat Mass Legs	7.58 ± 2.45	5.75 – 9.20
Android Fat Mass	2.97 ± 1.04	2.16 – 3.87
Total Fat Mass	27.24 ± 8.15	20.44 – 34.15
Legs Lean Mass	19.80 ± 2.32	17.74 – 21.85
Android Lean Mass	4.02 ± 0.44	3.78 – 4.35
Total Lean Mass	58.58 ± 5.11	54.65 – 63.55
Bone Mineral Quantity Legs	1.32 ± 0.18	1.20 – 1.45
Bone Mineral Quantity Android	0.06 ± 0.01	0.05 – 0.07
Total Bone Mineral Content	3.42 ± 0.49	3.00 ± 3.81
Postural control and balance		
SOT CES	76.74 ± 6.72	72.00 – 82.00
SOT SOM	96.46 ± 2.28	95.00 – 98.00
SOT VIS	91.28 ± 4.74	89.00 – 94.00
SOT VEST	62.36 ± 18.03	45.00 – 75.00
SOT PREF	100.59 ± 17.03	93.00 – 110.00

% Percentage; SOT-CES: composite equilibrium score; SOT-SOM: somatosensory organization test; SOT-VIS: visual sensory organization test; SOT-VEST: vestibular sensory organization test; SOT-PREF: preferential sensory organization test.

Table 2 shows the correlation between the anthropometric, body composition and postural control variables. The SOT SOM presented significant correlations for the weight, BMI, waist perimeter, waist-to-hip ratio, android fat mass percentage, total fat mass percentage, android lean mass, leg fat mass, android fat mass and total fat mass variables.

Table 2.
Spearman's Correlation (r) between the anthropometric, body composition and postural control variables.

	SOT CES		SOT SOM		SOT VIS		SOT VEST		SOT PREF	
	r	p	r	p	r	p	r	p	r	p
Weight	0.059	0.722	-0.431	0.006**	0.054	0.743	-0.041	0.804	0.036	0.829
Height	0.266	0.101	-0.078	0.636	0.214	0.191	0.221	0.176	-0.125	0.450
BMI	-0.089	0.592	-0.439	0.005**	0.002	0.989	-0.137	0.407	0.047	0.777
Waist perimeter	-0.021	0.897	-0.525	0.001**	-0.089	0.588	-0.010	0.953	-0.035	0.834
Ratio waist hips	-0.064	0.700	-0.396	0.013*	-0.220	0.179	0.041	0.804	-0.112	0.499
%Fat Mass Legs	0.083	0.615	-0.269	0.097	0.222	0.174	0.121	0.463	0.010	0.950
%Android Fat Mass	0.032	0.847	-0.389	0.014*	-0.011	0.949	0.114	0.488	-0.067	-0.686
%Total Fat Mass	-0.012	0.941	-0.327	0.042*	0.073	0.658	0.103	0.535	-0.099	0.548
Legs Fat Mass	0.121	0.463	-0.328	0.041*	0.238	0.145	0.082	0.618	0.033	0.841
Android Fat mass	0.028	0.864	-0.452	0.004**	0.007	0.968	0.089	0.581	-0.104	0.527
Total Fat Mass	0.047	0.774	-0.397	0.012*	0.073	0.659	0.059	0.723	-0.045	0.785
Lean Mass Legs	0.096	0.562	-0.274	0.091	0.011	0.949	-0.181	0.270	0.152	0.355
Android Lean Mass	0.133	0.419	-0.408	0.010**	0.143	0.384	-0.017	0.917	0.012	0.944
Total Lean Mass	0.078	0.637	-0.304	0.060	-0.018	0.912	-0.160	0.331	0.105	0.523
Bone Mineral Quantity Legs	0.186	0.257	-0.121	0.465	0.191	0.244	0.143	0.385	-0.075	0.651
Android bone mineral quantity	0.004	0.980	-0.007	0.967	0.114	0.490	0.065	0.693	-0.186	0.256
Total bone mineral quantity	0.074	0.655	-0.115	0.485	0.121	0.461	0.053	0.748	-0.044	0.789

SOT-CES: composite equilibrium score; SOT-SOM: somatosensory organization test; SOT-VIS: visual sensory organization test; SOT-VEST: vestibular sensory organization test; SOT-PREF: preferential sensory organization test. *$p<0.05$ ** $p<0.01$.

Table 3 shows the comparison between the means of the postural control tests for the variables of leg, android and total fat mass percentage displayed in two groups (low or high percentage). The subjects with a low leg fat mass percentage and with a low android fat mass percentage obtained significantly better results in the SOT SOM when compared to the subjects with high percentage (97.05±2.66; 97.00±2.61 VS 95,84±1.64; 95.83±1.69; p=0.01, p=0.02; leg and android respectively).

Table 3.
Comparison of the postural control tests in individuals with a low or high leg fat mass percentage, a low or high android fat mass percentage and a low or high total fat mass percentage.

	Leg fat mass percentage		
	Low (n=20)	High (n=19)	p-value
SOT CES	76.65 ± 6.25	76.84 ± 7.36	0.61
SOT SOM	97.05 ± 2.66	95.84 ± 1.64	0.01*
SOT VIS	90.05 ± 6.15	92.58 ± 2.00	0.26
SOT VEST	62.05 ± 16.00	62.68 ± 20.39	0.48
SOT PREF	101.3 ± 14.69	99.84 ± 19.59	0.99
	Android fat mass percentage		
	Low (n=21)	High (n=18)	p-value
SOT CES	77.28 ± 5.86	76.11 ± 7.74	0.97
SOT SOM	97.00 ± 2.61	95.83 ± 1.69	0.02*
SOT VIS	91.71 ± 4.70	90.78 ± 4.87	0.71
SOT VEST	64.48 ± 15.36	59.89 ± 20.91	0.69
SOT PREF	98.76 ± 15.99	102.72 ± 17.03	0.53
	Total fat mass percentage		
	Low (n=20)	High (n=19)	p-value
SOT CES	77.65 ± 5.60	75.79 ± 7.77	0.73
SOT SOM	96.85 ± 2.72	96.05 ± 1.68	0.08
SOT VIS	91.15 ± 5.70	91.42 ± 3.63	0.86
SOT VEST	63.70 ± 15.86	60.95 ± 20.42	0.99
SOT PREF	101.8 ± 14.24	99.32 ± 19.88	0.83

SOT-CES: composite equilibrium score; SOT-SOM: somatosensory organization test. SOT-VIS: visual sensory organization test; SOT-VEST: vestibular sensory organization test; SOT-PREF: preferential sensory organization test.*p<0.05

Discussion

Many studies have assessed the influence of weight, height and BMI on postural control (Delfa-de la Morena et al., 2021; Hofgaard et al., 2019; Aydog et al., 2006; Blaszczyk et al., 2009). Our results show that the BMI correlates positively with the SOT SOM and that individuals with a higher BMI tend to have poorer postural control. These results are similar to those reported in previous studies (Strobel et al., 2011; Ku et al., 2012). Aydog et al. (2006) studied a sample of 116 subjects aged between 35 and 60 years old and reported that the BMI was one of the most important factors that affected the postural balance. Greve et al. (2013) performed a study of 40 male adults between 20 and 38 years and found that a greater BMI is related to a greater requirement for maintaining postural control on one leg on an unstable platform. This relation was reported to exist, not only for obese men, but also for those ranging between normal weight and obesity. In addition, subjects with a higher BMI presented a greater sway, both in the anterior-posterior as well as the medial-lateral directions (Greve et al., 2013), as equal as in our study. Specifically, our study revealed that those with normal weight achieved higher scores in the SOT-SOM, when compared with obese subjects (p=0.016; data not shown).

In a study of 59 males with BMI between 17.4 and 63.8 Kg/m^2, Hue et al. (2007) reported that an increase in body weight was strongly related with a decrease in postural stability measured on a force platform both with eyes open as well as eyes closed. Some studies have confirmed Hue's findings, associating greater body weight with worse postural stability and poorer postural control (Singh et al., 2009; Menegoni et al., 2009). Our study also displays a significant correlation between weight and the SOT-SOM, indicating that the greater the body weight, the worse the postural control. Regarding height, some studies have reported that taller subjects have worse postural stability than shorter subjects (Era et al., 1996), although the reverse has also been observed. Our results did not show a relation between height and postural control. This may be due to the reduced variation in height between the subjects of our study (low standard deviation). Moreover, over the age of 40, muscle mass decreases and an increase of BMI is almost always related with an increase of fat mass (Strobel et al., 2011). This is why some studies have employed certain methods in order to differentiate the amount of fat mass and muscle mass or, at least, the fat mass from the remaining body mass, for the purpose of assessing how the body composition influences postural control (Misic et al., 2007; Valentine et al., 2009; Balogun et al., 1994). According to Gómez-Ambrosi et al. (2012) 77% of the subjects in our study were classified as obese. Our study displays a positive correlation between the amount of total fat mas and the percentage of total fat mass with the SOT-SOM. This coincides with the study by Winters & Snow (2000) in which greater percentages of fat mass were associated with poorer postural stability (30 seconds on an unstable platform). Similar results were obtained by Angyan et al. (2007) who reported a greater postural sway in young university students with higher fat percentages, although these findings were not significant. In Spain, Hita-Contreras et al. (2013) described how postural instability is associated both with obesity and with an android type distribution of body fat (waist-to-hip ratio >0.76)[6]. This demonstrates that the distribution of fat mass seems to be a more important factor in postural control when compared to the amount of fat. In agreement with Hita-Contreras et al. (2007), our results also show that the distribution of body fat influences postural control, as observed in table 3, and with significant differences in the postural control between subjects with low and high percentages of leg and android fat mass. Moreover, our study displays significant correlations between android lean mass and android fat mass (both, amount and percentage) with the SOM-SOT, therefore indicating that individuals with a greater abdominal mass have poorer postural control. This may be explained by the study of Corbeil et al. (2001), which reveals that obese people, especially those with an abnormal distribution of body fat in the abdominal area, may have greater difficulty maintaining balance, as the center of balance is more anterior. They thus require greater strength and speed in order to place their center of balance within their base of support. It is worth highlight that all the significant results from our study are with regard to the SOT-SOM. This indicates that a greater BMI, weight and android and total fat mass percentage are associated with a reduced ability to use somatosensory stimuli for the purpose of maintaining balance. This may be due to the fact that obesity is associated with a decline both in the quality of muscles (an excess of adipocytes and a reduction of the number of muscle cells) and of the joints, which causes a decline in the efficiency of proprioception and the motor response (Jensen, 2005; Villareal et al., 2005) .

The main limitation of the study is the absence of a control group of non-sedentary individuals and a small sample size. On the other hand, as the main strength, this study provides a relevant assessment of the influence of the distribution of body fat (assessed by DXA) on the postural control (assessed by posturography) of sedentary males.

Perspectives

This study demonstrates that the increase in BMI and android mass, affects the somatosensory system for the maintenance of postural stability in sedentary male adults. Furthermore, our subjects with a higher percentage of leg and android fat mass have worse SOT SOM when compared with those with a lower percentage. Our findings may be useful for planning programs for health promotion and improvement of the quality of life. Further research is necessary to study the relation and the effect of other several factors (physical activity, muscle strength, sex) on postural control.

References

Alonso, A.C., Luna, N.M., Mochizuki, L., Barbieri, F., Santos, S., Greve, J.M. (2012). The influence of anthropometric factors on postural balance: the relationship between body composition and posturographic measurements in young adults. *Clinics, 67*, 1433-1441.

Angyan, L., Teczely, T., Angyan, Z. (2007). Factors affecting postural stability of healthy young adults. *Acta Physiologica Hungarica, 94*, 289-299.

Aydog, E., Bal, A., Aydog, S.T., Cakci, A. (2006). Evaluation of dynamic postural balance using the Biodex Stability System in rheumatoid arthritis patients. *Clinical Rheumatology, 25*, 462-467.

Balogun, J.A., Akindele, K.A., Nihinlola, J.O., Marzouk, D.K. (1994). Age-related changes in balance performance. *Disability & Rehabilitation, 16*, 58-62.

Blaszczyk, J.W., Cieslinska-Swider, J., Plewa, M., Zahorska-Markiewicz, B., Markiewicz, A. (2009). Effects of excessive body weight on postural control. *Journal of Biomechanics, 42*, 1295-1300.

Buatois, S., Gauchard, G.C., Aubry, C., Benetost, A., Perrin, P. (2007). Current physical activity improves balance control during sensory conflicting conditions in older adults. *International Journal of Sports Medicine, 28,* 53-58.

Corbeil, P., Simoneau, M., Rancourt, D., Tremblay, A., Teasdale, N. (2001). Increased risk for falling associated with obesity: mathematical modeling of postural control. *IEEE Transactions on Neural System and Rehabilitation Engeenering, 9*, 126-136.

Delfa-de la Morena, J.M., Castro, E., Rojo-Tirado, M.A., Bores-García, D. (2021). Relation of physical activity level to postural balance in obese and overweight Spanish adult males: a cross-sectional study. *International Journal of Environmental Research and Public Health, 18*, 8282.

Era, P., Schroll, M., Ytting, H., Gause-Nilsson, I., Heikkinen, E., Steen, B. (1996). Postural balance and its sensory-motor correlates in 75-year-old men and women: a cross-national comparative study. *Journal of Gerontology. Biological Sciences, 51*, 53-63.

Gómez-Ambrosi, J., Silva, C., Catalán, V., Rodríguez, A., Galofré, J.C., Escalada, J., Valentí, V., Rotellar, F., Romero, S., Ramírez, B. (2012). Clinical usefulness of a new equation for estimating body fat. *Diabetes Care, 35*, 383-388.

Greve, J.M., Cug, M., Dulgeroglu, D., Brech, G.C., Alonso, A.C. (2013). Relationship between anthropometric factors, gender, and balance under unstable conditions in young adults. *Biomedical Research International, 2013,* 850424.

Handrigan, G., Hue, O., Simoneau, M., Corbeil, P., Marceau, P., Marceau, S., Tremblay, A., Teasdale, N.

(2010). Weight loss and muscular strength affect static balance control. *International Journal of Obesity (London)*, 34, 936-942.

Hita-Contreras, F., Martinez-Amat, A., Lomas-Vega, R., Alvarez, P., Mendoza, N., Romero-Franco, N., Aranega, A. (2013). Relationship of body mass index and body fat distribution with postural balance and risk of falls in Spanish postmenopausal women. *Menopause, 20*, 202-208.

Hofgaard, J., Ermidis, G., Mohr, M. (2019). Effects of a 6-Week Faroese Chain Dance Programme on Postural Balance, Physical Function, and Health Profile in Elderly Subjects: A Pilot Study. BioMed Research International. 2019, 5392970.

Hue O., Simoneau, M., Marcotte, J., Berrigan, F., Dore, J., Marceau, P., Marceau, S., Tremblay, A., Teasdale, N. (2007). Body weight is a strong predictor of postural stability. *Gait Posture, 26*, 32-38.

Jensen, G.L. (2005). Obesity and functional decline: epidemiology and geriatric consequences. *Clinical Geriatrical Medicine, 21*, 677-687.

King, A.C., Challis, J.H., Bartok, C., Costigan, F.A., Newell, K.M. (2012). Obesity, mechanical and strength relationships to postural control in adolescence. *Gait Posture, 35*, 261-265.

Ku, P., Osman, N.A., Yusof, A., Abas, W.W. (2012). Biomechanical evaluation of the relationship between postural control and body mass index. *Journal of biomechanics, 45*, 1638-1642.

Maktouf, W., Durand, S., Beaune, B., Boyas, S. (2018). Influence of obesity and impact of a physical activity program on postural control and Functional and physical Capacities in Institutionalized Older adults. A pilot study. *Human Kinetics, 17*, 169–176.

Menegoni, F., Galli, M., Tacchini, E., Vismara, L., Cavigioli, M., Capodaglio, P. (2009). Gender-specific effect of obesity on balance. *Obesity, 17*, 1951-1956.

Misic, M.M., Rosengren, K.S., Woods, J.A., Evans, E.M. (2007). Muscle quality, aerobic fitness and fat mass predict lower-extremity physical function in community-dwelling older adults. *Gerontology, 53*, 260-266.

Nashner, L.M., Shupert, C.L., Horak, F.B., Black, F.O. (1989). Organization of posture controls: an analysis of sensory and mechanical constraints. *Progress in Brain Research, 80*, 411-418.

Neri, S.G.R., Oliveira, J.S., Dario, A.B., Lima, R.M., Tiedemann, A. (2020). Does Obesity Increase the Risk and Severity of Falls in People Aged 60 Years and Older? A Systematic Review and Meta-analysis of Observational Studies. *Journal of Gerontology, 75*, 952–960.

Ochi, M., Tabara, Y., Kido, T., Uetani, E., Ochi, N., Igase, M., Miki, T., Kohara, K. (2010). Quadriceps sarcopenia and visceral obesity are risk factors for postural instability in the middle-aged to elderly population. *Geriatrics & Gerontology International, 10*, 233-243.

Pereira, C.L., Baptista, F., Infante, P. (2013). Men older than 50 yrs are more likely to fall than women under similar conditions of health, body composition, and balance. *American Journal of Physical Medicine Rehabilitation, 92,* 1095-1103.

Singh, D., Park, W., Levy, M.S., Jung, E.S. (2009). The effects of obesity and standing time on postural sway during prolonged quiet standing. *Ergonomics, 52*, 977-986.

Stewart, A., Marfell-Jones, M., Olds, T., de Ridder, H. (2011). International standards for anthropometric assessment. In. New Zealand: ISAK, Lower Hutt.

Strobel, J., Spengler, C., Stefanski, M., Friemert, B., Palm, H.G. (2011). Influence of bodily constitution and physical activity on postural stability. *Sportverletz Sportschaden, 25*, 159-166.

Valentine, R.J., Misic, M.M., Rosengren, K.S., Woods, J.A., Evans, E.M. (2009). Sex impacts the relation between body composition and physical function in older adults. *Menopause, 16*, 518-523.

Villareal, D.T., Apovian, C.M., Kushner, R.F., Klein, S. (2005). Obesity in older adults: technical review and position statement of the American Society for Nutrition and NAASO, The Obesity Society. *American Journal of Clinical Nutrition, 82*, 923-934.

Waters, D.L., Hale, L., Grant, A.M., Herbison, P., Goulding, A. (2010). Osteoporosis and gait and balance disturbances in older sarcopenic obese New Zealanders. *Osteoporosis International, 21*, 351-357.

Winters, K.M., Snow, C.M. (2009). Body composition predicts bone mineral density and balance in premenopausal women. *Journal of Womens Health Gender Based Medicine, 9*, 865-872.