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Assessment of postural stability in overweight and obese middle-aged women

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Background: Obesity and overweight are defined as abnormal or excessive fat accumulation and are associated with balance disorders. **Objective:** To assess the postural stability in a natural stance in overweight and obese women based on center of pressure (CoP) velocity in the anterior-posterior (AP) and medial-lateral (ML) directions. **Methods:** A total of 102 women categorized according to body mass index into normal weight, overweight and obese categories underwent a measurement of quiet standing with their eyes open (EO) and with their eyes closed (EC). Postural stability was assessed with a force platform. The mean CoP velocity was evaluated in both directions. **Results:** In the AP direction under EO conditions, obese women swayed significantly faster than normal weight women (1.01 cm/s and 0.80 cm/s). In the ML direction, a higher CoP velocity was observed in normal weight women than in obese women (0.52 cm/s and 0.41 cm/s). Under EC conditions in the AP direction, obese women swayed significantly faster than normal weight women (1.29 cm/s and 0.97 cm/s). In the ML direction, a higher CoP velocity was observed in normal weight women than in obese women (0.65 cm/s and 0.48 cm/s). **Conclusions:** Results suggest a negative impact of obesity on postural stability in the AP direction. In the ML direction, obese women were more stable than normal weight women, probably due to enlargement of the support base in a natural stance.

Keywords: body mass index, static balance, posturography, quiet stance, CoP velocity

Introduction

Obesity is among the greatest public health challenges of the 21st century, and it significantly increases the risk of developing numerous medical conditions. The prevalence of obesity in women older than 30 years of age in the Czech Republic is 32.9% (World Health Organization, 2013b). Increasing body weight with abnormal or excessive fat accumulation is associated with changes in body geometry and posture (Berrigan, Simoneau, Tremblay, Hue, & Teasdale, 2006; Fabris De Souza et al., 2005; Teasdale et al., 2007). Fregly, Oberman, Graybiel, and Mitchell (1968) proposed that in overweight individuals, body size and shape influenced static postural stability by altering the location of the center of gravity. A center of mass located closer to the anterior edge of the base of support, due to additional abdominal mass, presumably leads to increased ankle torque necessary to maintain balance (Fregly, Oberman, Graybiel, & Mitchell, 1968). Based on this idea, most studies dealing with obesity have focused predominantly on the assessment of postural stability in the anterior-posterior (AP) direction (Gravante, Russo, Pomara, & Ridola, 2003). There has also been limited information regarding the regulation of medial-lateral (ML) balance in obese adults. The integrity of the postural control system has most often been evaluated, in static conditions, by analyzing the center of pressure (CoP) movement (Menegoni et al., 2009). CoP parameters (i.e. velocity of CoP) can be classified as related to postural activity for maintaining stability (Hue et al., 2007). Dutil et al. (2013) reported decreased postural stability in obese older women based on increased CoP velocity. In the literature, we can find different approaches for the evaluation of obesity. We can assume that there is no universal method for assessing obesity and overweight that accounts all conditions. The most widely used "tool" is body mass index (BMI), which provides a useful population-level measurement of overweight and obesity, as it is the same for both sexes and for all ages of adults (World Health Organization, 2013a). Keionen, Kauranen, and Vanharanta (2003) investigated the relationship between body anthropometry and equilibrium, and

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BMI was the only parameter that was correlated with anterior-posterior sway in the bipedal quiet stance. Several studies (Dutil et al., 2013; Hue et al., 2007; Ku, Abu Osman, Yusof, & Wan Abas, 2012) have shown the existence of a close relationship between obesity and postural instability. However, there have been few studies regarding excessive body weight and postural control in middle-aged women (Błaszczyk, Cieślinska-Świder, Plewa, Zahorska-Markiewicz, & Markiewicz, 2009; Cruz-Gómez, Plascencia, Villanueva-Padrón, & Jáuregui-Renaud, 2011; Dutil et al., 2013; Hita-Contreras et al., 2013). These studies have used different parameters to assess postural stability. The mean velocity of displacement as a single parameter distinguishes appropriately between test situations, and it also has the smallest standardized intra-individual coefficient of variation, i.e. the smallest reproducibility error (Raymakers, Samson, & Verhaar, 2005). However, it has mostly been used as an overall parameter and not in individual directions. For this reason, the aim of our study was to assess postural stability in overweight and obese middle-aged women based on CoP velocity in different directions.

Methods

Subjects

A total of 102 women between 48 and 65 years old (55.6 ± 4.9) participated in our study and were categorized according to BMI (27.1 ± 5.9): 39 normal weight women (BMI 18.5–24.9 kg/m^2), 38 overweight women (BMI 25.0–29.9 kg/m^2) and 25 obese women (BMI ≥ 30.0 kg/m^2). The BMI ranges and categories corresponded to the international classification scale proposed by World Health Organization. The group characteristics are provided in Table 1. Women indicating any diseases (except for obesity) that could affect their balance were excluded from the study. This study was approved by the institutional research ethics committee. All of the participants were informed about purpose of this study and provided written informed consent prior to data collection.

Experimental setup and methods

Each subject first underwent anthropometric measurement of body weight and height. Following these measurements, BMI was calculated in kg/m^2. Then, postural stability was evaluated with a force plate (Kistler Instrumente AG, Winterthur, Switzerland). Subjects stood on the force plate barefoot and were instructed to stand normally as they would at home or at work. They had adopted their preferred stance position with their feet positioned comfortably. Any other feet correction was considered as an adjusted stance and was not allowed.

The women performed two trials of a quiet stance with eyes opened (EO) and with eyes closed (EC), in random order. Each test was performed 2 times for 30 seconds, and CoP movement was recorded at a sampling rate of 200 Hz. None of the subjects had any previous experience with a force platform.

Data analyses

The data were filtered using a fourth order low-pass Butterworth filter with a cut-off frequency of 7 Hz using MATLAB software (Version R2010b; Mathworks, Inc., Natick, MA). The mean CoP velocity in each direction and total CoP velocity were calculated with the same software. The average of the two trials was calculated. Statistical analysis was performed using Statistica software (version 10; StatSoft, Inc., Tulsa, OK). The normality of the data distribution was not confirmed (Kolmogorov-Smirnov test); thus, for statistical comparisons among the groups, the Mann-Whitney U test ($p < .05$) was used. Cohen's d was calculated and was interpreted as small ($d < 0.2$), medium ($0.2 < d < 0.5$), or large ($d > 0.8$) according to Cohen (1988), to assess the influence of obesity on postural stability.

Table 1
The characteristics of the groups (mean ± SD)

	Normal weight (n = 39)	Overweight (n = 38)	Obese (n = 25)
Age (years)	54.4 ± 5.3	56.2 ± 4.9	56.5 ± 4.1
Body height (cm)	163.8 ± 3.7	163.1 ± 5.6	163.0 ± 5.7
Body weight (kg)	58.9 ± 6.5	71.9 ± 5.5*	93.6 ± 16.3*§
BMI (kg/m^2)	21.9 ± 1.9	27.0 ± 1.5*	35.1 ± 5.5*§
Abdominal circumference (cm)	79.1 ± 13.9	92.1 ± 5.7*	107.9 ± 11.5*§

Note. *$p < .001$, significant difference in comparison with normal weight, §$p < .001$, significant difference in comparison with overweight.

Results

All of the data are presented in Table 2.

CoP velocity with opened eyes

The analysis of mean CoP velocity in the medial-lateral direction (V_{ML}) showed a significant difference between normal weight and obese women (medium effect) and between overweight and obese women (small effect). In the AP direction, a significant difference was observed in mean CoP velocity (V_{AP}) between normal weight women and obese women (large effect). In total velocity (V), no significant difference was found.

CoP velocity with closed eyes

Under the EC condition in the ML direction, the results showed significant differences (medium effect) in V_{ML} between normal weight women and obese women and between overweight women and obese women. In the AP direction, a significant difference was found between normal and overweight woman (small effect) and between normal weight and obese women (large effect). In total velocity (V), significant difference was found only between normal weight and obese women (small effect).

Discussion

In our study, we found significant difference between all three groups, however large effect was observed only between normal weight and obese women.

Obese women under the EO conditions swayed significantly faster in the AP direction than normal weight women. This finding was in agreement with those of Menegoni et al. (2009), who found the greatest significant difference in mean velocity in the AP direction between healthy and obese women. The first explanation for this finding could be that the obese individuals often display a protruding abdomen. The significant difference in abdominal circumference between normal weight and obese women in our study was 28.8 cm (36%; $p < .001$). Corbeil, Simoneau, Rancourt, Tremblay, and Teasdale (2001) assumed two main physical consequences of an abnormal distribution of body fat in the abdominal area: an increased mass to stabilize over the base of support; and anterior positioning of the center of mass relative to the ankle joint. In contrast, in obese and normal weight subjects, no differences were found in the percentages of pressure distribution on the anterior and posterior foot areas, and the CoP was equally distant from the tangent line to the inferior border of the posterior heel. Based on these findings, authors have suggested that the CoP location does not seem be influenced by excess weight or body fat distribution (Gravante, Russo, Pomara, & Ridola, 2003).

The greater pressure values and larger contact areas observed in obese subjects have been associated reductions in the quality and/or quantity of the sensory information arising from the plantar mechanoreceptors (Hue et al., 2007). Changes in the nature of information from these receptors increase postural sway and corrective muscular and torsional activity (Fransson,

Table 2
Postural parameters (mean ± SD) and significance, with and without vision

Parameter	Normal weight (n = 39)	Overweight (n = 38)	Obese (n = 25)	p value (Cohen' s d) Normal vs. overweight	Normal vs. obese	Overweight vs. obese
Eyes open						
V_{ML} (cm/s)	0.52 ± 0.17	0.47 ± 0.16	0.41 ± 0.16	.322 (0.29)	**.003** (0.68)	**.046** (0.42)
V_{AP} (cm/s)	0.80 ± 0.20	0.92 ± 0.26	1.01 ± 0.30	.072 (0.50)	**.002** (0.87)	.221 (0.35)
V (cm/s)	1.06 ± 0.25	1.14 ± 0.27	1.17 ± 0.33	.199 (0.29)	.088 (0.40)	.722 (0.13)
Eyes closed						
V_{ML} (cm/s)	0.65 ± 0.31	0.67 ± 0.46	0.48 ± 0.17	.765 (0.06)	**.001** (0.64)	**.015** (0.52)
V_{AP} (cm/s)	0.97 ± 0.24	1.28 ± 0.92	1.29 ± 0.39	.018 (0.46)	**< .001** (1.04)	.210 (0.01)
V (cm/s)	1.30 ± 0.39	1.59 ± 1.12	1.47 ± 1.40	.192 (0.35)	**.049** (0.45)	.601 (0.12)

Note. Statistically significant differences are in boldface.

Gomez, Patel, & Johansson, 2007). Experimental studies have confirmed in healthy (non-obese) individuals the decisive role of proprioception in the maintenance of postural stability during quiet standing (Åstrand, 2003; Peterka, 2002), mainly in the AP direction (Zemková, 2008). Under these conditions, only proprioception in the lower limbs was associated with sway (Lord & Menz, 2000). It is known that when proprioceptive information from the feet and ankles is reduced, other systems play important roles in the maintenance of postural stability. Handrigan et al. (2012) assumed that there was no difference in the visual and vestibular senses among normal weight, heavy athletic and obese people and that it was possible that plantar mechanoreceptor sensitivities differed because after vision removal, these authors observed greater increases in postural sway speed for obese and heavy athletic subjects compared to the control group. In contrast, we found under neither vision condition any significant differences in total mean velocity between normal weight and obese women. Surprisingly, separately in the AP and ML directions, significant differences were found. While in AP the direction obese women were significantly more affected by vision and showed higher values than the normal weight women, in the ML direction, the obese women achieved lower CoP velocity values. This finding was in disagreement with those of Dutil et al. (2013), who found in a group of older women more destabilizing effects of vision for the obese group in the ML direction.

In the ML direction under both conditions, the obese women in our study achieved lower CoP velocity than the normal weight group. It is well known that a side strategy is significantly better (more stable) than an ankle strategy, which results from a given anatomically more limited range of movement of the lower limbs and torso to the side. Lateral stability is highly sensitive to foot positioning (Day, Steiger, Thompson, & Marsden, 1993).

In some studies (Dutil et al., 2013; Hue et al., 2007; Menegoni et al., 2009), foot position during testing has been determined. In our study, the women were instructed to stand normally, as they would at home or at work, to maintain the most natural conditions. We believe that standardized foot positioning would have been unnatural for obese women. Observed postural deviations, such as separating the knees and ankles and flexing the legs, to achieve a lower center of gravity were associated with a wider natural stance in obese subjects (Fabris De Souza et al., 2005). Therefore, we can assume that the better postural stability in obese women in the ML direction is probably associated with a wider base of support due to overloading of the lower limbs (Fabris De Souza et al., 2005). Direct measurement of body movement confirmed that stance width influenced the velocity of body sway during a quiet stance (Day, Steiger, Thompson, & Marsden, 1993). Our results suggested that assessment of postural stability in both directions was significantly more sensitive.

One limitation of our study was the measurement of bipedal quiet standing on only one force platform, so it was not possible to determine stance width (base of support).

Conclusions

Results of our study showed that obesity increases postural sways in the anterior-posterior direction. In the medial-lateral direction obese women manifested smaller postural sways in comparison with normal weight and overweight women, probably due to enlargement of the support base in a natural stance.

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References

Åstrand, P. O. (Ed.). (2003). *Textbook of work physiology: Physiological bases of exercise*. Champaign, IL: Human Kinetics.

Berrigan, F., Simoneau, M., Tremblay, A., Hue, O., & Teasdale, N. (2006). Influence of obesity on accurate and rapid arm movement performed from a standing posture. *International Journal of Obesity, 30*, 1750–1757.

Błaszczyk, J. W., Cieślinska-Świder, J., Plewa, M., Zahorska-Markiewicz, B., & Markiewicz, A. (2009). Effects of excessive body weight on postural control. *Journal of Biomechanics, 42*, 1295–1300.

Cohen, J. (1988). *Statistical power analysis for the behavioral sciences* (2nd ed.). New York, NY: Academic Press.

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 Systems and Rehabilitation Engineering, 9*, 126–136.

Cruz-Gómez, N. S., Plascencia, G., Villanueva-Padrón, L. A., & Jáuregui-Renaud, K. (2011). Influence of obesity and gender on the postural stability during upright stance. *Obesity Facts, 4*, 212–217.

Day, B. L., Steiger, M. J., Thompson, P. D., & Marsden, C. D. (1993). Effect of vision and stance width on human body motion when standing: Implications for afferent control of lateral sway. *Journal of Physiology, 469*, 479–499.

Dutil, M., Handrigan, G. A., Corbeil, P., Cantin, V., Simoneau, M., Teasdale, N., & Hue, O. (2013). The impact of obesity on balance control in community-dwelling older women. *Age, 35*, 883–890.

Fabris De Souza, S. A., Faintuch, J., Valezi, A. C., Sant'Anna, A. F., Gama-Rodrigues, J. J., De Batista Fonseca, I. C., & De Melo, R. D. (2005). Postural changes in morbidly obese patients. *Obesity Surgery, 15*, 1013–1016.

Fransson, P. A., Gomez, S., Patel, M., & Johansson, L. (2007). Changes in multi-segmented body movements and EMG activity while standing on firm and foam support surfaces. *European Journal of Applied Physiology, 101*, 81–89.

Fregly, A. R., Oberman, A., Graybiel, A., & Mitchell, R. E. (1968). Thousand aviator study: Nonvestibular contributions to postural equilibrium functions. *Aerospace Medicine, 39*, 33–37.

Gravante, G., Russo, G., Pomara, F., & Ridola, C. (2003). Comparison of ground reaction forces between obese and control young adults during quiet standing on a baropodometric platform. *Clinical Biomechanics, 18*, 780–782.

Handrigan, G. A., Berrigan, F., Hue, O., Simoneau, M., Corbeil, P., Tremblay, A., & Teasdale, N. (2012). The effects of muscle strength on center of pressure-based measures of postural sway in obese and heavy athletic individuals. *Gait and Posture, 35*, 88–91.

Hita-Contreras, F., Martínez-Amat, A., Lomas-Vega, R., Álvarez, P., Mendoza, N., Romero-Franco, N., & Aránega, 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.

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

Keionen, P., Kauranen, K., & Vanharanta, H. (2003). The relationship between anthropometric factors and body-balancing movements in postural balance. *Archives of Physical Medicine and Rehabilitation, 84*, 17–22.

Ku, P. X., Abu Osman, N. A., Yusof, A., & Wan Abas, W. A. B. (2012). Biomechanical evaluation of the relationship between postural control and body mass index. *Journal of Biomechanics, 45*, 1638–1642.

Lord, S. R., & Menz, H. B. (2000). Visual contributions to postural stability in older adults. *Gerontology, 46*, 306–310.

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

Peterka, R. J. (2002). Sensorimotor integration in human postural control. *Journal of Neurophysiology, 88*, 1097–1118.

Raymakers, J. A., Samson, M. M., & Verhaar, H. J. J. (2005). The assessment of body sway and the choice of the stability parameter(s). *Gait and Posture, 21*, 48–58.

Teasdale, N., Hue, O., Marcotte, J., Berrigan, F., Simoneau, M., Doré, J., ... Tremblay, A. (2007). Reducing weight increases postural stability in obese and morbid obese men. *International Journal of Obesity, 31*, 153–160.

World Health Organization. (2013a). Obesity and overweight. Retrieved from http://www.who.int/mediacentre/factsheets/fs311/en/

World Health Organization. (2013b). WHO Global Infobase. Retrieved from https://apps.who.int/infobase/Comparisons.aspx?l=&NodeVal=WGIE_BMI_5_cd.0704&DO=1&DDLReg=ALL&DDLSex=2&DDLAgeGrp=15-100&DDLYear=2010&DDLMethod=INTMDCTM&DDLCateNum=6&TxtBxCtmNum=20%2c35%2c50%2c65%2c80&CBLC1=ON&CBLC3=ON&CBLC4=ON&CBLC6=ON&CBLC8=ON&CBLC10=ON&DDLMapsize=800x480&DDLMapLabels=none&DDLTmpRangBK=0&DDLTmpColor=-3342388

Zemková, E. (2008). *Diagnostika koordinačních schopností* [Diagnostics of coordination abilities] [Monograph]. Bratislava: Comenius University in Bratislava.