Anthropological Review • Vol. 86(4), 45–61 (2023)

ANTHROPOLOGICAL REVIEW

Available online at: https://doi.org/10.18778/1898-6773.86.4.04

Relationship between body sway and body build in healthy adult men and women

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Abstract: Studies investigating the relationship between balance ability and body size, build and proportions tend to concentrate on body mass and height rather than breadth parameters or size of individual body segments. The purpose of this study was to determine a relationship between the ability to keep balance and the size, build and proportions, based on breadth and length dimensions of the body in healthy adult men and women during a position of free standing. This study also aimed to investigate how the lack of visual control affects the analyzed relationship. The study group consisted of 102 adults of both sexes. The investigations encompassed anthropometric measurements of the body and the ability to keep balance. The analysis covered a of series anthropometric parameters, 9 indices of body proportions, mean velocity of the COP movement (MV) and ellipse area (EA). A statistical analysis of the results was carried out taking into consideration the division into groups due to sexes. The results of the Pearson correlation have revealed that there is a statistically significant correlation (weak or moderate degree) between anthropometric parameters of the body and stabilographic values. Results differ between sexes and depend on whether Romberg's test was performed with open or closed eyes. The obtained results showed that the surface area of ellipse significantly depends on the dimensions of these body elements which relate to the position of the centre of mass. The obtained results, which differ depending on sex, show that the values of the body sways in a position of free standing depend on breadth and length dimensions of the body, visual control and the analyzed parameter of balance.

Key words: anthropometry, body dimensions, stabilography, students, Romberg test.

Original article

Received: 06.08.2023; Revised: 30.10.2023; Accepted: 10.11.2023

Introduction

Balance is defined as the ability to keep the centre of gravity of the body over the base of support, restricted by the outline of the feet. The sense of balance makes it possible to determine a position of the body and its individual parts in space, the movement of the body, a direction and velocity of changes. An efficient sense of balance enables keeping balance and stability in an automatic and continuous way in changing conditions (Hanes and McCollum 2006; Panankin 2018). The sense of balance is controlled by the organ of vision, the vestibular system of the ear as well as proprioceptors in muscles, joints and tendons (Peterka 2018). Ageing, disease or damage to any of the above-mentioned elements may result in balance disorders causing symptoms, such as difficulty keeping the right body posture, dizziness, disorders of vision and hearing, difficulty in concentration and memory (Loyd et al. 2021).

The primary sensory system is the organ of sight. It provides information on the surroundings and objects moving around the body, which gives a signal for the movement of the body (Peterka 2018). Central vision enables stabilization and control of spontaneous sways and rocking triggered by visual signals, on the other hand, peripheral vision makes it possible to control the body posture (Gaerlan et al. 2012).

Proprioceptive sensibility involves receptors, such as muscle and joint spindles, tactile and lamellated corpuscles, Ruffini corpuscles as well as Golgi tendon organs. These are specialized mechanoreceptors sensitive to stretching (extension) and changes in pressure within muscles, tendons and joints. A special role in keeping balance is played by signals from receptors located in the neck and ankles of lower limbs. The former informs about the direction in which the head is turning, the latter about the movement of the body, swaying, the surface area of standing including its features, such as hardness and adhesion (Peterka 2018).

The vestibular system of the ear consists of 3 semicircular canals, which transmit signals about the position of the head in three-dimensional space. The system also contains utricle and sacculus, which are responsible for vertical orientation and linear movement. Proper work of the receptors of both (right and left) vestibular systems consists in symmetrical and simultaneous transmission of signals to the brain (in the case of the head movements of different intensity on both sides) (Peterka 2018).

Information obtained through the visual channel provides details only about the surroundings. On the other hand, the vestibular system sends signals only about the head position. Balance can be kept thanks to simultaneous signals from these two sources supplemented with additional information from proprioceptors (Gaerlan et al. 2012). Nervous impulses are segregated in the brain, especially in the cerebellum, where they are integrated with previously learned pieces of information and habitual movements.

Because balance is a motor skill based on a very complex mechanism of nervous and muscular control, there are various factors which determine its diversity in the population. It can be intuitively divided into a group of internal factors, including measurable morphological parameters and possible pathologies occurring within the motor system and nervous system.

One of the best-studied factors affecting the postural stability is age. Healthy children reach an adult pattern of balance by the age of 10–12 years (Humphriss et al. 2011). An optimum control of body balance is achieved at late adolescence and maintained until around 60 years of age (Gaerlan et al. 2012). A similarly strong differentiating demographic factor is sex. It is believed that women are characterized by better stability due to lower location of the centre of mass in their bodies (Greve et al. 2013; Puszczałowska-Lisis et al. 2018). Further factors influencing balance keeping involve parameters connected with the location of the centre of pressure (COP). The above-mentioned parameters include the body build and shape. It is assumed that mainly body sway is related to height according to inverted pendulum model (McGrath et al. 2015). The taller the person, the greater body sways he/she features (Alonso et al. 2015). Studies show that the sway values are also affected by the body mass; the greater the body mass, the higher the amplitude of sways (Hue et al. 2007). It is the most noticeable in obese people (Ku et al. 2012). Due to ambiguity of the BMI index (Body Mass Index), an attempt was made to differentiate the muscle content and fat tissue content from the total body mass. The conducted analyses only ascertained the influence of the above-mentioned parameters on the velocity of sways. Fat content percentage correlates negatively with sway velocity, whereas fat-free mass percentage shows positive correlation.

Among anthropometric parameters and posture-metric parameters, researchers analyzed postural features related, among other things, to spinal curvatures and pelvic asymmetry. The values which showed a negative impact on balance are: severe inclination of the sacral bone, backward deflection of the body and increased thoracic kyphosis (Walicka-Cupryś et al. 2013). In addition, patients with idiopathic scoliosis achieved significantly worse results in stabilometric tests (Catan et al. 2020).

Since balance is an ability which is strongly conditioned by the development of the nervous system, a considerable number of persons with different degrees of mental disabilities was tested. Those investigations revealed that patients with autism spectrum, borderline and other disorders of moderate degree show a significant loss of balance ability (Gouleme et al. 2017), and the value of such a loss correlates with the disability degree (Bibrowicz et al. 2019; Lipowicz et al. 2019a). In addition, patients that have experienced stroke suffer a reduction of postural stability. However, some studies reported that mentally disabled persons and those with damaged central nervous system tissue exhibit improved balance skills as a result of training (Kang 2015; Lee et al. 2016).

There have been few studies investigating the relationship between balance ability and body size, build and proportions. Instead, researchers have been concentrated on investigating other anthropological aspects, such as body mass and height, often neglecting breadth parameters or size of individual body segments. Moreover, research on the relationship between balance and the build and shape of the body in children and adolescents revealed that regardless of age, boys and girls who are characterized by smaller morphological parameters sway more than individuals with stronger body build (Lipowicz et al. 2019b). The present work aimed to determine the relationship between the ability to keep balance and the body size, build and proportions in healthy adult men and women in a position of free standing. In addition, this study aimed to examine the extent to which a lack of sight control affects the relationship analysed herein.

Material and methods

The investigations encompassed 102 adults of both sexes being the students of the Academy of Physical Education in Katowice (Department of Physiotherapy) and the Silesian University of Technology, at the age 20–24 years (body mass: 73±15 kg, body height: 172.65±8.59 cm). The study group consisted of 47 men (body mass: 82±13 kg, body height: 179.5±5.61 cm) and 55 women (body mass: 65±11 kg, body height: 166.79±5.94 cm). The tests involved anthropometric measurements of the body and the ability to keep balance. Students at both universities did not differ significantly in body build and balance.

All the test participants agreed to take part in the tests. The study design was approved by the Bioethical Committee at the The Jerzy Kukuczka Academy of Physical Education in Katowice before commencement of the study (decision no. 3/2019).

Balance measurements were conducted using the Zebris FDM-S measuring platform (Zebris Medical GmbH, Isny, Germany). Each participant's body was subjected to 26 measurements (Table 1). All measurements were carried out in accordance with the Martin technique. Mean values were adopted for the measurements done on both sides of the body. The measurements were conducted using an anthropometric equipment, such as anthropometer, callipers and centimetre tape measure. On the basis of the above-mentioned anthropometric measurements, 9 indexes of body proportions were calculated (Table 2).

Table 1. Characteristics of the examined material

	Men			Women			
	Mean	Min-max	SD	Mean	Min-max	SD	p
Age [years]	20.6	18.8-24.7	1.5	20.7	18.8-30.6	1.9	0.5929
Body measurements							
Body weight [kg]	81.9	55-117.5	13.9	65.4	48.0-106.0	10.7	<0.0001
Stature [cm]	179.5	168.5-194.4	5.6	166.7	154.3-179.0	6.0	<0.0001
Suprasternale height [cm]	145.7	136.5-159.1	5.1	135.7	127.0-146.0	5.1	<0.0001
Acromial height (standing) [cm]	146.6	135.5-161.0	5.2	136.0	127.8-147.5	5.5	<0.0001
Elbow height (standing) [cm]	113.2	100.5-127.9	5.0	105.4	98.5-114.8	4.2	<0.0001
Wrist height [cm]	87.6	76.0-98.8	4.4	82.1	71.4-89.6	3.9	<0.0001
Waist height (Natural) [cm]	113.6	102.0-123.8	4.4	106.6	98.6-115.1	4.7	<0.0001
Tibiale height [cm]	48.1	42.5-55.4	3.1	45.5	40.5-52.9	2.9	<0.0001
Mean Iliospinale height [cm]	101.1	91.8-11.8	4.3	94.0	56.9-103.2	4.2	<0.0001
Sitting height [cm]	94.5	89.8-102.3	3.1	89.2	81.4-96.7	3.2	<0.0001
Trunk length [cm]	54.5	48.3-65.9	4.1	51.1	45.3-57.5	2.9	<0.0001
Mean length of the upper body segment [cm]	90.3	81.5-99.7	4.6	82.1	74.1-90.9	3.8	<0.0001
Upper extremity length [cm]	77.7	61.5-85.7	4.3	70.7	47.3-85.6	6.5	<0.0001
Acromion-Radiale length [cm]	33.4	28.5-36.3	1.9	30.5	23.3-34.8	2.0	<0.0001

	Men			Women			
	Mean	Min-max	SD	Mean	Min-max	SD	p
Radiale-Dactylion III length [cm]	44.3	26.9-49.9	4.2	40.1	20.8-53.1	5.6	0.0001
Lower extremity length (Trochan-terion) [cm]	89.2	80.4-100.8	4.4	84.5	73.4-93.9	4.3	<0.0001
Mean Thigh length [cm]	53.0	46.3-60.0	3.0	48.6	40.6-56.0	3.4	0.0023
Head and neck height [cm]	33.8	30.6-38.2	1.5	31.0	27.1-34.5	1.6	<0.0001
Biacromial breadth [cm]	40.2	33.2-44.1	2.3	36.4	33.0-39.7	1.6	<0.0001
Bideltoid breadth [cm]	47.3	40.4-55.2	3.3	41.8	35.5-50.7	2.8	<0.0001
Chest breadth [cm]	28.9	24.5-33.5	1.9	24.8	22.4-29.0	1.8	<0.0001
Chest depth[cm]	19.5	16.4-23.0	1.5	18.1	14.6-23.0	1.9	0.0003
Biiliocristale breadth [cm]	28.8	22.6-33.5	1.9/2	27.9	25.1-32.0	1.7	0.0239
Chest circumference (below bust) –rest [cm]	87.6	75.7-102.5	6.2	75.4	67.0-89.0	5.5	<0.0001
Chest circumference (below bust)-inhalation [cm]	93.1	83.0-109.0	6.0	79.8	71.5-92.0	5.2	<0.0001
Waist circumference [cm]	79.1	66.0-101.0	6.7	72.1	62.0-93.0	7.2	<0.0001
Buttock (hip) circumference [cm]	98.9	82.7-115.0	6.7	98.1	83.0-123.0	7.4	0.5558
Thigh circumference [cm]	57.6	47.8-68.5	4.8	56.8	45.0-77.0	5.5	0.4881
Indices							
BMI [kg/cm^2]	25.4	18.0-35.3	3.9	2.5	17.8-36.7	3.6	0.0154
Sitting Height Ratio (SHR)	52.4	41.4-55.1	2.0	53.3	40.8-56.1	2.1	0.0004
Skelic index	91.1	81.6-141.5	8.6	88.0	78.1-145.3	9.1	0.0003
Upper extremity length to stature index	43.3	32.7-47.2	2.5	42.4	29.4-51.5	3.4	0.1219
Arm length to height index	18.6	15.4-20.8	1.1	18.3	16.6-20.2	1.0	0.1373
Arm to forearm index	76.9	61.3-97.2	7.8	76.9	62.1-112.9	8.3	0.3126
Lower extremity length to stature index	56.3	54.0-59.8	1.3	56.4	53.7-59.3	1.4	0.5640
Width- breadth chest index	67.7	56.6-84.2	6.4	73.4	58.3-84.4	7.1	<0.0001
WHR waist to hip ratio	0.81	0.73-0.90	0.03	0.73	0.66-0.85	0.04	<0.0001
WTR waist to high ratio	138.6	123.4-157.8	6.5	127.0	110.5-157.4	9.2	<0.0001
Body balance parameters							
Sway path (SP) EO [mm]	326.3	183.5-592.9	81.8	345.4	179.7-563.4	70.0	0.2126
Sway path (SP) EC [mm]	380.0	217.9-716.2	101.9	395.913	272.3-606.0	83.8	0.3948
Elipse area (EA) EO [mm^2]	95.1	12.4-264.4	59.6	96.0	20.4-331.6	67.6	0.9451
Elipse area (EA) EC [mm^2]	127.1	21.6-458.8	101.0	113.0	26.4-285.2	68.1	0.4122
Mean velocity EO [mm/s]	5.4	3.1-9.9	1.4	5.8	3.0-9.4	1.2	0.2126
Mean velocity EC [mm/s]	6.3	3.6-11.9	1.7	6.6	4.5-10.1	1.4	0.3948

Table 2. Anthropometric indexes calculated on the basis of the conducted measurements

Indices	Calculation method
SHR sitting height ratio	([BS-v]/[B-v])*100 SHR, sitting height/Stature ×100
Skelic index	([B-v]-[BS-v]/[BS-v])*100 (limb length / body length with head) * 100 (length of the legs / length of the trunk with head) x 100
Upper extremity length to stature index	([a-daIII]/[B-v])*100 (Upper extremity and palm length / Stature) * 100
Arm length to height index	([a-r]/[B-v])*100 (Acromion-Radiale Length / Stature) *100
Arm to forearm index	([r-sty]/[a-r])*100 (forearm length / Acromion-Radiale Length) *100
Lower extremity length to stature index	([B-is]/[B-v])*100 (length of the lower limb / Stature) *100
Width-breadth chest index	([xi-ths]/[thl-thl])*100 (Chest depth / Chest breadth) * 100
WHR waist to hip ratio	Waist circumference / Buttock (hip) circumference
WTR waist to high ratio	Waist circumference / Thigh circumference
BMI body mass index	Body weight / (Stature in m)^2

The balance test (the analysis of the position of the resultant of ground reaction forces) was based on the Romberg test. During that test, a study participant was standing on their lower limbs, which were positioned as wide apart as the width of their pelvis, and their arms were hanging freely alongside their body. Romberg's test was conducted twice: with eyes open (EO) and eyes closed (EC). The time of each test equalled 60 seconds.

The analysis involved 2 parameters:

- mean velocity of the COP movement (MV) [mm/s] – total length of the path covered by the COP (the path covered by the centre of pressure of ground reaction force during the measurement) divided by the time of the test duration,
- ellipse area (EA) [mm^2] in which the COP was located during the test (the surface area of ellipse created by 95% of the COP positions during the test).

Analyzed values were obtained from a 30-second measurement (i.e., from 15. to 45. second).

Descriptive statistics, which are presented in Table 3, include mean, standard deviation and range values. Analyses were performed for each sex separately. Because of non-normal distribution of stabilographic parameters, MV and EA were logarithmically transformed. Furthermore, correlation between stabilographic and anthropometric parameters were studied, using Pearson's coefficients. Computations were made for the values obtained during tests with eyes open and closed. Next, for each obtained correlation coefficient a significance test was carried out. The test values at *$p<0.05$; **$p<0.01$; ***$p<0.001$ were considered statistically significant.

Table 3. Pearson's correlation coefficient values between stabilographic parameters (MV and EA) in tests with eyes open (eo) and closed (ec)

	MV eo	EA eo	MV ec	EA ec
		Men		
MV eo	-	0.45**	0.76***	0.45**
EA eo	0.44**	-	0.44**	0.68***
MV ec	0.50***	0.28*	-	0.59***
EA ec	0.18	0.62***	0.40**	-
		Women		

Legend: MV – mean velocity of the COP movement [mm/s]; EA – ellipse area [mm^2]; eo – eyes open; ec – eyes closed; level of significance: ** $p<0.01$, *** $p<0.001$

Results

Table 3 presents the correlation values for the stabilographic parameters obtained in tests with open and closed eyes. In women, the correlation values were within the 0.18 to 0.62 range, whereas in men the values ranged between 0.44 and 0.76. The above-mentioned values indicated the lack of full dependence between the path length and ellipse area, which suggests a different impact of various factors on the balance parameters in both sexes in different conditions.

Table 4. Pearson's correlation coefficients between the body build and balance

	Men				Women			
	eyes open (eo)		eyes closed (ec)		eyes open (eo)		eyes closed (ec)	
	MV	EA	MV	EA	MV	EA	MV	EA
Body measurements								
Body weight [kg]	-0.33*	ns	ns	ns	-0.45**	ns	ns	ns
BMI	ns	ns	ns	ns	-0.51***	ns	ns	ns
Stature [cm]	ns	ns	ns	ns	ns	0.31*	0.30*	0.36**
Suprasternale height [cm]	ns	ns	ns	ns	ns	ns	ns	0.36**
Acromial height (standing) [cm]	ns	ns	ns	ns	ns	0.32*	ns	0.39**
Elbow height (standing) [cm]	ns	ns	ns	ns	ns	ns	ns	0.30*
Wrist height [cm]	ns	ns	ns	ns	ns	ns	ns	ns
Waist Height (Natural) [cm]	ns	ns	ns	ns	ns	ns	ns	0.33*
Tibiale height [cm]	ns	ns	ns	ns	ns	0.33*	ns	0.34*
Mean Iliospinale height [cm]	ns	ns	ns	ns	ns	ns	ns	0.29*
Sitting height [cm]	ns	ns	ns	ns	ns	ns	0.42**	0.33*
Trunk length [cm]	-0.29*	ns	ns	ns	ns	ns	0.35*	ns
Mean length of the upper body segment [cm]	-0.30*	ns	ns	ns	ns	ns	0.42**	ns

Tab 4 (cont.)

	Men				Women			
	eyes open (eo)		eyes closed (ec)		eyes open (eo)		eyes closed (ec)	
	MV	EA	MV	EA	MV	EA	MV	EA
Upper extremity length [cm]		ns	ns	ns	ns	0.31*	0.28*	0.39**
Acromion-Radiale length [cm]	-0.38**	ns	ns	ns	ns	0.36**		0.40**
Radiale-Dactylion III length [cm]		ns	ns	ns	ns		0.29*	0.32*
Lower extremity length (Trochanterion) [cm]		ns	ns	ns	ns	ns	ns	0.33*
Mean Thigh length [cm]	-0.31*	ns	ns	ns	ns	ns	ns	ns
Head and neck height [cm]		ns	ns	ns	.35*	0.28*	0.34*	ns
Biacromial breadth [cm]		ns	ns	ns	ns	ns	ns	ns
Bideltoid breadth [cm]	-0.29*	ns	ns	ns	ns	ns	ns	ns
Chest breadth [cm]		ns	ns	ns	ns	ns	ns	ns
Chest depth[cm]	-0.35*	-0.37*	ns	ns	-0.30*	ns	ns	ns
Biiliocristale breadth [cm]	-0.35*	ns	ns	ns		ns	ns	ns
Chest circumference (below bust) - rest [cm]	-0.34*	ns	ns	ns	-0.30*	ns	ns	ns
Chest circumference (below bust) - inhalation [cm]	-0.36*	ns	ns	ns	ns	ns	ns	ns
Waist circumference [cm]	-0.36*	ns	ns	ns	-0.44**	ns	ns	ns
Buttock (hip) circumference [cm]	ns	ns	ns	ns	-0.50***	ns	ns	ns
Thigh circumference[cm]	ns	ns	ns	ns	-0.51***	ns	ns	ns
Indices								
Sitting height ratio (SHR)	ns	ns	ns	ns	ns	ns	ns	ns
Skelic index	ns	ns	ns	ns	ns	ns	ns	ns
Upper extremity length to stature index	ns	ns	ns	ns	ns	ns	ns	0.29*
Arm length to height index	ns	ns	ns	ns	ns	ns	ns	ns
Arm to forearm index	ns	ns	ns	ns	ns	ns	ns	ns
Lower extremity length to stature index	ns	ns	ns	ns	-0.30*	ns	-0.37**	ns
Width-breadth chest index	ns	ns	ns	ns	ns	ns	ns	ns
WHR waist to hip ratio	ns	ns	ns	ns	ns	ns	ns	ns
WTR waist to thigh ratio	-0.31*	ns	ns	ns	ns	ns	ns	ns

Legend: MV – mean velocity of the COP movement [mm/s]; EA – ellipse area [mm^2]. Level of significance: * $p<0.05$; ** $p<0.01$; *** $p<0.001$; ns – not significant.

The tests of Pearson's correlation r (Table 4) revealed that correlation between body parameters and features connected with stability is statistically significant, in a small or moderate degree. Correlations of the highest level of statistical significance were observed only in women, in tests with open eyes. Such correlations were related to the association between sway velocity (MV) and factors such as: body mass ($r = -0.45$, $p<0.001$), BMI ($r = -0.51$, $p<0.0001$), hip circumference ($r = -0.50$, $p<0.0001$), the largest circumference of the thigh ($r = -0.51$, $p<0.0001$) and waist circumference ($r = -0,44$; $p<0.001$). Negative values of the correlation coefficients revealed that higher velocity was shown by women having smaller body mass as well as smaller circumferences of waist, hips and thighs. Moreover, women who swayed more quickly had significantly smaller circumference of the chest and smaller depth of the chest as well as a longer head with the neck. In addition, the MV EO significantly depended on the proportions of the length of the lower limb in relation to the body height (women with relatively short legs were prone to swaying more quickly). After the closure of the eyes, the correlation values decreased and became statistically insignificant. None of the breadth dimensions and body circumferences showed any considerable influence on the velocity of sways. After the elimination of the sight control, the sway velocity path was affected by the length dimensions of female bodies. Taller women having longer spine and longer upper limbs were characterized by considerably higher velocity. Moreover, the MV EC significantly depended on the proportions of the length of the lower limb in relation to the body height, which means that women with shorter legs in relation to the body height were prone to swaying more quickly).

In women, ellipse area EA, contrary to MV, showed a significant correlation solely with length parameters, and not with breadth parameters of the body. A bigger surface area of ellipse in tests with open eyes was typical of taller women with a higher position of their shoulder, knee, and longer upper limbs. After the closure of the eyes, different measurements describing the height of the body and length of its individual segments gained on statistical significance in their relation to the ellipse area confirming greater sways in taller women with longer upper and lower limbs.

In tests with open eyes, greater velocity of sways was characteristic of men with smaller body mass ($r = -0.33$; $p<0.05$), shorter trunk, shorter upper limbs and shorter thighs. Moreover, those who swayed more quickly were characterized by smaller breadth dimensions of the body, such as: upper breadth of the body ($r = -0.29$, $p<0.05$), hip breadth ($r = -0.35$, $p<0.05$), chest depth ($r = -0.35$, $p<0.05$) and smaller circumferences of the body, such as: chest at rest ($r = -0.34$, $p<0.05$) and chest while breathing in ($r = -0.36$, $p<0.05$) as well as waist ($r = -0,36$, $p<0.05$). Quicker sways were characteristic of men with lower WTR values, i.e., a smaller circumference of the thigh in relation to the waist circumference. After the closure of eyes, none of the parameters of the body build and shape in men significantly influenced the velocity of sways. This fact suggests that in such a situation the men's body build lost its significance for the stability of the body and men with various types of body build swayed in a similar way with their eyes closed.

Among all analyzed dimensions of male bodies, such as length, circumference and breadth, none showed any significant relationship with the ellipse area in tests with open eyes. The only dimension that revealed some relationship was the depth of the chest. Men with more oval chests had a significantly larger ellipse area describing the sways. After the closure of eyes, the men's body build and shape did not considerably affect the size of the ellipse area.

Moreover, it was observed that men revealed a significant relationship between sway velocity in tests with eyes opened (EO) and mainly the build of the upper part of their body, namely the length of trunk and upper segment of the body, the breadth of the upper part of the body, the circumference of thorax and waist as well as chest depth. On the other hand, in women, a significant relationship occurred both in the case of upper body dimensions (e.g., thorax and waist circumferences) and lower body dimensions (e.g., hip and thigh circumferences).

Discussion

Balance in terms of biomechanics is defined as ability to keep the centre of gravity of the body over the base of support. However, the borderline of stability does not coincide with the outline of the feet. Postural stability is one of the most important indexes of correct body posture and involves ability to regain balance. The size of sways is described by parameters connected with the stabilometric path, most often with the path length (or the velocity of sways – the value obtained from the division of the path length by the test time) and the size of the ellipse area describing maximum sways occurring in a position of standing (Jurkojć 2018). Velocity of sways and the ellipse area showed a moderate correlation (from 0.4 for women with eyes closed to 0.59 for men with eyes closed), which means that, for instance, study participants making quicker movements around the centre of mass (with a longer path of stabilogram) may achieve both large and small values of the ellipse area. The correlation values suggest that postural stability depends on various and not always the same factors. Literature mentions age and sex, efficiency of body functioning, proper posture, muscle strength as well as body build and shape (Wang et al. 2022).

The present study describes the ability to keep balance by means of the velocity of sways MV and the area of ellipse EA. The above-mentioned are indicated as the most informative parameter when body sway is assessed (Raymakers et al. 2005; Błaszczyk and Beck 2023). The obtained results showed a different influence of the body build on MV, and different on EA.

In general, the velocity of sways significantly depended on the dimensions describing the breadth of the body, for instance the breadth of the upper body (in men), hip breadth (in men), chest circumference (in both sexes), waist circumference (in both sexes), hip circumference and thigh circumference (in women). The smaller breadth dimensions in a tested person, the higher sway velocity (and the longer path of stabilogram) they showed. Similar results were obtained by Lipowicz et al. (2019a; 2019b) in the case of children and adolescence. Regardless of age, children and youth characterized by lower body circumferences (thorax, waist, hips, arms) swayed more, especially in medio-lateral plane. Also, Alonso et al. (2015) suggested that the fat mass concentration in the chest and abdomen (android shape) increases the load on the hips, explaining the larger stabilographic medio-lateral path. Smaller breadth dimensions may indicate weaker muscularity of the body, lower mass of muscles and more delicate skeleton structure (Xiao et al. 2005; Malakar et al. 2022). The dependence between the sway control and a relatively low muscle component was observed in the investigations of girl gymnasts, where ectomorphic subjects showed 72% of more body sway than endomorphic girls (Allard et al. 2001). It was also reported that there was a certain relationship between a degree of muscularity of lower extremity and sways (Muehlbauer et al. 2015). Weaker muscles of lower limbs are responsible for relatively greater sways, whereas strength training improves the postural stability of the body (Youssef et al. 2018). In addition, the results of Alonso et al. (2015) suggest that lower lean body mass can be a risk factor for the postural control. In addition, what cannot be excluded is greater tiredness of muscles in slimmer, less muscular subjects (Sterkowicz et al. 2016). This fact may cause greater difficulty in keeping motionless body posture and result in higher velocity of sways.

The ellipse area is a parameter describing the range of maximum sways which can be achieved by a person in a position of free standing. The obtained results show that the size of the ellipse area depends on the body elements connected with the location of the COP, namely the dimensions of the body height measured, for instance from the ground to the top of the head, shoulder, elbow, waist, knee, and correlated length of upper extremities. The higher the centre of mass is located, the greater ellipse area the body sways in free standing. Among the tested adults the ellipse area EA changed along with the length dimensions, such as the height of body, shoulder, knee, head with the neck as well as the length of upper extremity. In the test performed without eyesight control, the above-mentioned relationship only grew in importance. Generally speaking, the higher the measurement point was located in a tested person (e.g., the top of the head, jugular notch, iliac spine), the greater the ellipse area became in a standing position. These associations were statistically significant only in women. Similarly significant positive correlations of length dimensions (height and trunk-cephalic length), and not waist-hip ratio (WHR) with the COP area, were reported among adult men and women from Brazil in tests with open eyes (Alonso et al. 2015). From a biomechanical perspective, greater sways in tall and slim women result from a higher location of the centre of mass (COM) of the body. Such a postural sway can be explained by the inverted pendulum model, which is based on the relation between the motion of a pendulum and its length, mass, and stiffness. According to this model, in a position of free standing the body sways mostly around the ankle joint. It may be supposed that the fact that taller women are prone to greater sways results from behaviour. Shorter women far more often wear high-heeled shoes and thus most probably train the postural stability and cope with greater sways (Wan et al. 2019). However, whether foot shape and more flexible longitudinal arch observed in taller and heavier women leads to a greater postural sway (Aurichio et al. 2011; De Blasiis et al. 2023) is an area for further investigation.

Body mass and BMI are anthropometric variables which, next to body height, are the most often analyzed factors influencing the ability to keep balance. However, the results of investigations are not uniform. In the current work, the BMI turned out to be a vital factor affecting only the velocity of sways in women in the tests with open eyes ($r = -0.51$, $p < 0.0001$). The higher the BMI in women, the lower velocity of sways was achieved by women. Among young men no significant relationship was revealed, either with MV or EA. Among Brazilian adults aged over 60, the BMI and fat mass did not seem to influence the balance during a one-leg stance task (Pereira et al. 2018). A different study ascertained that the body mass was an independent factor and accounted for as much as 52-54% of the variance of balance stability in group of men with a wide BMI spectrum (17.4–63.8 kg/m^2; Hue et al. 2007), in whom the decline of balance stability was strongly correlated with an increase in body weight. Moreover, Mainenti et al. (2011) showed that elderly women with more fat mass had larger balance sway. In addition, Neri et al. (2021) found that there is no differences between women with gynoid and android obesity. Winters and Snow (2000) reported that 31% of postural sway variability in premenopausal women was caused by the fat mass. Conversely, Farenc et al. (2003) analysing the influence of body characteristics of 20-60 years-old individuals on their upright stance, showed that thinner subjects have larger horizontal displacements of the centre of gravity (COG) than normal or corpulent subjects. Smaller sways in subjects with larger BMI, which were observed in the present work, may relate to a low variability of this feature in the studied population (young healthy persons, without overweight or obesity) and specificity of the BMI index measuring rather muscularity than fat content in young people.

Our study confirmed the conclusion drawn by Alonso et al. (2015) reporting that for the young adults, without major diseases or other abnormalities, the anthropometric variables had different relations to postural sway according to sex. For instance, men showed a statistically significant correlation between the velocity of sways and the dimensions of the upper parts of the body, whereas women revealed such correlation for both upper and lower parts of the body. The reasons for such dimorphic differences can be found in diverse distribution of fat tissue (android and gynoid type of the adipose tissue distribution) and muscle tissue as well as different proportions of the body in both sexes (broader shoulders in men, broader hips in women).

After closing their eyes, both men and women showed an increase in sway velocity and ellipse area. This fact confirms significance of the visual stimulus for the body stability. However, the elimination of vision had a different impact on the analysed relationship in both sexes. In men with closed eyes, the value of sways ceased to depend on their body build, while in the case of women with closed eyes, their body build began to play a greater role for their stability. This fact can be observed particularly in the ellipse surface area. Similarly, Chiari et al. (2002) showed that the postural sway parameters increase while in a position of standing with eyes closed, and further, that body size and body composition are strongly related to postural sway in conditions with eyes closed. However, Alonso et al. (2015), in their multi-factor analysis encompassing both men and women, stated the significance of trunk-cephalic length for sway velocity and the COP area in tests with eyes closed, whereas the tests with eyes open showed the importance of only body height. This phenomenon can be explained by the possibility of two diverse strategies (ankle and hip strategies) applied by both sexes to both testing conditions (which can be seen in the differences in the degree of muscularity and muscle training, body shape and the point of the body mass weight, differences in the risk of falling at an elderly age between sexes). The literature reports some contrary observations showing that after the closure of eyes the stiffness decreases in the tarsal joint, which increases sways (Rothwell 2012), or vice versa, that the stiffness increases after the closures of eyes to reduce the risk of falling (Alonso et al. 2015). Regardless of the observations related to the change in body stiffness, it is clearly visible that when the visual information is omitted, signals from the somato-sensory and vestibular systems have a greater importance for the postural control, especially in women. An increased sensitivity to sensory information from proprioceptive and vestibular systems, activation of receptors placed in the muscles and joints, together with vestibular cues, provide the brain with information about where the body and its parts are located with respect to the gravitational environment (Tanaka et al. 2000). In addition, Alonso et al. (2015) suggested that ankle and hip strategies have opposite behaviours in relation to vision and the inverted pendulum.

Conclusions

From the perspective of postural correction therapy and the prevention of falls in persons with different types of disorders, investigating the relationship between body build and balance keeping is of considerable interest. Few studies investigating this issue have focused mainly on the relationships between sway values and body height, body mass and the BMI. Study participants of such studies tended to be characterized by specific features, for instance exhibiting obesity (Greve et al. 2007), disability (Lipowicz et al. 2019a), or focus on a specific age class, e.g., children (Lipowicz et al. 2019b; Plandowska et al. 2019) or the elderly (Jochymczyk-Woźniak et al. 2018).

This work, on the other hand, presents a relationship between balance parameters and a big number of measurements which precisely describe the body build of young adults, men and women, without balance disorders and with diverse body structure. The obtained results showed that the smaller breadth dimensions in a tested person, the higher velocity of sways (and the longer path of stabilogram) was observed. On the other hand, the ellipse area was substantially dependent on these body elements which is related to the location of the COP. The higher the position of the COP, the larger the ellipse area made by the body sway in a position of free standing. The pattern of dependence of sway values in adults was different in both sexes. It also depended on the visual control (eyes opened / closed) and the analysed balance parameter (sway velocity / ellipse area). These relations were often statistically significant although low; in general, they achieved higher values in women than in men.

Acknowledgement

The study was realized within the project "DISC4SPINE dynamic individual stimulation and control for spine and posture interactive rehabilitation" (grant no. POIR.04.01.02-00-0082/17-00) co-founded by the European Regional Development Found within Operational Program Smart Growth Action 4.1.2.

Ethics statement

The study design was approved by the Bioethical Committee at the The Jerzy Kukuczka Academy of Physical Education in Katowice before commencement of the study (decision no. 3/2019). All the test participants agreed to take part in the tests.

Authors' contribution

AL – is the initiator of the work, participated in the collection of material; she is a co-author of the paper's draft and final versions; MNB – performed the statistical analyses; KG – took part in collecting material and writing the text; KN-L – participated in collecting material and writing the text; KJ-W – participated in collecting material and writing the text; DF – participated in collecting material and writing the text; RM – participated in the interpretation of the results; AWM – participated in the interpretation of the results.

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