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Article

Body Weight Distribution and Body Sway in Healthy Female Adults Aged between 51 and 60 Years in Germany—Standard Values

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Abstract: Background: In order to determine possible pathological deviations in body weight distribution and body sway, it is helpful to have reference values for comparison: gender and age are two main influencing factors. For this reason, it was the aim of the present study to present reference values for women between 51 and 60 years of age. **Methods:** For this study, 101 subjectively healthy female Germans aged between 51 and 60 years (55.16 ± 2.89 years) volunteered and were required to stand in a habitual posture on a pressure measuring platform. **Results:** The average BMI of this age group was 25.02 ± 4.55 kg/m^2. The left and right foot showed an almost evenly balanced load distribution with a median load of 52.33% on the left foot [tolerance interval (TR) 38.00%/68.03%; confidence interval (CI) 51.00%/53.33%] and 47.67% on the right foot [TR 31.97%/62.00%; CI 46.67%/49.00%]. The measured median load of the forefoot was 33.33% [TR 21.37%/54.60%; CI 30.67%/36.00%] and that of the rear foot was 66.67% [TR 45.50%/78.63%; CI 64.00%/69.33%]. The median body sway in the frontal plane was 11 mm [TR 5.70 mm/26.30 mm; CI 10.00 mm/11.67 mm] and that of the sagittal plane was 16 mm [TR 7.37 mm/34.32 mm; CI 14.67 mm/18.67 mm]. The median ellipse area was 1.17 cm^2 [TR 0.29 cm^2/4.96 cm^2; CI 0.98 cm^2/1.35 cm^2], the median ellipse width was 0.91 cm [TR 0.42 cm/1.9 cm; CI 0.84 cm/1.02 cm] and its height was 0.40 cm [TR 0.22 cm/0.89 cm; CI 0.38 cm/0.43 cm]. **Conclusions:** The left-to-right ratio is almost balanced. The load distribution of the forefoot to the rear foot is approximately 1:2. The median body sway values for the frontal and sagittal planes (11 and 16 mm, respectively) agree with other values. The values for the height, body weight and the BMI are comparable to the values of average German women at this age; therefore, the measured values show a presentable cross section of women in the 51–60 age group in Germany. The present data can be used as a basis for women aged 51–60 years and can support the detection of possible dysfunctions as well as injury prevention in the parameters of postural control.

Keywords: body weight distribution; body sway; female subjects; standard value

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1. Introduction

In modern industrial societies, such as Germany, there is an increasing demographic change towards an aging society [1]. Every second adult in Germany is over 45 years old and, currently, every fifth adult is over 66 years old. In this context, it is important to maintain individual mobility for as long as possible and, consequently, to avoid falls due to a lack of balance. For this, functioning postural control is a significant aspect. However, muscle and bone masses as well as bone density are also important parameters when it comes to risk for falls. Postural control interacts with the functional ability of the sense of movement, position and balance[2]. Only if different systems, such as the vestibular organ, the visual system and/or the proprioceptive system, work together smoothly can the ability to balance be guaranteed at all. The systems involved can in turn influence different areas of the body, such as the musculoskeletal system, and at the same time be influenced by them (through endogenous or exogenous factors) [2–5]. Here, the musculoskeletal system neurophysiologically connects the muscles, fascia and nerves with each other [4,6–9]. If the sense of balance fails, dizziness (vertigo), among other things, can result and this is a frequent reason for medical consultation [2,10]. Accordingly, in the event of a loss of the sense of balance and, thus, of the ability to maintain equilibrium, severe limitations to everyday mobility are to be expected [2]. The importance of physical mobility in old age and, in particular, the problem of falls are well documented, according to which age-related diseases, such as sarcopenia, have a prevalence of up to 60% among the over-65 s [11]. The diseases that can result in the context of demographic change have equally costly consequences for the health system and for the labor sector through work absences [12].

Regarding the presence of normal values for equilibrium distribution and equilibrium fluctuations, there are often reference values for inhomogeneous age- or sex-specific groups. Pomarino and Pomarino [13] found no group or gender differences using 431 subjects of both sexes divided into 3 age groups; in the 11–69-year-old group, forefoot loading was 39.7% left to 39.6% right. Souza et al. [14] referred to an even distribution of left–right (50.31%: 49.76%) and a forefoot loading of 39.87% based on the study of 30 subjects (28 w/2 m) between 18 and 35 years of age. The equal left–right distribution was also confirmed by Syed et al. [15], with 628 (241 w/387 m) asymptomatic subjects aged 6–89 years; however, in terms of forefoot and rearfoot loading, it showed an almost symmetrical loading (46.05%/52.63%) in contrast to other authors [13,14]. Furthermore, all quadrants showed an almost identical weight distribution (approximately 23% left/right forefoot: approximately 26% left/right rear foot) [15]. Regarding the balance distribution of 416 subjects (208 w/208 m) aged 18–65 years, there was no gender difference observed by Ohlendorf et al. [16]; the left–right distribution (50.07%/50.12%) was consistently balanced. However, with increasing age, the left rearfoot load reduced in favor of the left forefoot load and, overall, the rearfoot was found to be approximately 10% more loaded than the forefoot [16].

Similarly, data published by Cavanagh et al. [17] from 108 healthy subjects (51 w/66 m) show that the rearfoot is loaded 60%, the metatarsus 8% and the forefoot 28%. Consideration of isolated age groups has also demonstrated a relatively balanced left–right balance distribution as well as forefoot and rearfoot loading in women aged 21–30 years (L 49.91%/R 50.09%; FF 33.33%/RF 66.67%) [18], 31–40 years (L 51.46%/R 48.54%; FF 33.84%/RF 66.16%) [19] and 41–50 years (L 51.00%/R 48.5%; FF 29.67%/RF 70.63%) [20]. Regarding the reference values of the postural variations, these are presented differently. Pomarino et al. [21] and Patti et al. [22] used the ellipse area as a reference for postural sway, which was reported as being 70 $mm^2 \pm 40$ mm^2 by Pomarino et al. [21] and 71.83 $mm^2 \pm 54.56$ mm^2 by Patti et al. [22]. In the 21–30 age group, men showed larger frontal and sagittal variations (11.67 mm/13 mm) [23] than women of the same age (9.5 mm/13 mm) [18]. Evidentially, frontal and sagittal balance variations increase with age, as can be seen on the basis of 41–50-year-old women with 13 and 16.5 mm, respectively [20]. However, lower values can also be found for the group of 31–40-year-old women with variations of 8.17 and 12 mm, respectively [19].

Thus, in times when raising the retirement age is virtually unavoidable in order to maintain the prosperity of society, the working and performance capacity of the economic population should be maintained for as long as possible [24,25]. In view of an aging society, the present study has the ambition to collect reference values for women aged 51–60 years and, as this study is of women only, gender differences are avoided, e.g., in constitution [26], BMI [26] and hormonal balance [7]. It is to be expected that for women, their occupational work and performance, due to the foreseen increasing compatibility of family life with work, will become an important focus in society. Therefore, the age group of 51–60 years is especially interesting since women of this age are often no longer the focus of child rearing;

this enables them to return to full-time work. In addition, the majority of these women might be within, or relatively close to, menopause which normally occurs between the ages of 48–52 [7]; this means that little hormonal variation is expected within the group and the negative effects of a deficiency in estrogens are also still relatively small. A deficiency of estrogens, which occurs after menopause, can lead to osteoporosis among other things [7].

To date, reference values are available for men in the age range of 21–30 years and for women in the age ranges of 21–30, 31–40 and 41–50 years [18–20,23]. These studies, as well as the present analysis, are part of a large project [27] to analyze, systematically, balance ability and postural fluctuations in relation to age and gender. Parts of this have already been published [18–20,23,28], but the analysis with regard to age- and gender-specific aspects has not yet been fully completed.

Since the ability to balance, as described above, is a multifactorial event which can be influenced by age-related and also gender-related factors, it is necessary to generate standard values in order to be able to distinguish pathologies of this age group from healthy issues and to help prevent injuries.

2. Methods

2.1. Subjects

A total of 101 subjectively healthy female subjects aged between 51 and 60 years, with an average age of 55.16 $\pm$ 2.89 years, volunteered in this study. Only women with an absence of any diseases that affect the body sway in any possible way were included, classed as subjectively healthy. Thus, a participant who is slightly overweight by the WHO definition can describe herself as healthy if she does not meet any of the following exclusion criteria.

The average BMI of the subjects was 25.02 kg/m^2. The BMI values were calculated from the self-reported weight and height data of each subject. According to the WHO classification [29], 52.5% were normal weight, 29.7% were pre-adipose, 13.86% were obese and 3.96% of the subjects were underweight. Ninety-two percent (n = 93) described themselves as being right-handed. The other 8% described themselves as being either left-handed, retrained left-handed or ambidextrous.

Regarding sports participation, 25.7% of the subjects reported that they do not participate in sports, while the same percentage stated that they participate in sports once a week. Sports participation of twice per week was reported by 16.8% of the test persons, while most, 31.68%, reported to partake in sports at least twice weekly. The present study included subjects with predominantly sedentary activities (administrative employees, office clerks, secretaries) as well as with activity-intensive activities (kindergarten teachers, stewardesses, teachers and employees in the medical /pharmaceutical sector such as dental assistants and nurses) and housewives. Overall, from a socio-economic point of view, a broad spectrum is covered, as both academics and non-academics are represented in sufficient numbers

All participants subjectively perceived themselves as being healthy. This implies the absence of surgery, acute complaints or even injuries related to the musculoskeletal system and the temporomandibular system in the period of the past 2 years. Exclusion criteria for this study included pain, discomfort or diseases of the musculoskeletal system, current surgery or injury in the above areas, current physiotherapeutic or orthopedic therapy, neuronal impairment, use of muscle relaxation medication or physician-diagnosed physical malpositions.

To ensure that only subjectively healthy subjects of this age would be part of this study, a general medical history [30] was obtained by means of a special questionnaire; the subjects' handedness, height, weight and sporting activities in their extent and intensity were also queried. All subjects were informed in detail and in advance on the subject of the investigations and their procedures. An informed consent was obtained from all subjects and/or their legal guardian(s). An approved ethics application of the medical faculty of the Goethe-university Frankfurt/Main (ethics no. 103/16) is available for the present study.

The requirements of the ethics application are based on the ethical principles that apply to medical research on living subjects (humans). The principles are published in the latest edition of the Declaration of Helsinki, Finland (2013).

2.2. Pressure Measurement Plate including Evaluation Parameters

The examination of postural control was performed with the help of the GP Multisens pressure measurement plate from GeBioMmbH (Münster, Germany). The plate has a total measuring area of 38.5 cm × 38.5 cm. The 8 mm × 8 mm sensors (a total of 2304 sensors) scan at a frequency of 200 Hertz. According to the manufacturer, the measurement error is ±5%.

The data acquisition guarantees the following evaluation parameters:

Equilibrium sway is recorded via the maximum deflection of frontal sway (FS) and sagittal sway (SS) in millimeters. In addition, the fluctuation is displayed by means of an ellipse in its area (cm^2), width (cm) and height (cm).

Furthermore, the percentage balance distribution (%) in all four quadrants (left/right of the forefoot and rearfoot) is visualized.

In total, each subject underwent three measurement cycles, each lasting 30 s. The subjects were asked to stand still, barefoot, on the pressure measurement plate unsupported in a habitual body posture with open eyes and a relaxed lower jaw position without moving. Figure 1 shows the experimental setup.

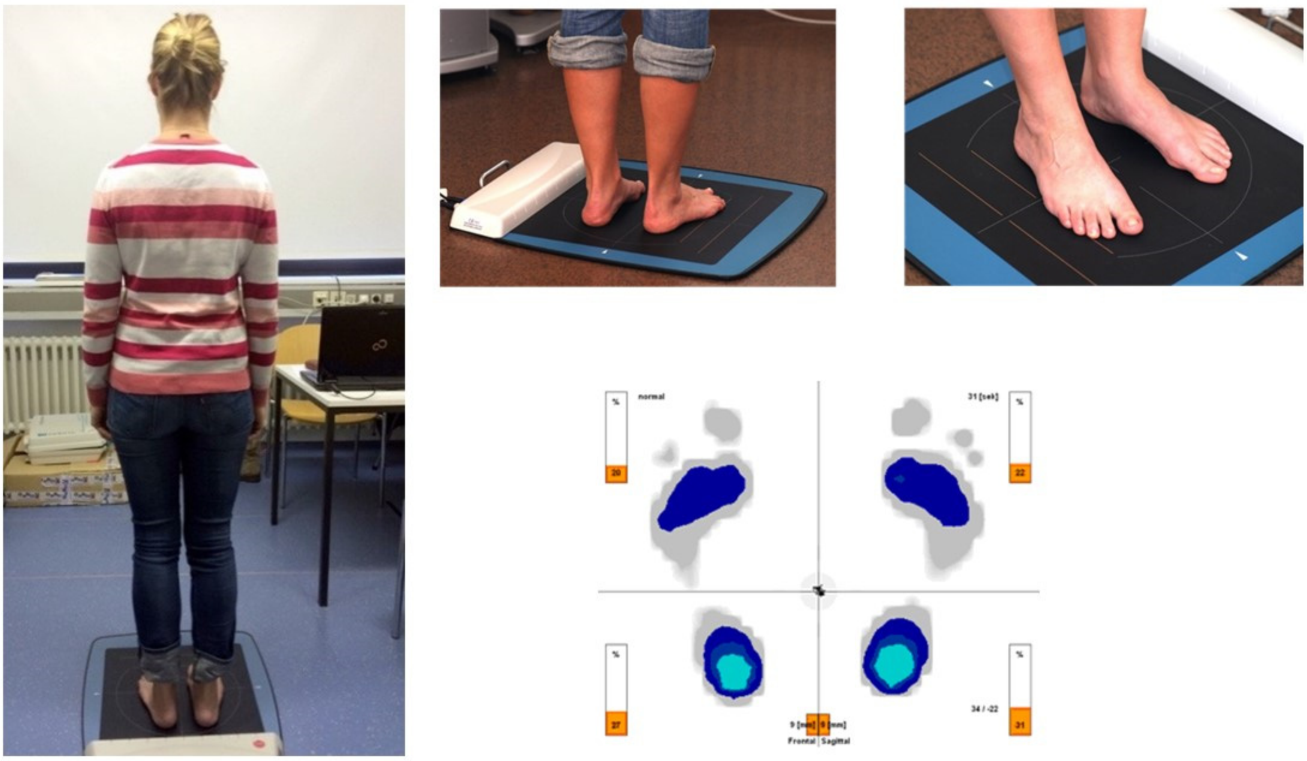

Figure 1. Experimental study setup.

2.3. Statistical Evaluation Procedures

All calculations in the present study were performed with the program BIAS (version 11.08) (Epsilon Verlag, Darmstadt, Germany). In order to test for normal distribution of the data, the Kolmogorov–Smirnov test was used. Parametric and non-parametric tolerance ranges (TR) were calculated by defining the upper and lower limits for 95% of all values (±2 SD), which were determined for >95% of all subjects. For the two-sided 95% confidence interval (CI) with corresponding left and right limits, the range of the determined average, median value, was presented as a function of distribution quality.

For the comparison between the BMI and sports activity groups, the Kruskal–Wallis test with included Conover–Iman comparison was used. All significant p values ($\leq$0.05) were then subjected to Bonferroni-Holm correction.

Correlation calculations were performed using Spearman–Kendall correlation. The effect size rho of the correlations was given according to Evans (1: <0.2 poor; 2: 0.2–0.4 weak; 3: 0.4–06 moderate; 4: 0.6–0.8 strong; 5: >0.8 optimal). The significance level was set at 5%.

3. Results

Table 1 contains the median values and the tolerance ranges with lower and upper limits as well as the confidence intervals with the left and right limits of the posturographic parameters.

Table 1. Median, tolerance area (TR) and confidence interval (CI) of all parameters.

	Median	TR Lower Limit	TR Upper Limit	CI Left Limit	CI Right Limit
Forefoot left (%)	19.33	8.33	34	18	21
Forefoot right (%)	13	2.4	29.33	12.67	15
Rearfoot left (%)	32.67	17.85	48.63	31.33	34
Rearfoot right (%)	33.67	16.65	47.82	31	35.33
Left foot (%)	52.33	38	68.03	51	53.33
Right foot (%)	47.67	31.97	62	46.67	49
Forefoot (%)	33.33	21.37	54.6	30.67	36
Rearfoot (%)	66.67	45.5	78.63	64	69.33
Frontal sway (mm)	11	5.7	26.3	10	11.67
Sagittal sway (mm)	16	7.37	34.32	14.67	18.67
Ellipse area (cm^2)	1.17	0.29	4.96	0.98	1.35
Ellipse width (cm)	0.91	0.42	1.9	0.84	1.02
Ellipse height (cm)	0.4	0.22	0.89	0.38	0.43

The rear foot had a greater balance distribution of 66.67% than the forefoot (33.33%). In addition, there was an approximately equal loading of both feet with the left foot being 52.33% and the right being 47.67%. The increased left loading resulted mainly from the forefoot loading which was found to be more pronounced on the left side (19.33%/13.00%). The frontal variation of 11 mm was less than the sagittal variation of 16 mm. Accordingly, the ellipse area was found to be 1.17 cm^2, with a width of 0.91 cm and a height of 0.40 cm.

Table 1 Examination of the demographic parameters (age and BMI) (Table 2) revealed a significant positive correlation ($p \leq 0.04$; rho: 0.21) between age and sagittal sway with a weak effect. Positive correlations were also observed ($p \leq 0.04$ and 0.02, respectively; rho: 0.21 and 0.24, respectively) between age and the ellipse area and between age and the ellipse width with a weak effect size. There were no significance differences between the other parameters and age.

The significant, positive correlations with low effect strength related to age are illustrated in Figure 2. The graphs show that with increasing age the sagittal sway increased, as well as the ellipse area and width.

However, with respect to BMI (Table 3), no significant correlation between the BMI and posturographic parameters could be demonstrated ($p > 0.05$; low effect size).

Table 2. Correlations of all parameters with demographic parameters (age and BMI). Significant *p*-values are shown in bold; correlation coefficient rho according to Evans (1996): <0.2: poor (1), 0.2–0.4: weak (2), 0.4–0.6: moderate (3), 0.6–0.8: strong (4) and >0.8: optimal (5).

	Age		BMI	
	***p*-Values**	**Rho + Effect Size**	***p*-Values**	**Rho + Effect Size**
Forefoot left (%)	0.2	−0.13 [1]	0.36	0.09 [1]
Forefoot right (%)	0.6	0.05 [1]	0.11	0.16 [1]
Rearfoot left (%)	0.5	0.07 [1]	0.21	−0.13 [1]
Rearfoot right (%)	0.81	0.02 [1]	0.23	−0.12 [1]
Left foot (%)	0.38	−0.09 [1]	0.86	−0.02 [1]
Right foot (%)	0.38	0.09 [1]	0.86	0.02 [1]
Forefoot (%)	0.79	−0.03 [1]	0.08	0.18 [1]
Rearfoot (%)	0.8	0.03 [1]	0.08	−0.17 [1]
Frontal sway (mm)	0.06	0.19 [1]	0.18	−0.14 [1]
Sagittal sway (mm)	0.04	0.21 [2]	0.71	0.04 [1]
Ellipse area (cm^2)	0.04	0.21 [2]	0.47	−0.07 [1]
Ellipse width (cm)	0.02	0.24 [2]	0.83	−0.02 [1]
Ellipse height (cm)	0.2	0.13 [1]	0.16	−0.14 [1]

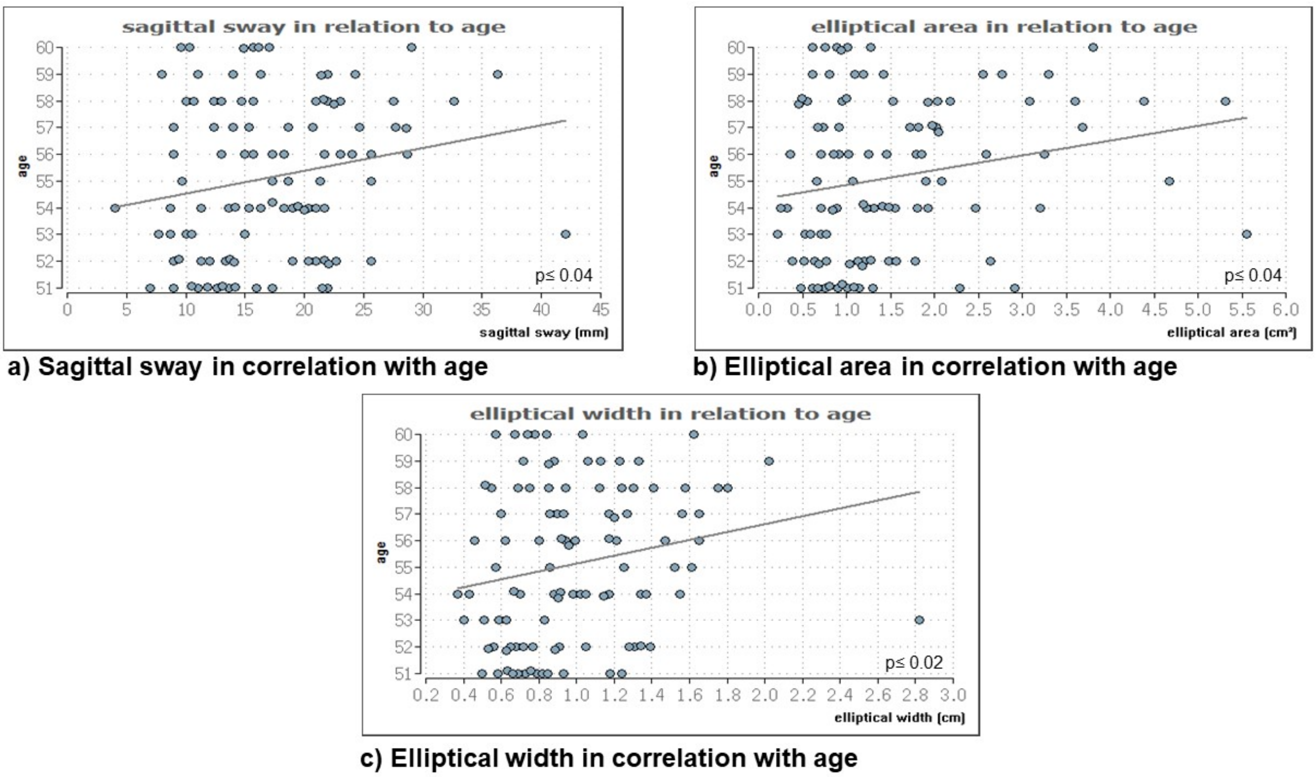

Figure 2. (**a**) Sagittal sway in correlation with age, (**b**) elliptical area in correlation with age, (**c**) elliptical width in correlation with age. The significant *p*-value is given in the respective graph.

Table 3. Influence of all parameters on the BMI. Median, minimum and maximum of the parameters surveyed in subjects with different BMI groups (1 = normal; 2 = pre-obese; 3 = obese; 4 = underweight). Since the number of cases was too low, BMI group 4 was not included in the calculations and is, therefore, highlighted in gray. Significant *p*-values are shown in bold; n = number of subjects.

	BMI (1) n = 53		BMI (2) n = 30		BMI (3) n = 14		BMI (4) n = 4		Conover–Iman test after Bonferroni-Holm Correction
	Median	**Min./Max.**	**Median**	**Min./Max.**	**Median**	**Min./Max.**	**Median**	**Min./Max.**	***p*-Value**
Forefoot left (%)	18.00	8.33/33.33	19.17	5.67/34.00	22.5	16.67/34.00	24.17	18.00/34.33	1 vs. 3: 0.05 2 vs. 3: 0.05
Forefoot right (%)	13.00	1.33/32.00	16.00	3.00/29.33	13.84	6.67/25.00	10.17	1.67/19.33	0.28
Rearfoot left (%)	33.33	18.33/50.00	33.50	18.00/48.00	30.67	17.67/48.33	30.17	15.00/46.67	0.19
Rearfoot right (%)	35.33	6.33/51.67	31.84	18.00/47.67	28.67	20.67/41.00	34.50	23.33/43.67	0.23
Left foot (%)	51.67	38.00/74.67	52.33	31.00/64.00	53.84	42.67/65.33	56.34	45.33/64.67	0.50
Right foot (%)	48.44	25.33/62.00	47.67	36.00/69.00	46.17	34.67/57.33	43.67	35.33/54.67	0.50
Forefoot (%)	31.67	21.00/56.33	32.50	21.67/62.33	40.00	24.00/52.00	36.34	20.00/49.33	**1 vs. 3: 0.03**
Rearfoot (%)	68.33	43.67/79.00	67.50	37.67/78.33	60.00	48.00/76.00	63.67	50.67/80.00	**1 vs. 3: 0.03**
Frontal sway (mm)	11.33	6.67/32.67	10.33	3.67/17.67	10.67	5.33/18.67	12.00	7.00/16.00	0.24
Sagittal sway (mm)	15.67	4.00/42.00	16.17	7.67/36.33	19.17	8.67/28.67	13.50	7.00/21.67	0.81
Ellipse area (cm^2)	1.19	0.25/5.55	1.09	0.22/3.69	1.24	0.33/3.30	1.04	0.48/3.20	0.50
Ellipse width (cm)	0.93	0.37/2.82	0.90	0.40/2.02	1.01	0.43/1.65	0.79	0.50/1.55	0.88
Ellipse height (cm)	0.40	0.21/0.98	0.39	0.18/0.71	0.37	0.22/0.81	0.42	0.30/0.62	0.26

In Table 3, the influence of the BMI is analyzed in more detail by comparing groups (4-part subdivision according to the WHO definition). However, the group of underweight subjects could not be included in the Kruskal–Wallis test due to there being too few cases (n = 4). For the sake of completeness, the group is listed in the table but grayed-out accordingly.

In the area of the left forefoot, a group difference was observed ($p \leq 0.05$). In the multiple Conover–Iman comparison with corresponding Bonferroni-Holm correction, significant pairwise comparisons between groups 1 and 3 ($p \leq 0.05$) as well as 2 and 3 ($p \leq 0.05$) were found. The forefoot and rearfoot loads also showed significance in this regard ($p \leq 0.04$), with a significant difference here between groups 1 and 3, i.e., between normal weight and obese female subjects, with $p \leq 0.03$ for both parameters.

The larger the BMI, the more pronounced the forefoot strain resulted due to the increased forefoot strain on the left side. The obese participants stood significantly more anteriorly (40%) compared to 31.67% of normal weight participants; in this context, the rear foot load decreased accordingly.

With regard to the possible influence of the anamnestic parameter "athletic activity" (Table 4), no group differences on the balance distribution or on the balance fluctuations ($p > 0.05$) could be found.

Table 4. Comparison of the parameters of the equilibrium distribution and postural sway in test subjects. Sports activity groupings: (1) No sport undertaken; (2) 1× per week; (3) 2× per week; (4) >2× per week; median, minimum and maximum of the posturographic parameters. Significant *p*-values are shown in bold; n = number of subjects.

	No Sport (n = 26)		**1×/Week Sport (n = 26)**		**2×/Week Sport (n = 17)**		**>2×/Week Sport (n = 32)**			
	Median	**Min./Max.**	**Median**	**Min./Max.**	**Median**	**Min./Max.**	**Median**	**Min./Max.**	***p* Values**	**Eta**
Forefoot left (%)	19.33	10.33/34.33	18.67	8.33/34.00	17.67	10.33/28.33	21.84	5.67/34.00	0.59	0.02 [1]
Forefoot right (%)	14.50	1.33/29.33	12.17	3.00/29.33	13.00	1.67/24.33	14.67	6.00/32.00	0.33	0.03 [1]
Rearfoot left (%)	31.33	19.00/50.00	32.67	17.67/49.00	34.67	18.00/48.00	32.50	15.00/48.33	0.68	0.02 [1]
Rearfoot right (%)	32.33	6.33/48.00	35.00	20.33/51.67	34.67	25.00/40.67	30.83	15.00/47.67	0.58	0.02 [1]
Left foot (%)	52.17	41.67/74.67	52.50	38.00/71.33	51.00	40.67/64.67	52.83	31.00/65.33	0.95	0.003 [1]
Right foot (%)	47.84	25.33/58.33	47.50	28.67/62.00	49.00	35.33/59.33	47.17	34.67/69.00	0.95	0.003 [1]
Forefoot (%)	35.17	22.33/62.33	30.34	22.33/56.33	30.33	20.00/50.67	36.00	21.00/53.00	0.20	0.05 [1]
Rearfoot (%)	64.84	37.67/77.67	69.67	43.67/77.67	67.67	49.33/80.00	64.00	47.00/79.00	0.20	0.05 [1]
Frontal sway (mm)	11.00	6.33/32.67	11.34	5.33/23.00	9.00	3.67/17.00	12.00	6.00/26.67	0.14	0.05 [1]
Sagittal sway (mm)	17.17	9.00/36.33	16.83	8.67/27.67	14.67	7.00/24.67	15.00	4.00/42.00	0.72	0.01 [1]
Ellipse area (cm^2)	1.20	0.38/5.31	1.33	0.33/4.39	1.07	0.22/2.05	1.19	0.25/5.55	0.47	0.03 [1]
Ellipse width (cm)	0.90	0.54/2.02	0.96	0.43/1.75	0.82	0.40/1.56	0.92	0.37/2.82	0.52	0.02 [1]
Ellipse height (cm)	0.41	0.22/0.98	0.43	0.24/0.98	0.38	0.18/0.51	0.44	0.21/0.75	0.35	0.03 [1]

4. Discussion

The subjects studied showed a nearly balanced weight distribution of the feet, 52.33% left to 47.67% right. The forefoot load was 33.33% compared to the rearfoot with 66.67%. While the rear foot load was nearly identical between the left and right sides of the body (32.67% left to 33.67% right), the left forefoot showed a greater load (19.33%) than the right forefoot (13%). The increased rear foot loading is due to the center of mass of the human body at the level of the promontory [8]. The line of gravity starting from the total body center of mass runs through the ankle joints toward the balls of the feet, thus leading to increased weight bearing on the rearfoot [8,31]. Due to orthopedic diseases being considered exclusion criteria in the present study, knee disorders [32], ankle instabilities [33] or neuropathies of the feet [34,35], for example, were not responsible for the negative effects on weight distribution and body sway. The increased left forefoot loading of approximately 5% difference to the right forefoot loading should be analyzed more thoroughly in further studies. An influence of handedness seems rather unlikely here as the test subjects were mostly right-handed. A more detailed investigation of exclusively left-handed subjects in future would be able to show any influence of handedness in comparison with the present study. Despite that this study involves balance and thus the question of the dominant leg would have been more obvious, here the focus has been on handedness. Since the dominant leg can vary depending on the activity, i.e., shooting soccer with the right leg and jumping high jump with the left leg, this orientation is not as useful as the handedness. Therefore, the question of dominant leg overwhelms many individuals, especially females of this age. Therefore, the question of handedness is easier and clearer to answer than the question of the dominant leg. Even though the dominant leg question is closer in terms of the measurement system at hand, we chose to ask about handedness, we have eliminated the bias of unconscious misreporting due to overwhelm. The differences between the dominant hand and the dominant leg in terms of available results, should be considered in further studies. Additionally, of interest in this context would be the assessment of lower and upper limb muscle strength, which can be recorded using other methods.

The values of approximately balanced left–right loadings obtained from this work correspond fundamentally to the data of other authors [14,16,18–20,36]. This is also true for the forefoot and rear foot loadings [13,14,18,19,36,37].

These body weight distribution values appear to be consistent, regardless of age and/or sex. Consequently, due to the large number of subjects, the reproducible analysis procedure and the comparability to other studies [13,14,16,18,19,36,37], the values of the present work can be regarded as representative cross section for healthy women aged 51–60 years.

Standard values for body sway in the frontal and sagittal planes, as well as the ellipse area, can also be assigned as 11 mm in the frontal plane and 16 mm in the sagittal plane, with a standardized ellipse area of 1.17 cm^2 from this study. However, when considering the frontal and sagittal sway values of 21–30-year-old women (9.50 and 13 mm, respectively) [17] and 31–40-year-old women (8.17 mm/12 mm) [19], these values are lower than those in the present study, while those of 41–50-year-olds are larger and almost identical, respectively, with 13 mm in the frontal variation and 16.5 mm in the sagittal variation [20]. Consequently, the notion that the sway in joint weight is influenced by age can only be partially confirmed [4,5,38]. Regarding the weak positive correlations between age and the parameters sagittal and frontal body sway as well as the ellipse area and width, it can be concluded that the ability to balance slowly decreases over the course of life even without subjective, pathological information. As aging is a continuous process knowing about the raising body sway might help the understanding on health risks such as fall and fractures and motivate women to train systematically in order to prevent or to slow down the negative impact.

Accordingly, the values for the ellipse area published by Pomarino et al. [11] of 70 mm^2 and 72 mm^2 are smaller than the values measured in this study [21]. This discrepancy is because the group of subjects measured by Pomarino et al. [11] had a wide age range of 11–69 years, with only 30 persons of these 431 subjects belonging to the age range of 50-60 years. Furthermore, both genders were represented in the group of 30 subjects. Therefore, the age-related differences [5,39–43] in the ellipse area can be explained by the predominance of younger subjects in the subject collective. This effect is due to the multifactorial changes of age [4,5,38,42–45]. Thus, the higher values of the ellipse area in the present study are to be expected in a differentiated consideration of the age group of 50–60-year-olds.

The subjects of the present study had an average BMI of 25.02 ± 4.55 kg/m^2 and were, therefore, on average, in the preadipose stage according to the WHO classification [29]. It should be noted, however, that the limit to the preadipose stage was exceeded by the test subjects by 0.02 kg/m^2. The German Federal Statistical Office provides an average BMI of 25.2 kg/m^2 for women in the 50–55 age group and 25.6 kg/m^2 for women in the 55–60 age group, thus, the selected group of test subjects was, in fact, even below the stated German average [26]. In a different study of the Robert Koch Institute on the representative data for height, weight and BMI of the German population from 2013, present subjects were on average 3 kg/m^2 lighter [46].

With regard to the influence of BMI, the statistical analysis showed no significance for the postural fluctuations ($p > 0.05$), neither for the absolute BMI values nor when differentiating into different groups according to the WHO classification [29]. Only a descriptive trend for sagittal sway was found: a BMI > 30 led to increased sway compared to normal-weight subjects (normal BMI: 15.67 mm; obese BMI: 19.17 mm). The results of the present study regarding a lack of significant ($p > 0.05$) association between BMI and balance control are confirmed by the studies of other investigators [35,47,48]. Due to the weak effect size of the change in body sway, this finding should be interpreted as a trend rather than as clinically relevant. Accordingly, even without subjective, pathological information, the balance ability slowly decreases over the course of life. The use of BMI as a criterion has limitations, as there is no sufficient differentiation as to whether the person in question is, for example, overweight or merely heavily muscled. Nevertheless, the authors deliberately chose BMI as a measure because it facilitates comparability with other studies, since BMI is still a commonly used criterion. In addition, the calculation of BMI is based on the self-report of each participant. However, if the examiner had any doubts about the accuracy of the self-report, a scale or centimeter measure was used to check the information. This was only the case three times.

Błaszczyk et al. [49] also confirmed that the extent of the fluctuation in the anterior–posterior direction does not increase significantly ($p > 0.05$) in obese persons compared to normal weight persons, but only tends to increase (sagittal fluctuation: normal weight 21 mm; obese 21.6 mm) and justified this with a functional adaptation of the control mechanisms of the upright posture.

Cimolin et al. [50] postulated that the center of pressure shifts anteriorly with increasing BMI and, thus, to a greater distance from the ankle [50,51]. Possible causes for the lack of influence of BMI on balance control under static conditions are sometimes manifold. Here, adaptation of sensorimotor systems to obesity [49] may have occurred. For the maintenance of postural stability in the sagittal plane, the ankle strategy is used [52] to compensate for small corrections in balance [53–55]; two synergistic muscle groups are activated during the change of stance in the upper ankle joint [5,56]. In contrast, the hip joint strategy is used only when the ankle strategy is insufficient or when the complexity of the motor task increases [5,52–56]. According to Olchowik et al. [47], the strategies for maintaining balance seem to be BMI dependent; women with a larger BMI use the hip joint musculature more and the ankle joint musculature less because, with increasing BMI, the stability to maintain balance becomes more complex and the hip musculature has to become supportive. At the same time, obesity leads to limitations in balance control as it is a factor in reduced plantar sensorimotor mechanoreceptors; this can also have a negative effect on balance control [57].

Another theory considers an increased gravitational torque as a result of the shifted center of mass as the cause of the increased postural sway [57,58]. The type of obesity is also crucial; abdominal obesity appears to be associated with increased anterior–posterior sway [59,60]; however, women often exhibit genoid obesity [29,61].

In the present study, with regard to the balance distribution, the forefoot load increased by approximately 8% when the BMI is >30 kg/m^2 compared to normal-weight peers and, at the same time, the rearfoot load decreases. Overall, it can be assumed that the increase in forefoot loading is due to the change in the center of mass. At the same time, genoid obesity is more frequently present in females which influences the center of mass when compared with male abdominal obesity [29,61]. Nevertheless, the BMI results of the present study can be confirmed by other investigations [18,50,62]. The systematic review by Cimolin et al. [50] highlights the different results regarding the influence of BMI on balance regulation. However, they conclude that when BMI increases, functional limitation occurs with decreased stability and an increased risk of falls. It should be noted here, however, that in most studies an assessment of BMI does not sufficiently differentiate between individuals who are highly muscular or obese [50].

Overall was the group of obese women aged 51–60 years in this recent study rather small (n = 14) compared to normal (n = 53) and pre-obese (n = 30). This descriptive observation should be continued in larger, balanced groups of a higher degree of obesity in further studies. Therefore, the conclusion that obesity has no negative effect on the postural sway should be drawn with caution. Furthermore, it should be kept in mind that balance ability is a multifactorial construct.

The body weight distribution as well as the body sway act in this study as an indirect factor to better understand health issues with the aim to reduce the risk of fall and fractures. This is not only a matter of balance and body mass but also body composition such as muscle and bone masses and bone density. Using a dual x-ray measurement as a body composition assessment would certainly have provided more clarity. However, this evaluation is based on X-rays and is not permitted by the ethics committee in Germany for reasons of radiation protection in healthy patients without a clear indication. Regarding the anamnestic parameter of the frequency of sports activity per week, no influence on the balance distribution and balance fluctuations could be found. It must be taken into account here that only the frequency/week was queried; no differentiated consideration of the sporting activity performed or the type of sport was made.

In order to investigate the differentiated effect of a sporting activity, a more differentiated distinction between individual sporting activities would be desirable in follow-up studies to demonstrate any influence of the different sports on balance control. With regard to the data on athleticism, it must be taken into account that these data were collected on a voluntary basis and, therefore, reflect a subjective assessment. Nevertheless, it can be assumed that each participant gave an honest answer since the survey was conducted in the context of a scientific study.

However, physical activity can influence balance control to different extents [63–65], e.g., gymnasts are considered to be the athletes with the best postural control [65]. Thus, the type and frequency of sports activity may provide an explanation for the lack of significant results. Nevertheless, pure sporting activity alone in the sense of a basic program is not sufficient to compensate for age-related losses in postural control [64]. The fact that the frequency of the sports activity alone is not sufficient to act as a positive effect on the equilibrium distribution and fluctuations [63] can be, thus, confirmed from the results in the present study. The maintenance of good static and dynamic postural control required is only possible through regular training66. Though, targeted training should improve postural control in aging [43–45,55,66,67]. The general aging population, should be encouraged to exercise with increasing age as it increases self-confidence in one's own ability to balance and, thus, reduces the fear of falling and has a correspondingly prophylactic effect [55,63,68].

Finally, it should be emphasized that in view of an increasingly aging population, especially in industrialized countries, and increasing multimorbidity, such data are of particular relevance with regard to preventive aspects. Especially the focus on a homogeneous group of subjects (regarding age and gender) with this large number of subjects has not been conducted so far. Furthermore, only women who subjectively feel healthy are included in this study, with clearly defined exclusion criteria. Furthermore, in addition to postural sway data, data on COP movements (ellipse area, height, and width) and percentage distributions of balance give a more comprehensive insight into the normal values of this female age population.

5. Conclusions

In summary, the present work shows that healthy women aged 51–60 years old exhibit a balanced equilibrium distribution (left vs. right side of the body) with increased rear foot loading (67%). Balance fluctuations are independent of BMI in the habitual stance, in contrast to balance distribution. However, the sagittal sway tends to increase when the BMI is >30 kg/m^2 compared to normal-weight subjects. In relation to the balance distribution, forefoot loading increases significantly when the BMI is >30 kg/m^2 compared to normal-weight subjects. Pure athletic activity, without differentiation of the activity, shows neither a negative nor a positive influence. Furthermore, with increasing age, the anterior–posterior fluctuations increase (a weak trend).

Therefore, available data can be used as a baseline to describe gradations to pathological developments. Additionally to be mentioned here is injury prevention, where sports activity is a major factor with regard to body sway and body weight distribution.

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Abbreviations

BMI	Body Mass Index
WHO	World Health Organization
FS	Frontal Sway
SS	Sagittal Sway

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