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Original Article

Inferred Influence of Human Lateral Profile on Limb Load Asymmetry during a Quiet Standing Balance Test

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Although the identification and characterisation of a participant's lateral profile during quiet standing have not received much research attention, they have the potential to greatly extend our understanding of upright stance stability control. This study further examines limb load asymmetries during quiet bipedal stance. During voluntary frontal-plane weight shifting for 2 min, 300 centre-of-pressure displacements on 14 blindfolded right-handed young adults were recorded. Four biomechanical indices were used to assess postural behaviour. These were the bias of time and the magnitude of the partial ground reaction forces from both legs, and the bias in the number and magnitude of microshifts influencing stability. Our study identifies a significant level of asymmetry in the quiet bipedal stance of right-handed people. This asymmetry is associated with the right-sided bias of the ground reaction force and the angle of inclination to the upright (vertical) centroidal line. We found that the initial lateralisation of the partial ground reaction forces from both feet, as well as the period of ground reaction force bias, are important elements in any clinical tests involving quiet bipedal stance.

Key words: laterality, asymmetry, handedness, stability, force

Measurement of postural balance has numerous potential applications in medicine, ergonomics, and athletic training. This balance has been investigated using various experimental designs. Some authors have examined the control of dynamic balance during locomotion [1-3], whereas others [4-7] have investigated the control of static balance. During quiet standing, the body has been observed to slightly and rhythmically sway [7-9].

Postural sway is a complex phenomenon that occurs as a result of many interacting factors [6, 8, 10]. Some researchers have analysed the lateral fluctuation of the human body in the quiet upright position [11-13]. Body sway during unipedal or bipedal stance was usually measured either as the total displacement of a body's centre of mass from the equilibrium position, the displacement of the centre of pressure, or the amplitude of sway. Some authors measured the velocity or acceleration of swing in either the anterior-posterior [14], mediolateral [15], or both [7, 16] directions.

The influence of lateralisation of the human body on upright stability control during quiet standing has received scarce research attention. Limb load asymmetry may serve as a veridical measure of postural stability and can be used for the early diagnosis of age-related decline in balance control [17, 18]. The term "asymmetry" is often used to describe unequal weight distribution between the left and right ground reaction forces [19-21]. The existing literature does

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not precisely scrutinise the direct influence of the preferential manual asymmetry on the lateral sway of the body of healthy right-handed young adults. In one study [22], no difference was found in the distribution of partial weight between the legs of participants, although the handedness of the participants was not initially identified. Other studies recorded a large asymmetry in the partial weights, but these results were obtained in a study in which one limb was paretic [20, 23] or contained a prosthetic part [24].

These and a few other studies on weight distribution in normal adults have found some degree of asymmetry in favour of the left or right foot [25, 26]. Murray and Peterson [25] reported lateral differences of up to 15% on a sample of males ranging in age from 20 to 60 years old. A study by Dickstein *et al.* [27] ignored the influence of ageing on laterality and noted lateral differences of up to 8% in the individual leg ground reaction force among elderly participants. Blaszczyk *et al.* [17] measured the limb load partial asymmetry in young, middle-aged, and old healthy people, but they did not precisely measure manual laterality.

The focus of the present study was, therefore, to examine the profile of the ground reaction force on each foot during quiet bipedal standing of young healthy right-handed people, and to show that handedness itself might affect quiet stance.

Materials and Methods

Participants. Fourteen normal volunteer participants were recruited from the student and staff population of Unitec (Auckland, New Zealand), based on the selection criteria of being male, right-handed, and aged between 18 and 35 years. Exclusion criteria were: a history of serious neck injury or pathology (any injury or disease resulting in lasting damage to spine-related areas); a history of spinal pain, headaches, or any spinal dysfunction in the last 6 weeks; or participation in regular balance training exercises in the last 6 months (*e. g.,* yoga). The number of participants was consistent with other physiological research in this area [28].

Males were selected for 2 reasons: first, they have less variability in postural sway due to their lower variation in pelvic anatomy compared to females [10]; second, they have better stability than females [29, 30]. The age range of 18 to 35 years was chosen for the experiment for several reasons. By 18 years, growth in height and foot size is nearly complete [7, 10, 31]. The upper limit of 35 years was used because morphological and developmental changes occurring after this may affect posture and sway [17, 32]. The primary anthropometrical measurements of mass and height as the important factors of stability [6, 31] were used to calculate the "body mass index" of each participant as well. This index did not exceed 27 units, which is typical for healthy young participants [33].

Handedness was assessed by the Edinburgh Inventory test [34], which has been proven valid and reliable [35, 36]. Only participants with a 100% laterality quotient were selected for future investigation.

Thus, our selected group may be considered right-handed healthy young males with close anthropometrical characteristics, as recommended for experiments involving standing balance [37]. All of the participants gave informed consent prior to commencement of the study in accordance with the requirements of the Unitec Ethics Committee.

Data collection. This study focused on the measurement of the medial-lateral vector of postural sway, as this component is more sensitive to perturbing stimuli than the anterior-posterior component [38].

The weight on the left foot was measured using a standard static force DIGI DI-80 scale with a platform size of 800 mm × 800 mm and a measurement increment of 0.05 N. The platform was connected to a 3-channel DC amplifier. Signals from the amplifier were digitized using a 12-bit converter with a sampling frequency of 50 Hz, and were stored on a personal computer running the Windows XP operating system. Foot positions, which were marked on the support platforms, were aligned so that a participant's feet were parallel, facing forward, and as close together as possible [39] while the left foot was kept solely on the measuring platform and the right foot on the adjoining box. The distance between the medial malleoli was 0–5 mm, with about 100 mm between the centres of the talo-crural joint of the left and right legs. This stance aligned the upright centroidal axis of the participant's body with the boundary between the platform and the box.

During postural sway, the body moves in synchro-

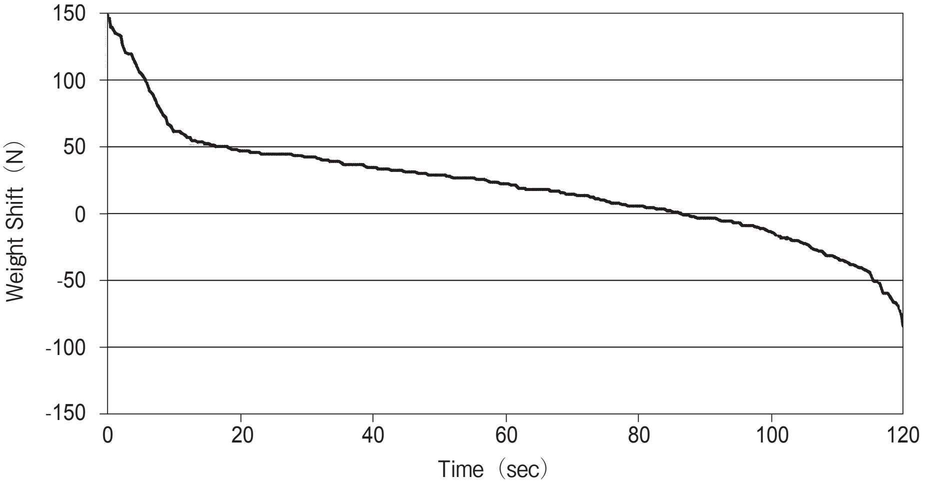

Fig. 1 Variation in the partial ground reaction force under the left foot.

nisation with the movements of the centre of gravity [7]. If the centre of gravity shifts to the left, the left leg will support a larger proportion of the body's weight, and the weight recorded on the platform will increase. If the centre of gravity shifts to the right, the platform will register less weight. Hence, the oscillations in weight borne by the left or right foot were recorded, and the medial-lateral component of the oscillations of the centre of gravity was detected.

To remove the stabilising effect of vision on postural sway [7, 18, 32, 40] and to increase the demands placed on the participant's proprioceptive systems, the participants were blindfolded while standing on the platform. Weight was recorded by computer every 0.4 sec over a 2 min period as specified by Caron *et al.,* 2004 [41]. Lateral weight displacement was calculated over about 300 data points, as was recommended for this type of study [18]. This sampling rate allowed an accurate representation of the movement of the centre of mass.

Prior to the commencement of data recording, there was a conditioning period of 30 sec, during which participants stood barefoot and erect, facing directly forward towards a marked area on the wall. Participants were instructed to stand with their arms at their sides and their feet aligned within the pre-marked areas, and to remain as stable as possible for the complete duration of the trial, as recommended by Rival *et al.* [42]. After the initial conditioning period, the participants were blindfolded and allowed to stand for a further 30 sec to adjust to the lack of visual feedback and reach equilibrium while standing. Each participant was subjected to 3 separate experiments. The first 2 experiments were separated by a 10 min interval, and the third began almost exactly 24 h later. All conditions in each experiment remained the same. Each experiment was videotaped to provide a control record of any incidents during the experiments in which a participant's behaviour could cause anomalous weight readings. The video camera was not used as a primary data source for assessing postural sway.

Primary data analysis. We assessed 2 main important factors in relation to postural instability. The first factor, gross postural bias, was identified as a potential bias of inclination of a body's centre of mass to the left or right side overall experiment. The second factor, microshifting, was related to the change in magnitude and direction of the shift in the centre at each successive time step (see example below).

General approach to the assessment of gross postural bias. The assessment of postural sway began by comparing the total weight of each participant with twice the recorded weight of the left foot on the weighing platform as recommended by Pyöriä *et al.* [43]. The difference between the values was converted to a percentage. The variation in the partial ground reaction force under the left foot is shown in Fig. 1.

The data consist of between 285 and 315 points plotted at the recorded time interval of 0.40 sec. A positive sway represents greater partial weight on the

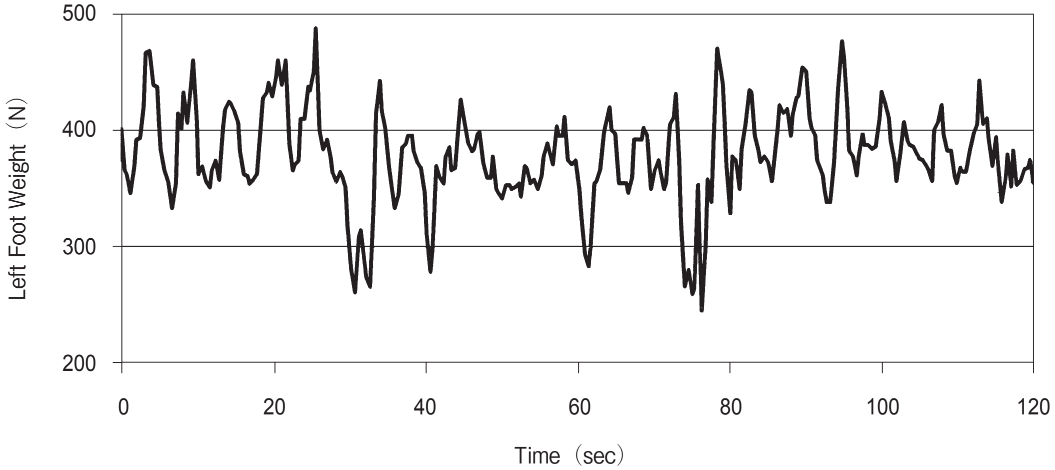

Fig. 2 Sorted data with microshifting removed showing the variation in partial.

left foot, while a negative sway represents more weight on the right foot, as shown in Fig. 2. For example, if a participant's total weight was 600 N and the measured ground reaction force from the left foot on the weighing platform was 350 N, then the shift to the right is equivalent to 0.5 × 600 − 350 = −50 N.

Specific mechanical approach in gross postural bias assessment. Postural sway was assessed by determining the angle of lateral sway for each participant during each time interval from partial weight measurements that occurred only on the left foot.

The angle of lateral sway was determined from an analysis of the mechanics of the lower body, as shown in Figs. 3 and 4.

If forces W_A and W_B are the weights on each leg spaced at distance D apart and ΔW is the partial weight shift that occurs due to the centre of mass moving the lateral distance ΔL, then for stability the sum of the moments about A must equal zero.

Hence: $W_A(\Delta L) - (W_B + \Delta W)D + W_B(D + \Delta L) = 0$ or

$$\Delta L = \frac{\Delta W}{W} D$$

but also $\Delta L = H\theta$. Therefore $\theta = \frac{\Delta WD}{WH}$ where θ is the angular movement in radians or $\theta = \frac{180(\Delta W)D}{\pi WH}$ where θ is the angular movement in degrees, H is the height of the participant in metres, and W is the total body weight in Newtons weighed on the platform.

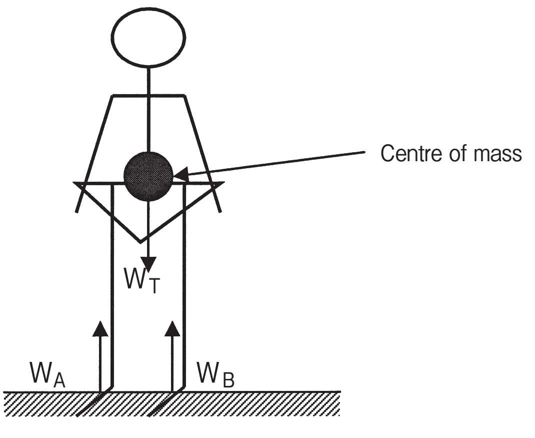

Fig. 3 Force diagram of a body in quiet bipedal stance.

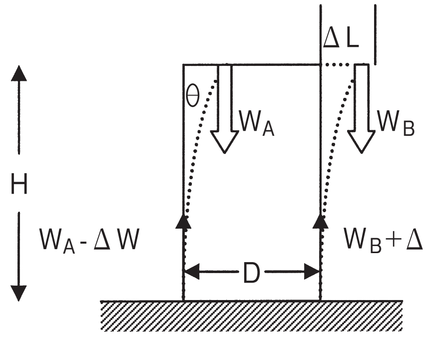

Fig. 4 Force diagram of legs and pelvis with lateral shift.

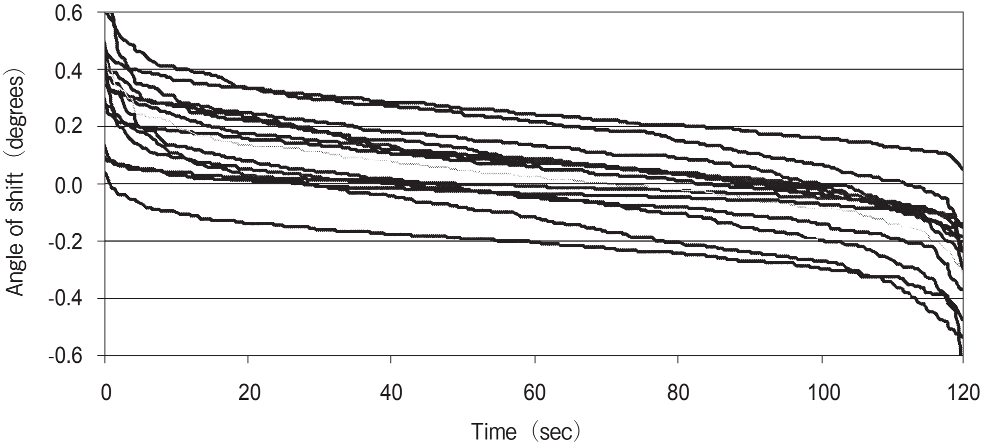

Fig. 5 Variation in angle of sway for 14 participants during one of the 3 tests. Force diagram of legs and pelvis with lateral shift.

It is clear from this equation that if body weight is shifted to the left, the magnitudes of both ΔW and θ increase, but if body weight is shifted to the right, the magnitudes of both ΔW and θ decrease.

Assessment of microshift. We recorded the number of microshifts during quiet stance and calculated their average magnitude in the left or right lateral direction. A microshift was defined as the difference in the magnitude of the ground reaction forces between successive data. Consider successive measurements of 300 N, 340 N, 311 N and 315 N for the partial ground reaction force of the left foot. The microshift from the first pair of data points is 340 N $-$300N or $+$40 N and is directed to the left. The second pair of data points gives 311 N$-$340 N or $-$29 N, and this microshift is directed to the right. The third pair of data points gives 315 N$-$311 N or $+$4 N, and this microshift is directed to the left.

The number of microshifts toward each side (left or right) was calculated as the percentage of the total number of microshifts.

Statistical methods. The significance of the duration and magnitude of the preferential weight shift to 1 leg was analysed using 2-way ANOVA from the MINI-TAB statistical package. Statistical significance was defined as $p < 0.05$ or a 95% confidence level.

Results

***Gross postural bias assessment.* Angle of body inclination on sway of the centre of gravity.** The angles of sway for all 14 participants, in one of the 3 trials, are shown in Fig 5. The values of gross postural sway ranged from +0.6 degrees to $-$0. 6 degrees. Bias in the inclination angle either to the right side [F = 0.31; $p > 0.05$, Df = 2 (83)] or the left side [F = 1.15; $p > 0.05$, Df = 1 (42)] was not a significant factor in determining the gross sway pattern during any of the 3 trials, although we found a bias of the inclination angle to the right side [F = 15.15; $p < 0.001$, Df = 1 (83)].

Period of action bias of the partial ground reaction force over left and right foot. There was no significant effect of the bias of the ground reaction force on one leg on the gross microshift pattern among the three trials [F = 0.81; $p > 0.05$, Df = 2 (83)]. Over the 3 trials, the ground reaction force was greater on the right leg 60% of the time, or an average of 71.46 sec out of the total test time of 120 sec in each trial [F = 9.34; $p < 0.01$, Df = 1 (83)] (see Table 1).

Microshift assessment. There were significant differences among individuals in the number of microshifts directed to the right or left side [F = 0.81; $p < 0.001$, Df = 13 (83)]. However, for each individual there was no significant difference between the number of microshifts to the left or to the right. Analysis of the data for the participant with the largest right-foot weight bias [F = 0.46; $p > 0.05$, Df = 1 (83)] showed no significant differences among the 3 trials in the number of microshifts to the right [F

$= 0.58$; $p > 0.05$, Df $= 2$ (83)] or to the left [F $= 0.4$; $p > 0.05$, Df $= 2$ (83)].

There were significant differences among participants in the magnitude of the ground reaction force depending on whether the participant was shifting to the right or left [F $= 31.02$; $p < 0.001$, Df $= 13$ (83)]. There was no significant difference in the magnitude of the ground reaction force during microshifts depending on whether the participant was shifting to the right or left. Even the participant with the largest ground reaction force bias on the right foot showed no significant difference [F $= 1.10$; $p > 0.05$, Df $= 1$ (83)] in the 3 trials between microshifts to the right side [F $= 0.84$; $p > 0.05$, Df $= 2$ (83)] and the left

Table 1 The period of lateral ground reaction force bias and average angle of inclination of body

Person	Time interval when the right leg developed a greater ground reaction force than left (sec)			Time interval when the left leg developed a greater ground force than right (sec)		
	Trial 1	Trial 2	Trial 3	Trial 1	Trial 2	Trial 3
1	109.34	103.52	111.42	10.66	16.48	8.58
2	78.79	55.09	92.92	41.21	64.91	27.08
3	58.62	66.10	90.01	61.38	53.90	29.99
4	112.05	40.54	40.95	7.95	79.46	79.05
5	103.11	120	85.85	16.89	0	34.15
6	120	120	120	0	0	0
7	111.42	111.01	52.80	8.58	8.99	67.20
8	18.71	60.91	94.79	101.29	59.09	25.21
9	85.65	45.32	99.99	34.35	74.68	20.01
10	59.24	23.91	71.09	60.76	96.09	48.91
11	58.83	64.65	29.10	61.17	55.35	90.90
12	85.44	6.86	30.56	34.56	113.14	89.44
13	77.12	10.39	1.25	42.88	109.61	118.75
14	51.76	76.71	45.52	68.24	43.29	74.48
Average	**80.72**	**64.644**	**69.018**	**39.28**	**55.36**	**50.98**
± SD	**29.04**	**38.168**	**35.721**	**29.04**	**38.17**	**35.72**
Total average and ± SD	71.46 ± 34.545			48.540 ± 34.545		
	Average angle of inclination of the body to the right side (in degrees)			Average angle of inclination of the body to the left side (in degrees)		
	Trial 1	Trial 2	Trial 3	Trial 1	Trial 2	Trial 3
1	0.25	0.22	0.23	-0.05	-0.05	-0.02
2	0.10	0.15	0.12	-0.06	-0.16	-0.05
3	0.07	0.06	0.15	-0.06	-0.05	-0.06
4	0.12	0.09	0.07	-0.02	-0.12	-0.09
5	0.12	0.23	0.11	-0.02	0	-0.05
6	0.29	0.31	0.25	0	0	0
7	0.14	0.11	0.03	-0.02	-0.02	-0.04
8	0.14	0.08	0.14	-0.16	-0.07	-0.05
9	0.16	0.14	0.18	-0.08	-0.12	-0.06
10	0.11	0.08	0.11	-0.10	-0.16	-0.07
11	0.11	0.16	0.10	-0.08	-0.14	-0.18
12	0.05	0.04	0.03	-0.02	-0.10	-0.04
13	0.12	0.09	0.04	-0.07	-0.23	-0.21
14	0.12	0.16	0.10	-0.11	-0.09	-0.13
Average	**0.136**	**0.137**	**0.119**	**-0.061**	**-0.094**	**-0.075**
± SD	**0.064**	**0.075**	**0.068**	**0.044**	**0.067**	**0.059**
Total average and ± SD	0.130 ± 0.068			0.076 ± 0.058		

[$F = 0.92$; $p > 0.05$, Df = 2 (83)] (see Table 2).

Discussion

The primary aim of our work was to investigate limb ground reaction force asymmetry during quiet standing of strictly right-handed people. According to Nichols [30], standing balance is a somewhat ambiguous term used to describe the ability to maintain or move within a weight-bearing posture without falling. Balance can be divided into 2 main components: the symmetry/asymmetry of the lateral distribution of ground reaction forces from the legs, and the steadiness of the symmetry/asymmetry, which is the ability to maintain a given posture with minimal extraneous movements (sways) [19, 43]. We investigated both aspects here by examining the ground reaction force and the angle of the upright centroid axis. Our results demonstrated that 60% of the time, right leg loading was significantly greater than left leg loading. This confirms earlier findings that the majority of normal adults do not stand with exactly half their body weight on each foot (25–27, 44]. Based on the data in the literature, we suggest specific factors affect postural control, possibly due to some anthropometrical factors, based on the fact that the right side of the human body is often slightly heavier that the left [43, 45].

Several studies lend specific support to the idea that exercise can increase bone size [45, 46]. Usually the dominant arm has 1–2% greater body mineral density than the contralateral arm in young

Table 2 Number of microshifts and the difference in ground reaction force for individual participants

	Direction	No1	No2	No3	No1	No2	No3
1	→R	44.82	44.30	46.20	16.22	15.03	18.04
	←L	50.84	50.80	50.81	14.37	13.23	15.43
2	→R	49.30	52.88	51.33	22.41	19.24	16.07
	←L	49.30	46.10	47.00	20.85	16.80	14.15
3	→R	47.32	49.50	46.98	8.11	16.52	9.47
	←L	48.66	48.49	47.65	8.16	16.52	9.31
4	→R	48.78	50.33	49.16	15.99	16.57	11.09
	←L	48.43	47.67	47.16	16.36	17.10	11.36
5	→R	50.34	48.67	47.84	9.67	10.15	8.71
	←L	47.24	49.33	48.84	10.70	10.27	8.82
6	→R	50.50	51.16	47.84	8.05	9.42	9.84
	→L	46.15	48.86	46.51	7.22	8.53	9.53
7	←L	46.49	43.67	48.03	7.09	4.93	6.57
	→L	46.82	45.00	47.04	6.91	4.74	6.72
8	→R	47.83	45.03	48.68	10.91	9.18	13.89
	←L	49.16	50.00	47.68	10.27	7.74	13.36
9	→R	48.84	47.23	46.82	24.99	16.24	20.24
	←L	48.84	48.86	51.17	25.27	15.66	18.44
10	→R	48.24	49.18	47.83	16.80	12.00	13.83
	←L	47.60	48.12	48.49	17.12	12.66	13.68
11	→R	50.17	48.49	47.49	26.40	31.46	24.32
	←L	48.84	50.84	50.50	27.63	30.00	22.18
12	→R	43.14	45.15	45.54	5.88	4.29	5.20
	←L	45.48	41.81	44.88	5.68	4.41	5.29
13	→R	50.46	48.85	47.49	24.89	15.52	24.32
	←L	47.37	48.85	50.50	22.21	15.50	22.18
14	→R	50.17	48.67	45.82	23.44	29.36	20.42
	←L	48.16	50.00	51.51	24.70	28.44	17.97
Average	→R	48.31	48.08	47.65	15.78	14.99	14.43
	←L	48.06	48.20	48.55	15.53	14.40	13.46

active participants [47] and consequently may have greater mass and rotational inertia. Canadian scientists [48] used computer tomography to determine right bias asymmetry in the pelvis in 95 of 323 adults (29.4%). The right hemi-pelvis in these 95 adults was larger by an average of 2.1 mm (in a control group of adults with a sedentary lifestyle). In other research performed on muscles of the legs and forearms of normal participants, the dominant side tended to be larger and stronger than the nondominant side and appeared denser on computed tomography scans [49]. Also the data from the experiments by Slemenda *et al.* [50] and Welle *et al.* [51] suggest that important increments in skeletal mass may result from physical activity. Matava *et al.* [52] investigated 44 males and 36 females and found that the dominant segments of the body tended to be heavier. Some researchers [53] have found significantly greater biepicondylar widths of humeri in studies of right-hand dominance, which indicates that dominant-side forearms are heavier.

Dimitrova *et al.* [54] demonstrated the maximal activation of the right and left soleus muscles while testing standing balance stability in old healthy participants during both wide and narrow bipedal stance. They concluded that in both cases the right-sided muscles at the moment of right-sway demonstrated a greater level of activation and consequently greater torque than the left-sided muscles during left-sway. Several studies have found some degree of asymmetry in cross-sectional dimensions of the same isolateral skeletal segments [55, 56].

Equally, we do not exclude from our explanation the well-known phenomenon in which footedness itself can also influence postural asymmetry [57]. Footedness is closely associated with handedness, and right-handers consistently show a dominant lower limb, very often from the same side of the body [58, 59]. In the research of Matava *et al.* [52], 89% of right-handed males were right-leg dominant for kicking. Niemuth *et al.* demonstrated hip muscle imbalance between dominant and nondominant legs [60]. The dominant right leg can be more active and consequently have a greater effect in a quiet stance [30, 61]. Cottalorda *et al.* [62] and Stacoff *et al.* [63] showed that the right leg also produced higher propulsive forces than the left during walking. Maki & McIlroy [64] showed that the centroidal line of the body inclines mostly to the dominant (in the dominant-hand reference) side of the body. Some researchers [65, 66] have demonstrated a close relationship between handedness and some physiological characteristics of the principal muscles that control posture. Tan [66] concluded that there is a spinal motor asymmetry in the postural leg muscle, which may be related to handedness. Gatev *et al.* [39] found a very small left-foot ground bias, but the handedness of the participants was not precisely identified. Some authors concluded that congenital motor asymmetry could entail postural asymmetry [57], while others expressed the opposite point of view [67]. In experiments by Allard *et al.* [6], adolescents with scoliosis had a tendency to shift their centre of mass more to their right, but this may be due to the initial structural asymmetry of their bodies. Some researchers found that subjects in the unilateral stance stood for longer periods on the right leg than on the left [68]. Unfortunately, the level of handedness and leg dominance was not established prior to testing [69] or was not precisely specified in the experiments [30].

We found that postural balance is related to the number of microshifts of posture in different (left or right) directions. This pattern may be explained by some neural mechanisms of postural control [69]. The human body may be imagined as a multi-segmented structure, giving the body a large number of degrees of freedom, which can mitigate postural disturbances. The maintenance of postural stability in response to different disturbing influences may utilise many neurological and biomechanical compensatory strategies [7, 10, 13, 28, 38, 49, 54, 61, 64]. It is notable that we found no significant difference between the number and magnitude of microshifts to different directions. These results may be explained in terms of oscillating repetitive movements. The repetitive horizontal microshifts could be due to regular periodic "on" and "off" switching of the activity in α motor neurone pools of the left- and right-sided postural muscles, suggesting that the oscillator controlling this movement is similar to that proposed for rhythmical movements in general [70]. This regular activity is typically initiated by spinal pacemakers or neural rhythmic motor circuits (which likely extend their influence to both sides of body).

Thus, the lateral profile of participants appeared to be a significant factor in asymmetrical standing balance. Therefore, any study of asymmetry in balance control should include an assessment of the impact of a participant's handedness or lateral profile on the result of upstanding balance.

Conclusion. Our study identified a significant level of asymmetry in the quiet bipedal stance of right-handed people. This asymmetry is associated with right-sided bias of the ground reaction force and the angle of the right-sided inclination to the vertical position. However, we did not find any asymmetrical bias in the difference between the number and magnitude of microshifts to the left or right side. We found that the initial lateralisation of the partial ground reaction forces from both feet, as well as the period of the ground reaction force bias, are important elements in any clinical tests involving quiet bipedal stance.

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