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ARTICLE

Asymmetry of Body Weight Distribution During Quiet and Relaxed Standing Tasks

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The goal of this work was to investigate body weight distribution during relaxed and quiet (constrained) standing tasks. Forty-one healthy, young adults performed relaxed and quiet standing tasks, and they stood with each leg on a separate force plate. The weight distribution asymmetry across time was computed as the difference between the right and left vertical force time series. The subjects presented a small average across time asymmetry during relaxed and quiet standing. However, during relaxed standing, the subjects alternated between postures, and, as a result, they were largely asymmetrical over time (instant by instant). Two unexpected results that the authors found for the relaxed standing task were that women were more asymmetrical over time than men and that there were two preferential modes of weight distribution.

***Keywords*:** balance, posture, postural control, symmetry, weight-bearing asymmetry

Symmetry might be ubiquitous in nature (Lederman & Hill, 2007), but, upon closer inspection, so is its counterpart. In biology, this topic may refer to the symmetry in the form of living organisms, that is, a mirrored spatial distribution of parts of the body with respect to an axis or plane. For organisms with a single axis of symmetry, such as humans, this reduces to bilateral symmetry. The apparent external physical symmetry of our body is largely broken in our sensory–motor functions. For instance, humans usually display handedness, footedness, and eyedness (Porac & Coren, 1981). Concerning our upright standing, we also seem to be asymmetrical, although this is yet to be determined, given the myriad of body postures, we adopt daily when standing in a relaxed manner. When standing naturally in daily life activities, also referred here as relaxed standing, people stand in an unconstrained manner, performing postural changes, and freely alternating between different body postures (Duarte, Harvey, & Zatsiorsky, 2000; Duarte & Zatsiorsky, 1999).

Symmetry in body posture has been of interest since the first studies that employed mechanical measurements toward the way we stand. Borelli (1989) was the first to investigate this question in the 17th century, but his device (a flat table

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equilibrating on a prismatic support) only allowed him to measure the center-of-gravity position of an erect man along the craniocaudal axis, which he successfully determined to lie between the buttocks and the pelvis in that posture. In the late 19th century, Vierordt (1864) was likely the first to quantitatively measure postural sway during standing; he employed a device that measured the sway of the head. Neither Borelli nor Vierordt measured the forces on the feet, although they acknowledged the asymmetry of upright standing. For Borelli (1989), “standing alternately on one foot with the other loaded vertically is less fatiguing than standing on both feet simultaneously.” For Vierordt (1864), “body fluctuations are much lower when asymmetrically standing.” Hellebrandt (Hellebrandt, 1938; Kelso & Hellebrandt, 1937) was one of the first to actually measure the center of foot force during standing—employing a rudimentary version of a force plate—and he found that the stance of women was asymmetrical during a comfortable stance, even when the “best posture” was assumed. Borelli, Vierordt, and Hellebrandt clearly recognized in their work the diversity of standing postures; all of them noted that the most natural and comfortable form of standing was asymmetrical. Furthermore, these authors considered the stance whereby people try to stand as still (or quiet) as possible in a symmetrical posture as unnatural and less common.

With the development of more precise instruments, notably the force plate, and the wish for greater reproducibility, scientists have been compelled to measure more controlled conditions and the task of still (or quiet) upright standing, when the subject is not allowed to perform any postural change, has prevailed as more of an interest inside a laboratory. Bearing in mind these task constraints, studies about the symmetry of quiet or dynamic standing for few seconds were conducted, and all of the reports have noted small values of weight distribution asymmetry (Aruin & Kanekar, 2013; Blaszczyk, Prince, Raiche, & Hebert, 2000; Murray, Seireg, & Sepic, 1975; Rougier & Genthon, 2009; Sackley & Lincoln, 1991). Notwithstanding their valuable contribution, however, it is likely that these studies, which investigated only a constrained postural condition, tell us little about symmetry of the relaxed standing in daily life activities, in which we typically have no constraints regarding how to stand. Probably the symmetry of our posture during relaxed standing is largely broken and because of the associated postural changes in this task, this supposed asymmetry will change over time. In a previous study, we indeed observed that postural changes are associated with asymmetry in the weight distribution between sides (Prado, Dinato, & Duarte, 2011), but the body weight asymmetry during relaxed standing was never quantified.

Whether humans have a prevalent side during relaxed standing, that is, if they load more on one side of the body than the other, and how the asymmetry of standing changes over time during relaxed standing, are unknown. Yet, these questions are important for a greater understanding of the control of posture during standing tasks. For instance, an incorrect weight transfer is believed to be the primary cause of falling in elderly in daily life activities (Robinovitch et al., 2013).

We will address these issues in the present study, and we hypothesized that individuals would present large asymmetry during relaxed standing and that asymmetry would markedly change over time. We will also characterize the weight distribution asymmetry in the more constrained condition typically performed inside a laboratory (quiet standing).

Materials and Methods

Subjects

Forty-one healthy, young adults, 23 females (mean ± 1 *SD*: age 25 ± 9 years, mass 61 ± 9 kg, height 163 ± 5 cm, and body mass index 23 ± 4 kg/m^2), and 18 males (age 26 ± 8 years, mass 79 ± 15 kg, height 179 ± 8 cm, and body mass index 25 ± 4 kg/m^2), voluntarily participated in this study. In comparison with the male subjects, the female subjects had the same age, Cohen effect size, $d = 0.14$; unpaired *t*-test statistic, $t(39) = –0.44$, $p = .7$; and were significantly lighter, $d = 1.46$, $t(39) = –4.6$, $p < .001$ and shorter, $d = 2.57$, $t(39) = −8.2$, $p < .001$, but both groups had a similar body mass index, $d = 0.39$, $t(39) = −1.2$, $p = .2$. At the time of the study, none of the subjects had any known neurologic or musculoskeletal disorders that could affect their postural control.

The subjects were asked which leg they preferred to use to kick a ball. The preferred kicking leg was considered the dominant leg. There were only five left-dominant subjects (four females and one male). All subjects signed a consent form, and this experiment was approved by the ethics committee from the University of São Paulo. The subjects were instructed to wear their comfortable shoes (high heels were not allowed) for the data collection.

Tasks and Procedure

The subjects were asked to perform two tasks in our laboratory: relaxed standing, the focus of this study, and quiet standing, to reproduce the findings of the literature and to serve as a reference to the relaxed standing for some specific data analysis of this study. The relaxed standing trial was performed for 16 min; the rationale for this time period is that relaxed standing in daily life activities can last from few seconds to few hours and about 15 min is long enough to observe the subject producing postural changes, such as side-to-side body weight transfers between limbs, a typical trait of relaxed standing (Prado et al., 2011). The quiet standing trial was performed for 70 s; a period of about 1 minute is usual in studies of postural control during quiet standing. Of note, the goal of this study was not to compare the postural control of these standing tasks performed with such different durations. The control of posture, described for example by the quantification of the center of pressure, exhibits a fractal behavior in such a way that the amount of postural sway is proportional to the amount of time a person stands (Duarte & Zatsiorsky, 2000). All trials were performed with the subjects standing with each leg on a separate force plate (each force plate had an area of 50.8 × 46.4 cm, model OR6; AMTI, Watertown, MA).

For the relaxed standing task, the subjects were allowed to change their posture freely at any time, change the feet positioning, and there were no specific instructions on how to stand, except that they were required to not step off the force plates. To mimic natural standing in everyday life, as we usually do something else while standing, all subjects performed the relaxed standing task in two conditions: (a) watching a television documentary on a television set located 3 m in front of them and (b) reading a magazine that they held with their hands. For the quiet standing task, subjects were asked to select a comfortable position, with their feet approximately at shoulder width, and to stay as still as possible, while looking straight ahead at a point about 3 m in front of them, at head height.

The relaxed standing trials were always performed first, followed by the quiet standing trial in order to prevent the subjects from being influenced by the instructions given for the quiet standing task; however, the order of the conditions, that is, watching television and reading, was randomized among the subjects and then this order was reversed in a second session. In addition, participants were given a 5-min break between trials. In a first session, each subject performed two trials of relaxed standing and one trial of quiet standing; to test the reproducibility of the experiment, each subject repeated these three trials in a second session, 1 week later.

Data Analysis

The force plate signals were acquired with a 120-Hz sampling frequency and they were stored in a computer for future analysis. To guarantee that the two force plates would measure the vertical ground reaction force (the Fz component) in the exact same way, the Fz of each force plate was recalibrated, using the weight of the subject, measured in separate trials, in which the subject stood quietly for 10 s on each force plate. All the force plate data from the quiet and relaxed standing trials were first smoothed with a, 10-Hz, low-pass Butterworth filter of fourth order and zero lag. After the filtering process, the first 10 s of the quiet standing data and the first minute of the relaxed standing data were discarded, because they were considered to be accommodation periods. To quantify the weight distribution asymmetry (WDA) at each instant, WDA(t), between lower limbs, we calculated the difference between the right (R) and left (L) Fz time series, normalized by the subject's body weight:

$$\mathrm{WDA}(t) = \frac{\mathrm{FzR}(t) - \mathrm{FzL}(t)}{\mathrm{FzR}(t) + \mathrm{FzL}(t)}$$

According to this definition, the weight distribution between the lower limbs can vary from −1 (all the weight on the left side of the body) to 1 (all the weight on the right side of the body); 0 means the weight is equally distributed on both lower limbs. To determine the average weight distribution asymmetry, disregarding its side (sign), we calculated the absolute value (modulus) of the mean of WDA(t) for each subject, which will be referred to as |WDAm|. To determine the average instant-by-instant weight distribution asymmetry, disregarding its side (sign), we calculated the mean of the absolute values of WDA(t) for each subject, which will be referred to as |WDA|m. To determine whether there is a prevalent side for asymmetry, we simply computed the sign (+ or −) of the mean across the time of WDA(t), for each subject. For instance, if a subject stood half of the time entirely with the weight on the right side and the other half of the time on the left side, the |WDAm| value will be equal to 0, because on average across time the subject was symmetric, but the |WDA|m value will be 1, indicating the subject was at each instant asymmetric (in this case with the largest possible asymmetry).

Regarding the |WDAm| and |WDA|m metrics, because they are calculated for both quiet and relaxed standing tasks, which have very different temporal durations (60 and 900 s, respectively), one could argue that the duration itself could affect these metrics. To address this question, for the relaxed standing data, we also computed these metrics over 60-s duration windows and then all the 60-s window values are averaged resulting in one value for each metric, $|WDA_{60m}|m$ and $|WDA|_{60m}m$. However, because the average is a linear process, that is, the average of the averages over 60-s windows is equal to the average over the entire 900-s window, the values of the metrics $|WDA|m$ and $|WDA|_{60m}m$ will be identical. Regarding $|WDAm|$, the value of $|WDA_{60m}|m$ can be different because the absolute value is a nonlinear process, that is, the average of the absolute values of the averages over 60-s windows is not necessarily equal to the absolute value of the average over the entire 900-s window. Consequently, we expect to find a difference only between $|WDAm|$ and $|WDA_{60m}|m$ and only if there is a systematic difference between sides for the asymmetry in the data partitioned in 60-s windows. For the sake of clarity, considering that for the present data the values of these two metrics are similar to the values of the former two metrics, we will present all the results, but analyze only the data of $|WDAm|$ and $|WDA|m$. Finally, note that because these metrics are averages over time of the asymmetry index, computing these metrics over 60-s duration windows, it is equivalent to apply a moving average filter to the WDA(t) data with a sliding window size of 60 s and compute the metrics as described in the previous paragraph. For the present calculation, we implemented the moving average filter using the convolution of the data, which is more efficient computationally.

To visualize how the weight distribution during standing varies over time, we plotted the histogram of the weight distribution asymmetry time series and calculated the frequency of occurrence of the weight distribution asymmetry for particular ranges: $WDA(t) > 0$ and $WDA(t) < 0$ (most frequent side); $0 < WDA(t) < 0.1$ and $-0.1 < WDA(t) < 0$ (low asymmetry range); and $WDA(t) > 0.5$ and $WDA(t) < -0.5$ (high asymmetry range). The histograms were calculated with a bin width of 0.01 body weight, but the results are independent of the bin width.

To quantify a possible weight transfer during standing, we detected abrupt changes in the weight distribution asymmetry time series by employing the same change detection algorithm we previously used (Prado et al., 2011). We quantified weight transfers of at least 5% of the body weight from one leg to the other (implying a $|WDA|$ of at least 0.1). To quantify the relation between weight transfers and weight distribution asymmetry during standing, we calculated a linear least squares fitting between these two quantities across subjects.

Normality and homogeneity of variances of the variables were verified using the Shapiro–Wilk test and the Levene statistic, respectively. We employed t tests to determine the difference between dependent variables; when the data did not satisfy the normality and homogeneity assumptions, we employed a Wilcoxon rank sum test. To compare the frequency of occurrence of a given asymmetry, we employed the Pearson chi-squared test (χ^2). We calculated the Cohen d as measures of effect size for each comparison. To determine the reproducibility of the asymmetry variables across sessions, we calculated intraclass correlation coefficients between the first and second sessions. An alpha level of .05 was used for all statistical tests.

Results

All subjects successfully completed the trials and none of them reported any discomfort or fatigue between trials or after completing the experiment. Figure 1

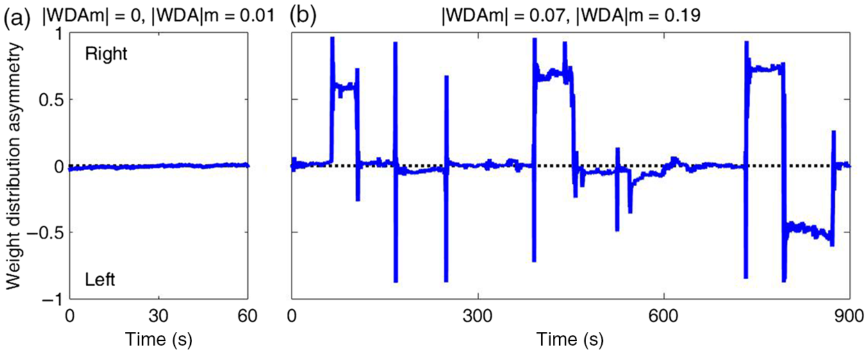

Figure 1 — Examples of the time series of weight-distribution asymmetry during quiet (a) and relaxed (b) standing for one female subject, and the corresponding values of the absolute averaged weight-distribution asymmetry, |WDAm|, and of the averaged absolute instant-by-instant weight-distribution asymmetry, |WDA|m. Positive values in the plots indicate asymmetry toward the right side of the body

shows examples of the weight distribution asymmetry time series WDA(t) during quiet and relaxed standing for a female subject. The values of |WDAm| and |WDA|m were reproducible across the first and second sessions for all quiet and relaxed standing trials (intraclass correlation coefficient ≥ .72). In addition, during relaxed standing, |WDAm| and |WDA|m variables were not significantly different between conditions, that is, reading a text or watching a video (intraclass correlation coefficient ≥ .76). As the trials were reproducible within each task and the conditions had no significant effect during relaxed standing, the WDA values of the two trials for quiet standing and of the four trials for relaxed standing were combined (averaged) for each task and their mean values across subjects are presented in Table 1 (mean values of $|WDA_{60m}|m$ and $|WDA|_{60m}m$, which are identical to the mean values of |WDAm| and |WDA|m, are also shown). During quiet standing, both female and male subjects displayed asymmetries in the weight distribution, |WDAm| and |WDA|m variables were significantly greater than zero ($d \geq 1.16$ and $p < .001$), with no gender difference ($p \geq .26$) and no prevalent side of asymmetry for either gender ($p \geq .09$). During relaxed standing, both female and male subjects displayed asymmetries in the weight distribution, both |WDAm| and |WDA|m variables were significantly greater than zero ($d \geq 1.27$ and $p < .001$). Women were more asymmetric than men (see Table 1), and there was no prevalent side of asymmetry for either gender ($p \geq .22$). The asymmetries were greater during relaxed standing than during quiet standing for both |WDAm| and |WDA|m variables (females: $d = 0.81$, $t = 3.9$, $p < .001$; males: $d = 0.61$, $t = 2.6$, $p = .02$ and females: $d = 1.77$, $t = 8.5$, $p < .001$; males: $d = 1.15$, $t = 4.9$, $p < .001$, respectively).

The histograms for the frequency of occurrence of WDA across time revealed distinct patterns for quiet standing in comparison with relaxed standing (see Figure 2). During quiet standing, the histogram of the WDA time series presented the most frequent value as being near zero (indicating no asymmetry), followed by a rapid decrease for higher values of asymmetry. All the subjects produced this

Table 1 Mean and *SD* for the Female and Male Groups of the |WDAm| and |WDA|m During Quiet and Relaxed Standing

	Group		
	Females ($N = 23$)	Males ($N = 18$)	Gender comparison (Cohen d, *t* test, *p* value)
Quiet standing			
|WDAm|	0.05 ± 0.05	0.04 ± 0.02	(0.36, 1.1, .26)
|WDA|m	0.05 ± 0.04	0.04 ± 0.02	(0.35, 1.1, .27)
Relaxed standing			
|WDAm|	0.10 ± 0.05	0.07 ± 0.05	(0.68, 2.2, .04)
|WDA|m	0.33 ± 0.16	0.17 ± 0.11	(1.16, 3.7, <.001)
$\|WDA_{60m}\|m$	0.10 ± 0.05	0.07 ± 0.05	
$\|WDA\|_{60m}m$	0.33 ± 0.16	0.17 ± 0.11	

Note. The statistical results for the comparisons between genders are shown as Cohen *d* effect size, the *t*-test value, and the *p* value. Mean and *SD* for the metrics when the relaxed standing data are partitioned in 60-s windows ($|WDA_{60m}|m$ and $|WDA|_{60m}m$) are also shown. |WDAm| = absolute averaged weight distribution asymmetry; |WDA|m = averaged absolute instant-by-instant weight distribution asymmetry.

pattern during quiet standing, hereafter referred to as the single mode of weight distribution (see Figure 2, top). During relaxed standing, the histogram of the WDA time series also presented the most frequent value near zero (indicating no asymmetry), followed by a decrease for higher values of asymmetry. However, at 0.5 (and −0.5) of asymmetry, the curve increased again, culminating with two additional smaller peaks, one at each side of the curve, symmetrically located at −0.8 and 0.8 (implying 90–10% of weight distribution between sides). Thirty-four (21 women and 13 men) of the 41 subjects produced this pattern during relaxed standing, hereafter referred to as the dual mode of weight distribution, and the remaining seven subjects (five males and two females) exhibited the single mode of weight distribution during relaxed standing. The dual mode of weight distribution was significantly more frequent than the single mode across all subjects ($\chi^2 = 35.6$, $p < .001$), and there was no gender difference for the frequency of occurrence ($\chi^2 = 2.6$, $p = .11$).

The average absolute weight distribution asymmetry, |WDA|m, was linearly correlated with the number of weight transfers across all subjects during relaxed standing ($R^2 = .37$, $p < .001$; see Figure 3), and similar relations were observed separately for each gender (females: $R^2 = .30$, $p = .009$ and males: $R^2 = .41$, $p = .008$). The number of weight transfers were not different for women and men during relaxed standing ($d = 0.16$, $z = 1.1$, $p = .29$).

Discussion

The goal of this study was to investigate the asymmetry in weight distribution during relaxed and quiet standing by healthy, young adults. We observed that

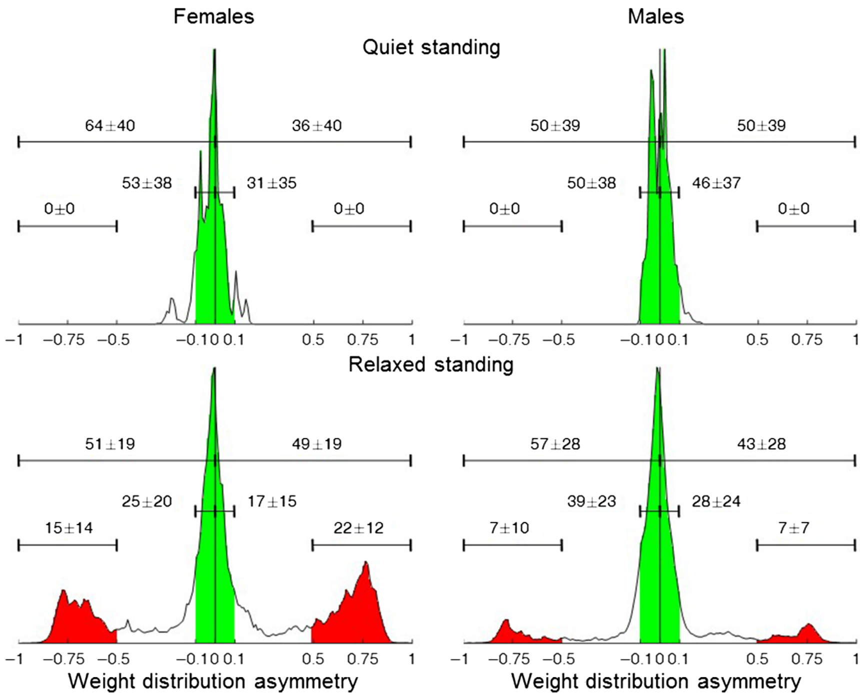

Figure 2 — Resultant histograms across all female and male subjects of the weight-distribution asymmetry during quiet and relaxed standing. Positive values indicate asymmetry toward the right side of the body. The numerical values represent percentages ($M \pm 1SD$) across subjects of frequency of occurrence in each range of weight-distribution asymmetry (preferred side: below or above 0; low asymmetry: between –0.1 and 0.1; high asymmetry: below –0.5 or above 0.5).

subjects presented on average small overall asymmetries during quiet standing and larger asymmetries during relaxed standing. However, when we looked at the asymmetry instant by instant, subjects were largely asymmetrical during relaxed standing and not during quiet standing. Two unexpected results we found were that during relaxed standing women were more asymmetrical than men, and that we observed a specific pattern of asymmetry during relaxed standing. Next, we discuss the implications of these results.

In typical quantitative studies of upright standing inside a laboratory, such as one of the tasks studied here, subjects are asked to select a comfortable posture with their feet and hands symmetrically and separately positioned at shoulder width and to stay as still as possible, while looking at a point straight ahead; this condition is commonly referred to as quiet standing (Duarte & Freitas, 2010; Winter, Patla, & Frank, 1990). In such a stereotypical condition, we observed only small overall differences (up to 5%) in the body weight distribution between feet, in agreement with other studies (Anker et al., 2008; Blaszczyk et al., 2000; Jonsson, Henriksson, & Hirschfeld, 2007). However, with specific regard to body posture and weight

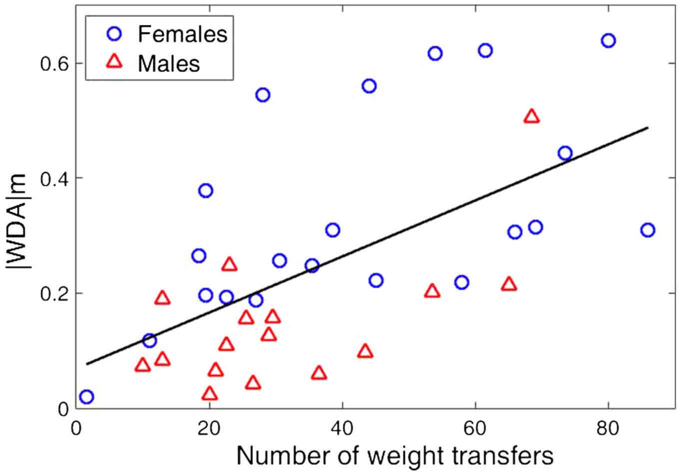

Figure 3 — Average absolute weight-distribution asymmetry, |WDA|m, versus number of weight transfers for each female and male subject during relaxed standing. The line represents a least squares linear fitting across all subjects.

distribution asymmetry, quiet standing is remarkably different from the standing positions in daily life activities, referred here as relaxed standing, as we typically do not have any constraint on how to stand. The contrast between these two standing conditions is evident in the representative examples presented in Figure 1 of body weight distribution across the task duration. Because, by definition, quiet standing imposes on the subject a lack of motion, performing quiet standing for several minutes, if feasible, would not considerably change the amount of asymmetry nor how this asymmetry would change over time, simply because if it was altered, the subject failed to stand as quiet as possible. (In fact, trying to stand as still as possible for several minutes would likely induce fatigue, for which the "natural response" by the postural control system is postural changes, disrupting the nature of the quiet standing task.) The key difference between the standing tasks is related to the nature of the task—quiet (constrained) versus relaxed (minimal constraint) standing.

During quiet standing, we observed that people started almost symmetrical regarding weight distribution and they stayed slightly asymmetrical (did not move) over the entire trial, as expected given the nature of the task. The two metrics we employed to describe the weight distribution asymmetry, that is, the absolute averaged weight distribution asymmetry, |WDAm|, and the averaged absolute instant-by-instant weight distribution asymmetry, |WDA|m, captured this unaltered small asymmetry during quiet standing. During relaxed standing, because of the weight transfers caused by postural changes (Prado et al., 2011), the weight distribution is repetitively changed, captured here by the different values of |WDAm| and |WDA|m (in other words, the symmetrical weight distribution over a large time scale is, in fact, realized by time-local asymmetries). The differences in the weight distribution asymmetry metrics between the two tasks are not due to the difference in temporal duration of the tasks (60 vs. 900 s). When we computed the metrics for the relaxed standing trials partitioning the data in 60-s windows and averaged each metric across windows (metrics referred as $|WDA_{60m}|m$ and $|WDA|_{60m}m$, see the "Materials and Methods" section for more details), the resultant values were identical. In addition, our results suggest that, independent of the type of task performed during relaxed standing (watching television or reading a text), both young men and women present a consistent pattern of body weight transfer in conditions with minimal postural constraint. This finding is in contrast with other studies that have reported that body posture and asymmetry vary depending on the type of secondary task performed while standing (Whistance, Adams, van Geems, & Bridger, 1995; Wong & Chen, 2015). Bear in mind, that the quantitative measurements employed in those studies were different.

We observed a moderate positive correlation between the number of weight transfers and the weight distribution asymmetry during relaxed standing (illustrated in Figure 3). These findings suggest that subjects who tend to be more asymmetrical instant by instant (larger values of |WDA|m) also tend to change their posture more often. A possible explanation for this correlation between asymmetry and postural changes it is that, by loading relatively more weight on one side of the body than the other, subjects need to more frequently alleviate the loaded structures of the musculoskeletal system, providing better comfort for them during standing for a prolonged period.

We found that women were more asymmetrical and stood for longer periods with larger weight distribution asymmetries than men during relaxed standing (women were also more asymmetrical during quiet standing, but with a smaller effect size). A gender-related difference has also been observed in another study regarding gait kinematics: women exhibit greater pelvic obliquity in the frontal plane than men while walking (Smith, Lelas, & Kerrigan, 2002). In a similar manner as argued by Smith and collaborators for the gait task, it is possible that a wider or more mobile pelvis may facilitate the body weight transfer between limbs during standing; however, this hypothesis requires further investigation.

We believe this is the first study to report quantitative measurements of asymmetry in standing conditions closer to those of our daily life activities, and the patterns of asymmetry observed were remarkably different from the pattern observed during quiet standing, which is the typical task analyzed in laboratory conditions. Indeed, the asymmetry in relaxed standing is more intricate, notably, the existence of two preferential modes of weight distribution (one 50/50% symmetrical mode, the most common, and another mode, less frequent, of 90/10% weight distribution without side preference), and it has a time-varying structure that is lost when subjects are constrained to a single posture. This asymmetrical mode corresponds to an asymmetrical posture in which we bear practically all the weight on one side of the body, while leaving the other leg resting on the ground; 34 of the 41 subjects produced this pattern during relaxed standing.

It is known that the ability to transfer weight between lower limbs decreases with aging (Prado et al., 2011), in neurological diseases with unilateral deficit such as stroke (Aruin & Kanekar, 2013; Ma, Rao, Muthukrishnan, & Aruin, 2018), that individuals with low-back pain after relaxed standing produce fewer postural changes (Lafond et al., 2009), and that an incorrect weight shifting is believed to be the primary cause of falling in elderly in daily life activities (Robinovitch et al., 2013). Although, in the present study, we only investigated healthy, young individuals, it is our view that the study of relaxed standing, where postural changes are a natural event, including consideration of how its asymmetry varies over time, will be useful for understanding how aging and certain health problems affect our ability to stand in daily life.

We usually treat posture maintenance and body movements as two separate entities, and this is typically reflected in some theories of postural control (e.g., confer the inverted pendulum hypothesis of the quiet standing). However, posture maintenance and body movements actually act interchangeably during relaxed standing. An appropriate theoretical framework to encompass the control of posture and movement required in relaxed standing tasks is the equilibrium-point hypothesis (Feldman, 1986), specifically the referent control theory (Feldman, 2015; Mullick et al., 2018). Under this theory, the control of relaxed standing would be described as the central nervous system setting a referent body orientation, defined as spatial thresholds at which multiple muscles begin to be activated and at which muscle activation is minimized. Then, under the effect of external forces, the body would be deflected from this referent body orientation to an actual orientation until active and passive musculoskeletal forces balance the external forces to maintain body stability. During relaxed standing, the typically observed posture changes would simply reflect the CNS setting a different referent body orientation over time. This rationale is somewhat similar to the idea of conservative and operative hierarchical levels in the rambling–trembling hypothesis proposed by Zatsiorsky and Duarte (1999, 2000) to explain the control of quiet standing if now we extend it to relaxed standing. Conceptually, the different body orientations caused by posture changes would represent different instant equilibrium positions set by a conservative level where the sway around these positions would reflect the action of an operative level to maintain balance.

A limitation of our study is how close we were able to reproduce the natural (relaxed) standing observed in daily life with a task inside laboratory settings. For example, in our study, subjects were constrained to stand with each foot inside the force plate area. However, although we do not have independent data to support our claim, we feel confident that the experimental task we designed indeed satisfactorily mimics natural standing. Given the state of the art in wearable technology, it should be viable to acquire data in real-life situations to look at specifically balance symmetry and postural changes during standing. Another limitation is that we allowed the subjects to wear their own comfortable shoes (high heels were not allowed); it is known that shoes with different characteristics may influence the way individuals stand (e.g., see Ma, Lee, Chen, & Aruin, 2016) and we did not control this effect.

The present study provided insights about how young, healthy individuals stand during relaxed standing, which mimics the demands of daily life activities. It would be particularly relevant to investigate the dynamics of postural asymmetries and postural changes during relaxed standing in populations with less ability to perform body weight transfers, such as neurological and musculoskeletal patients and elderly subjects. Future studies addressing these issues might be relevant to understand postural control failure and to develop rehabilitation programs to enhance postural control in individuals with balance impairment in daily life situations.

At last, the present results challenge the general concept that symmetry should be preferred over asymmetry concerning balance during standing. It is not that recommendations such as stand evenly on both feet are unfounded; but healthy, young adults stand a nonnegligible part of the time in asymmetrical manner.

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