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Age-related difference on weight transfer during unconstrained standing

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ABSTRACT

The ability to transfer weight from one lower limb to the other is essential for the execution of daily life activities and little is known about how weight transfer during unconstrained natural standing is affected by age. This study examined the weight transfer ability of elderly individuals during unconstrained standing (for 30 min) in comparison to young adults. The subjects (19 healthy elderly adults, range 65–80 years, and 19 healthy young adults, range 18–30 years) stood with each foot on a separate force plate and were allowed to change their posture freely at any time. The limits of stability and base of support width during standing, measures of mobility (using the timed up and go and the preferred walking speed tests), and fear of falling were also measured. In comparison to the young adults, during unconstrained standing the elderly adults produced four times fewer weight transfers of large amplitude (greater than half of their body weight). The limits of stability and base of support width were significantly smaller for the elderly adults but there were no significant differences in the measures of mobility and in the fear of falling score compared to young adults. The observed significant age-related decrease in the use of weight transfer during unconstrained standing, despite any difference in the measured mobility of the subjects, suggests that this task reveals unnoticed and subtle differences in postural control, which may help to better understand age related impairments in balance that the elderly population experiences.

1. Introduction

When people stand naturally during daily activities, they are usually not forced to stand as still as possible and they stand in an unconstrained manner. During such unconstrained standing for a prolonged period, besides a continuous low-amplitude and slow sway of the body (which is similar to what is observed during standing still), one can also observe postural changes characterized by voluntary fast and gross body movements [1–3]. Although the exact reasons for producing postural changes are not clear, postural changes are sought, mainly in an ergonomic perspective, as a response to avoid discomfort and complications caused by the continuous pressure of a static posture [1]. During unconstrained standing, Duarte et al. [1,2] detected and classified postural changes measuring the center of pressure of subjects while standing on a force plate and found that young adults tended to produce about two postural changes per minute during unconstrained standing [1].

Freitas et al. [4] employed this paradigm and discovered that elderly individuals produced fewer large-amplitude postural changes compared to young adults. They observed that elderly individuals tended to maintain the same posture and did not shift from one posture to another during unconstrained standing as often the young adults did. A possible underlying mechanism for this altered behavior is that elderly individuals produce fewer weight transfers from one lower limb to the other during unconstrained standing. By weight transfer, we mean the act of transferring partially or completely the supporting forces acting on one lower limb to the other lower limb during a task.

The affect of aging on weight transfer is not only important for understanding unconstrained standing but also for mobility because it is essential for the initiation and termination of any voluntary whole-body movement. Several studies have shown that the ability to transfer weight deteriorates with age during tasks such as gait initiation, sit-to-stand, and standing [5–8]. However, little is known about how weight transfer (specifically large-amplitude weight transfers such as observed during whole-body movement) during natural standing is affected by age. Our hypothesis is that elderly individuals perform fewer weight transfers of large amplitude compared to young adults during unconstrained standing. In turn, it is well known that there is a decrease in mobility (defined as the general ability to move) with ageing [9,10]. Hence, a decrease in the number of weight transfers

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during unconstrained standing might be related to a decrease in the general mobility of elderly individuals. Our second hypothesis is that the number of postural changes during unconstrained standing is related to independent measures of mobility of elderly individuals. Therefore, the purpose of this study was to investigate the age-related difference on weight transfer during unconstrained standing and test these two hypotheses.

2. Materials and methods

2.1. Subjects

Nineteen elderly individuals (mean age $\pm$ standard deviation of 70 ± 5 years, range 65–80 years, height of 1.60 ± 0.10 m, and mass of 69 ± 20 kg) and 19 young adults (25 ± 4 years, range 18–30 years, height of 1.70 ± 0.10 m, and mass of 69 ± 13 kg) participated in this study. The elderly subjects were significantly shorter than the young adults ($t(36) = 2.1$, $p = 0.04$), although this difference was only 6%. None of the subjects in both groups had any known postural or skeletal disorders. At the time of evaluation, all older subjects had participated in physical activity at least twice a week during the past year and none of them fell during the past year. This experiment was approved by the local ethics committee and all subjects participated voluntarily and signed a consent form.

2.2. Tasks and procedure

The subjects performed one trial of unconstrained standing for 30 min with the subjects standing with each leg on a separate force plate (each force plate had an area of 50.8 cm $\times$ 46.4 cm, model OR6, AMTI, US). Subjects were allowed to change their posture freely at any time and there were no specific instructions on how to stand, except that they were required to not step off the force plate. To mimic natural standing in everyday life, all subjects performed a secondary task: they watched a television documentary on a TV set located 3 m in front of them.

In addition, the functional limits of stability for each subject were measured by asking the subject to slowly lean his or her body in all directions as far as possible, while keeping both feet completely on the ground and maintaining balance. The subjects had enough time (typically 2–3 min) to explore their base of stability in all directions. For all tasks, the forces and moments measured by each force plate were recorded at a 60-Hz sampling frequency. To describe the change in the base of support during the unconstrained standing task, we used a three-dimensional motion capture system (model 460, Vicon, US) to record at a 60-Hz sampling frequency the position of passive reflective markers placed on the first and fifth metatarsal head and the calcaneous of each foot.

To measure mobility, we employed two common tests: timed up and go test [11] and preferred walking speed during regular walking test [12,13]. The timed up and go test measures the time it takes for an individual to stand up from a standard arm chair, walk a distance of 3 m, turn, walk back to the chair, and sit down at a preferred speed. The walking speed was calculated as the stride length divided by the stride time, which were measured from the kinematic data of the subject's feet with the motion capture system. Subjects performed these tests three times, the best time and speed were used for each test. We also measured the fear of falling for each subject by employing the Falls Efficacy Scale-International [14]. This 16-item scale measures confidence (range 1–4) in performing activities of daily living without falling: 1 indicates the subject is not at all concerned in performing the activity and 4 indicates the subject is very concerned about performing the activity. The mean score across items in the scale was used.

2.3. Data analysis

All the data analysis was implemented in Matlab (Mathworks, US). The data from the force plates were first smoothed with a 10-Hz 4th order zero lag low-pass Butterworth filter. To quantify a weight transfer from one limb to the other, we employed the vertical ground reaction force (*Fz* component) of each force plate (*Fz* right, *FzR*, and *Fz* left, *FzL*) and calculated a normalized difference between *FzR* and *FzL*:

$$FzRL = \frac{1}{2}\left(\frac{FzR - FzL}{FzR + FzL}\right)$$

Using this formula, for example, in the initiation of gait starting with the weight equally distributed on both lower limbs, the transfer of weight from one lower limb to the other has an amplitude of 0.5 units of body weight (BW) if all the weight is transferred to the right side or -0.5 BW if all the weight is transferred to the left side. Likewise, during regular walking the weight transfer amplitude alternates between approximately 1.2 and -1.2 BW.

During unconstrained standing, a weight transfer was detected as an abrupt change in the FzRL time series by an algorithm based on the CUSUM decision rule [15]. Briefly, the CUSUM technique involves the calculation of the cumulative sum of positive and negative changes (g_t^+ and g_t^-) in the FzRL time series (y_t) and comparison to a threshold (h). When this threshold is exceeded a change is detected (t_{alarm}) and the cumulative sum restarts from zero:

$$s_t = y_t - y_{t-1}$$

$$g_t^+ = \max(g_{t-1}^+ + s_t - \nu, 0)$$

$$g_t^- = \max(g_{t-1}^- - s_t - \nu, 0)$$

$$if\ \ g_t^+ > h \text{ or } g_t^- > h: \ \ t_{alarm} = t,\ \ g_t^+ = 0,\ \ g_t^- = 0$$

To avoid the detection of a change in absence of change or a slow drift, this algorithm also depends on a parameter (ν) for drift correction, which after tuning was fixed to 0.001 in this study. We selected a threshold of 0.5 BW to detect the weight transfers during unconstrained standing (a change in the FzRL time series is be considered a weight transfer if more than half of the body weight is transferred from one lower limb to the other). To investigate whether elderly subjects would rather produce weight transfers of smaller amplitudes, we also quantified weight transfers with amplitudes between 0.1 and 0.5 BW. A minimum amplitude of 0.1 BW was necessary to differentiate actual discrete weight transfers from the continuous low-amplitude changes in *Fz* similar to what is observed during standing still, which were quantified separately and explained next. The instantaneous change in FzRL was measured as the median of the absolute differences between consecutive values of FzRL (in Matlab, this is computed with the command 'median(abs(diff(FzRL)))', where 'diff()' calculates $\mathrm{FzRL}_t - \mathrm{FzRL}_{t-1}$ for all data). The median was used because of the skewed distribution of the data.

The functional limits of stability in the anterior-posterior and medio-lateral directions were calculated as the range (maximum minus minimum) in each respective direction of the center of pressure data from the functional limits of stability trial. The base of support width at each instant during the unconstrained standing task was calculated as the distance at the medio-lateral direction between the centers of the right and left feet. In turn, the center of each foot was calculated as the average position (baricenter) among the markers on the first and fifth metatarsal heads and calcaneous. Then, the mean base of support width

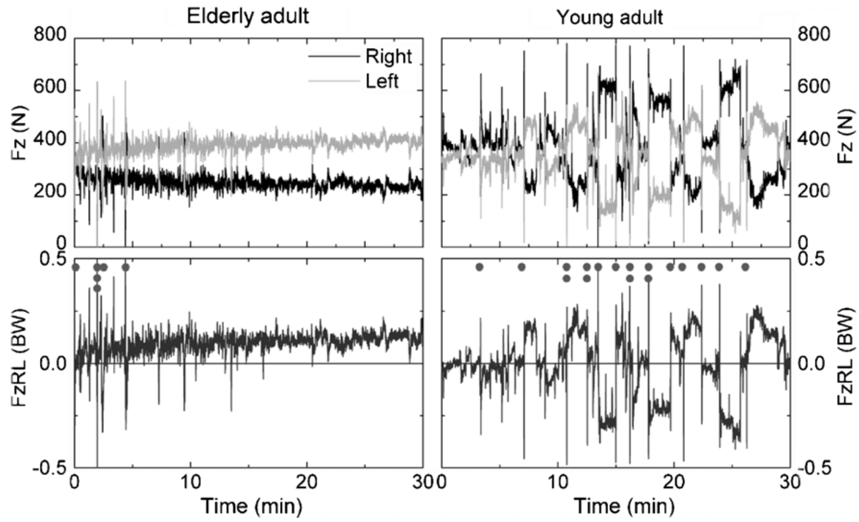

Fig. 1. Time series of the vertical ground reaction forces (*Fz*) on the right and left feet during prolonged unconstrained standing by an elderly adult (left) and a young adult (right) and the respective normalized difference between these two time series (FzRL) in units of body weight (BW) plotted at the second row. The elderly adult produced 6 large-amplitude (>0.5 BW, ●) and 59 small-amplitude (between 0.1 and 0.5 BW, not shown for sake of clarity) weight transfers. The young adult produced 17 large-amplitude (●) and 85 small-amplitude weight transfers.

was calculated as the mean of the base of support width across the trial duration. To account for the stature difference between groups, these measures were also compared after normalization by the respective subject height.

Both parametric and nonparametric statistics were used to analyze the data according to the tests of normality and homogeneity of variances (tested by the Shapiro–Wilk test and the Levene statistic, respectively). Wilcoxon rank sum tests were used to investigate the affect of the group (adult versus elderly) on the number of weight transfers and functional limits of stability. The results of these tests are reported as Z values and the data are summarized as median and 25th and 75th percentiles. Independent t-tests were used to investigate the affect of the group on all the other dependent variables and the data for these variables are summarized as mean and standard deviation. Likewise, the statistical correlations between variables were determined employing the nonparametric Spearman (ρ) or the parametric Pearson (r) correlation coefficients. An alpha level of 0.05 was used for all statistical tests.

3. Results

Fig. 1 shows representative examples of the Fz time series on each force plate, the respective FzRL time series, and the weight transfers detected for a threshold of 0.5 BW. In comparison to the young adults, the elderly adults produced significantly fewer weight transfers of large amplitude ($Z(36) = 2.5$; $p = 0.014$) but the number of weight transfers of small amplitude (between 0.1 and 0.5 BW) was not different ($Z(36) = 1$; $p = 0.31$) during prolonged unconstrained standing (median, 25th and 75th percentiles for each group are shown in Fig. 2). The instantaneous change in FzRL was not different between elderly and young adults (Elderly: $1.0 \pm 0.5 \times 10^{-3}$ BW; Young: $1.2 \pm 0.4 \times 10^{-3}$ BW; $t(36) = -1.59$, $p = 0.12$).

The limits of stability in the anterior-posterior and medio-lateral directions were significantly shorter for the elderly adults in comparison to the young adults (median, 25th to 75th percentiles, Elderly: 8, 6–10 cm; Young: 11, 9–12 cm, $Z(36) = -2.4$, $p = 0.02$ and Elderly: 28, 23–32 cm; Young: 31, 30–34 cm, $Z(36) = -2.1$, $p = 0.04$, respectively). These differences were still significant after normalization of the limits of stability by the subjects' height. The base of support width during unconstrained standing was significantly narrower for the elderly adults in comparison to the young adults (Elderly: 33 ± 5 cm; Young: 37 ± 4 cm; $t(36) = -2.8$, $p = 0.008$). However, this difference disappeared after normalization of the limits of stability by the subjects' height.

With regards to the measures of mobility, the time in the timed up and go test and the walking speed test were not different between the young adults and the elderly adults (time: Elderly: 10.0 ± 1.9 s; Young: 9.0 ± 1.1 s; $t(36) = 2.0$, $p = 0.05$; speed: Elderly: 1.20 ± 0.25 m/s; Young: 1.18 ± 0.14 m/s; $t(36) = -0.20$, $p = 0.85$). Within each group, the speed of walking was negatively correlated to the time in the TUG test for both elderly and young adults ($r = -0.68$, $p = 0.001$, $r = -0.60$, $p = 0.007$, respectively). With regards to the fear of falling, the scores of the elderly and young adults were not different (Elderly: 1.4 ± 0.3; Young: 1.2 ± 0.3; $t(36) = 1.8$, $p = 0.08$).

There was no significant correlation between any of the measures of mobility and fear of falling or the number of weight transfers for both elderly and young adults ($|\rho| < 0.41$, $p > 0.08$).

4. Discussion

This study investigated how weight transfer during unconstrained standing is affected by aging and we confirmed our first

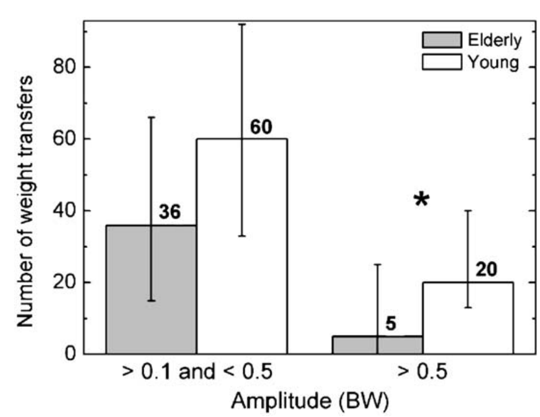

Fig. 2. Median, 25th and 75th percentiles of the number of weight transfer for the young and elderly groups and different amplitudes. $^{*}p < 0.05$.

hypothesis that elderly individuals perform fewer weight transfers of large amplitude (greater than 0.5 BW) from one lower limb to the other compared to young adults (the median number of large amplitude weight transfers by the young adults was four times larger than for the elderly adults). The number of weight transfers of small amplitude (between 0.1 and 0.5 BW) and the instantaneous change in FzRL were both smaller for elderly adults but these differences did not reach statistical significance.

A possible explanation for the difference in the number of weight transfers between subjects would be that they have different levels of mobility. However, contrary to our second hypothesis, there was no correlation between the number of weight transfers during unconstrained standing and any of themeasurements for mobility. The elderly adults were on average 1 s (10% of the total time) slower than the young adults in the timed up and go test at their preferred speed and this difference was close to statistical significance with a *p*-value of 0.05. For the walking speed test, the elderly adults had a similar walking speed compared to the young adults. The obtained values in the timed up and go test and the walking speed test are in the range of other reported values in the literature for these populations [11,16]. Since the investigated elderly adults were healthy and physically active, this lack of statistical difference in mobility between the age groups is not surprising. Nevertheless, the huge difference in the number of large amplitude weight transfers during unconstrained standing was corroborated by the visual observation of the subjects during the experiment: elderly adults clearly tended to move less compared to young adults. The results above suggest that mobility observed during locomotor tasks is different from mobility observed during unconstrained standing.

One hypothesis to explain why elderly adults produced fewer weight transfers during unconstrained standing would be that elderly adults have an increased fear of falling and may adopt a more cautious and safe strategy to control their equilibrium during unconstrained standing. The premise would be that to remain stable, elderly adults would avoid any intentional weight transfer that could take the vertical projection of their center of gravity closer to their limits of stability. However, if the elderly adults were more cautious or afraid of falling we should have observed a similar cautious behavior during the tests to measure their mobility, the timed up and go and the walking speed tests, and also in the response to the fear of falling questionnaire. But this was not the case; there were no statistically significant differences in any of these measures comparing elderly adults to younger adults and no correlation between these measures and the number of weight transfers.

Another possible explanation for this supposed cautious behavior by the elderly adults is that they have smaller limits of stability (i.e., how much the base of support can actually be used by the individual during standing without falling) and a narrower base of support; consequently they could move less during unconstrained standing. The limits of stability were indeed smaller in elderly adults compared to young adults. However, this decrease was mostly in the anterior-posterior direction (30%), the limits of stability in the medio-lateral direction were smaller only by 10%. The base of support width was also smaller in elderly adults compared to young adults during the unconstrained standing, but only by 11% and this difference could be explained by the observed 6% difference in group's stature. Therefore even with these differences we suggest the limits of stability and base of support were still large enough to allow producing weight transfers in the medio-lateral direction.

The difference in the number of postural changes might also simply reflect a different social behavior with ageing. Elderly adults may be less fidgety (more calm) during unconstrained standing, which could be a strategy to spend less energy. In addition, although both elderly and young adults performed the same secondary task, it is possible that somehow the task of watching a television documentary evoked a different response in the elderly adults. However, with the current results we are unable to test these hypotheses.

Yet another possible explanation for a decrease in the number of postural changes during unconstrained standing was proposed by Lafond et al. who also observed this behavior in individuals with chronic low back pain in comparison to matched healthy adults [17]. Hence individuals with chronic low back pain may present an impairment of the somatosensory system, Lafond et al. suggested this impairment as a possible factor related to the reduced number of postural changes [17]. In this hypothesis, postural changes are viewed as a physiological response to reduce musculoskeletal fatigue and discomfort [1,18–20] and in this way, postural changes, and specifically weight transfer, are triggered by somatosensory information. Considering that it has been shown that somatosensory information deteriorates with aging [21,22], it is possible that the observed decrease in weight transfer by the elderly adults during unconstrained standing would be due to the diminished somatosensory information in these individuals, which may not be triggering the appropriate postural changes. However, this hypothesis has not yet been tested.

The main limitation of this study is that natural (unconstrained) standing is a poor controlled task for investigation. Due to the subjects being allowed to perform any movement during standing, it causes a large amount of variability within and between subjects. However, the current methodology reproduces natural standing that occurs during daily living activities, which is indeed very variable.

In summary, why elderly adults produced fewer large amplitude weight transfers during unconstrained standing compared to young adults, despite any difference in the measured mobility of the subjects, still has no answer. Nevertheless, the observed significant age-related difference in the weight transfer during unconstrained standing suggests that this task unveils subtle differences in postural control, which might help to better understand the impairments in balance related to aging that occurs in the elderly population.

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Conflict of interest

There is no conflict of interest.

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