Age effect on the stabilization of the whole-body angular momentum during stepping

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1. Introduction

Whole-body angular momentum (WBAM) appears to be a highly controlled variable to safely and efficiently perform daily motor tasks (Herr and Popovic 2008; Robert et al. 2009). Recent results suggest that aging affects the control of WBAM during motor tasks, such as walking (Vistamehr and Neptune 2021) and stepping (Begue et al. 2021). Specifically, these studies revealed that old adults had a larger range of WBAM than young adults. These results have generally been interpreted as a poorer control of WBAM with aging. However, in these earlier studies, the authors did not quantify WBAM control. Therefore, to date, it remains unclear whether age-related changes in WBAM during these motor tasks actually reflect poorer control of this mechanical variable with aging.

Uncontrolled manifold (UCM) analysis is an approach classically used to identify control variables and the degree to which these variables are controlled during a motor task (Latash et al. 2007). In this study, we used this approach to quantify the control of sagittal-plane WBAM during stepping. We hypothesized that old adults would control this variable less compared to younger adults. Furthermore, we assumed that the poorer control of WBAM would be correlated with the larger range of WBAM in older adults.

2. Methods

2.1. Participants

Twelve healthy young adults (age: 25 ± 3 years) and 14 healthy older adults (age: 68 ± 4 years) volunteered for this study. All participants were physically active and had not experienced a fall in the past 12 months. All subjects gave their written consent after being fully informed of the test procedure.

2.2. Experimental protocol

Subjects were asked to stand barefoot in a natural upright posture as still as possible with their arms



Figure 1. Comparison of the synergy index (ΔV_Z) between young adults (black) and old adults (red) using SnPM. SnPM{t}is the t-value at each instant. Significance levels (p < 0.05; |t| > 3.9) are indicated. Restabilization phase ranges from the foot-contact of the non-dominant leg to the end of movement.

alongside their trunk. After receiving a verbal GOsignal from the experimenter, they stepped forward at their self-selected preferred pace. They were asked to initiate step with their dominant leg and to follow through with the non-dominant leg to stop in a comfortable upright posture with both feet shoulder-width apart. During the experiment, a total of 49 retroreflective spherical markers (14 mm diameter) were fixed on bony landmarks of all participants to define 19 rigid bodies (head, torso, pelvis, right and left arms, forearms, hands, fingers, thighs, shanks, feet and toes) (Begue et al. 2021). A Vicon motion capture system equipped with 14 cameras was used to collect the 3D whole-body kinematic data at 200Hz. After familiarization trials, twenty trials were collected.

2.3. Data analysis

WBAM was computed as the sum of the angular momenta of the 19 rigid bodies about the body's center of mass. We also calculated the angular momenta of five segment groups: right arm (upper arm, forearm, hand), left arm, right leg (thigh, shank, foot), left leg, and trunk (head, torso, pelvis). Sagittal-plane WBAM and segment angular momenta over the entire stepping movement were time normalized from 0 to 100%, with 0% being the onset of stepping movement. WBAM was normalized by the participant's mass, height and $\sqrt{g \cdot height}$ with $g = 9.81 \text{ m.s}^{-2}$. To quantify variation in WBAM, peak-to-peak WBAM range was calculated over the entire stepping movement.

An UCM analysis was conducted to determine the presence of synergy among the angular momenta of the five segments (elemental variables) to control WBAM (performance variable) during stepping. At each normalized time, we calculated the Jacobian matrix (1-by-5 matrix) containing the partial derivatives of the performance variable with respect to the elemental variables. Afterwards, a singular value decomposition was performed on the Jacobian matrix to identify the vectors associated with the null space (UCM subspace) and the space orthogonal to it (Orthogonal subspace). The variances associated with the UCM and orthogonal subspaces, i.e. $V_{\rm UCM}$ and V_{ORT}, respectively, were computed and normalized by their dimensions at each time. A synergy index (ΔV) was then computed as:

$$\Delta V = \frac{V_{UCM} - V_{ORT}}{V_{UCM} + V_{ORT}}$$

Fisher's Z-transformation was applied to synergy index (ΔV_Z) before statistical analysis (Robert et al. 2009). Mean value of ΔV_Z over the entire stepping movement was calculated. $\Delta V_Z > 0$ indicates the presence of a synergy among the segment angular momenta stabilizing WBAM. Conversely, $\Delta V_Z < 0$ indicates the presence of an anti-synergy destabilizing WBAM (Robert et al. 2009). $\Delta V_Z = 0$ implies the absence of synergy.

2.4. Statistical analysis

Statistical Parametric Mapping (SPM) was used to evaluate the effect of age on the waveform of ΔV_Z . After checking for data normality, non-parametric two-sample t-test (SnPM{t}, $\alpha = 0.05$) was conducted on the waveform of ΔV_Z . The critical t-statistic and areas of significance between the two groups were reported. Finally, the effect of age on mean ΔV_Z and WBAM range was tested using t-tests for independent samples. Relationship between WBAM range and mean ΔV_Z was assessed using Pearson correlation coefficient. The level of statistical significance was set at p < 0.05.

3. Results and discussion

Statistical analysis revealed no age effect for stepping progression velocity (Young: $0.68 \pm 0.16 \text{ m.s}^{-1}$ and Old: $0.71 \pm 0.13 \text{ m.s}^{-1}$; p > 0.05). In contrast, we found a significant larger sagittal-plane WBAM range in older adults compared to young adults (Young: 11.5 ± 1.9 and Old: 14.9 ± 3.9 ; p = 0.01), which is congruent with our previous findings (Begue et al. 2021).

SPM analysis revealed that old adults had larger negative ΔV_Z values compared to young adults during the restabilization phase (86–100%; p < 0.001; Figure 1), resulting in a larger negative mean ΔV_Z value in these subjects (Young: -0.07 ± 0.09 and Old: -0.15 ± 0.07 ; p = 0.017). These results may reflect a higher need for old adults to adjust WBAM during the restabilization phase, probably to ensure a safe stepping termination. Further investigation is needed to confirm this.

Contrary to our initial hypothesis, we found no significant correlation between mean ΔV_Z and WBAM range (p > 0.05). Together, these results suggest that the age-related changes in WBAM during stepping are not ascribed to alterations in the ability to control this variable with aging. Differences in WBAM with aging could instead result from less segment-to-segment angular momentum cancellation induced by the adoption of an adaptive strategy aimed to compensating for leg muscle weakness, as previously hypothesized (Begue et al. 2021).

4. Conclusions

The present results reveal that old adults had greater negative values of the synergy index during the restabilization phase of stepping compared to young adults. However, we found no correlation between the synergy index and WBAM range, suggesting that the age-related changes in sagittal-plane WBAM during stepping are not ascribed to poorer control of this mechanical variable in aging adults.

Disclosure statement

No potential conflict of interest was reported by the authors.

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