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Ankle muscle co-contractions during quiet standing are associated with decreased postural steadiness in the elderly

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ABSTRACT

It has been reported that the elderly use co-contraction of the tibialis anterior (TA) and plantarflexor muscles for longer duration during quiet standing than the young. However, the particular role of ankle muscle co-contractions in the elderly during quiet standing remains unclear. Therefore, the objective of this study was to investigate the association between ankle muscle co-contractions and postural steadiness during standing in the elderly. Twenty-seven young (27.2 ± 4.5 yrs) and twenty-three elderly (66.2 ± 5.0 yrs) subjects were asked to stand quietly on a force plate for five trials. The center of pressure (COP) trajectory and its velocity (COPv) as well as the center of mass (COM) trajectory and its velocity (COMv) and acceleration (ACC) were calculated using the force plate outputs. Electromyograms were obtained from the right TA, soleus (SOL), and medial gastrocnemius (MG) muscles. Periods of TA activity (*TAon*) and inactivity (*TAoff*) were determined using an EMG threshold based on TA resting level. Our results indicate that, in the elderly, the COPv, COMv, and ACC variability were significantly larger during *TAon* periods compared to *TAoff* periods. However, in the young, no significant association between respective variability and TA activity was found. We conclude that ankle muscle co-contractions in the elderly are not associated with an increase, but a decrease in postural steadiness. Future studies are needed to clarify the causal relationship between (1) ankle muscle co-contractions and (2) joint stiffness and multi-segmental actions during standing as well as their changes with aging.

1. Introduction

Characteristics of postural steadiness during quiet standing have been used widely in research and clinical practice to quantify postural balance abilities in different populations [1–4]. In this context, many studies over the last two decades have shown that the elderly exhibit lower postural steadiness during quiet standing than the young, and this in terms of a larger center of pressure (COP) displacement [1,3–5], a larger COP velocity [1,3–5], and a larger center of mass (COM) acceleration [3,5]. More importantly, strong evidence exists that: (1) medial-lateral measures of postural steadiness are predictive of fall risk; and (2) anterior-posterior and medial-lateral measures of postural steadiness in the elderly can distinguish fallers from non-fallers [2,6]. Falls, however, are a serious concern considering the potential implications of falling for affected individuals' health and quality of life [7]. Due to this reason, mechanisms underlying age-related changes in postural steadiness during quiet standing have been investigated extensively, with numerous studies focusing on the time-varying characteristics of the aforementioned COP and/or COM variability [2,6,8,9].

During quiet standing, the COP variability is approximately proportional to the ankle joint torque variability, whose primary task is to

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regulate the body's COM position [10,11]. Since the COM is located in front of the ankle joint during quiet standing, a continuous ankle extension or plantarflexor joint torque is needed to stabilize the ankle joint and the COM. Therefore, the plantarflexors and especially the soleus muscles are continuously active to provide the required plantarflexion torque. In addition, in healthy *young* individuals, the dorsiflexors such as the tibialis anterior muscles are rarely activated during quiet standing [12,13]. In healthy *elderly* individuals, however, the tibialis anterior muscles are frequently activated during quiet standing [14,15], which directly results in frequent co-contractions between the plantarflexors and dorsiflexors [14].

Co-contractions in general and those described above in particular are assumed to increase respective joint stiffness. In fact, single joint examinations of the ankle joint have demonstrated that activation of plantarflexors [16] and dorsiflexors [17] positively correlates with ankle joint stiffness. Therefore, co-contractions of plantarflexors and dorsiflexors may increase ankle joint stiffness in a similar matter as stays of a sailboat support the mast − a concept that has been used to describe the mechanisms involved in human trunk stability [18]. Indeed, Carpenter et al. [19] demonstrated in healthy young individuals that the postural threat induced by changes in base of support height leads to ankle muscle co-contractions, which increase ankle joint stiffness.

In light of these considerations, it would be reasonable to assume that co-contractions frequently observed in the elderly contribute to increased ankle joint stiffness during quiet standing. Since elderly individuals are believed to have inferior postural balance abilities in comparison to the young, such increase in ankle joint stiffness should also affect their postural steadiness as measured by COP and COM variability. Note that these dependencies are supported by the aforementioned study in healthy young individuals [19], where ankle muscle co-contractions induced by the postural threat reduced the variability of both COP and COM (measured via standard deviation) while increasing the mean power frequency of COP.

In spite of the known relation between ankle muscle co-contractions and postural steadiness for the task described in [19], the particular role of ankle muscle co-contractions in the elderly during quiet standing remains unclear. Insights on this role are, however, of substantial interest given the overall decrease in postural steadiness in the elderly in comparison to the young. Therefore, the objective of this study was to quantify the association between ankle muscle co-contractions and postural steadiness during quiet standing and to characterize the effect of aging on this relationship.

2. Methods

2.1. Subjects

Experimental data were acquired in the context of a previous study [20]. Twenty-seven healthy young adults (14 female; age: 27.2 ± 4.5 years; height: 168 ± 9 cm; weight: 62.3 ± 10.9 kg) and twenty-three healthy elderly adults (12 female; age: 66.2 ± 5.0 years; height: 157 ± 7 cm; weight: 59.3 ± 8.4 kg) participated in this study. They had no medical history of neurological disorders. All subjects gave their written informed consent to participate in the study, whose experimental procedures were approved by the local ethics committee.

2.2. Procedure

Each subject stood quietly with bare feet, eyes open, and the arms hanging along the sides of the body for the duration of 90 s. The subject was instructed to stand quietly and to refrain from any voluntary movements. Each subject completed five trials with sufficient resting time in between the trials. A force platform (Type 9281B, Kistler, Switzerland) was used to measure the ground reaction force during quiet standing. Surface electromyograms (EMGs) were recorded from the right tibialis anterior muscle (TA), soleus muscle (SOL), and medial (MG) and lateral (LG) heads of the gastrocnemius muscle. The EMGs were amplified and band-pass filtered between 20 and 500 Hz (Bangnoli 8 EMG System, Delsys, Boston, MA). Due to the similarity of the MG and LG activation profiles, the EMG of LG was not further analyzed in this study. In addition, postural sway data from a laser displacement sensor was acquired for the purpose of a previous study [20] and not further processed. Note that this study revealed a smaller sway size during standing being associated with a longer time shift between soleus EMG and COM fluctuations for both the young and elderly. In the present study, all data were sampled at 1 kHz and stored on a personal computer for subsequent analyses. Prior to the standing task, resting EMG levels were recorded in a seated posture for 30 s.

2.3. Data processing

We focused on the analysis of the anterior-posterior direction given that TA with its particular geometric configuration primarily contributes to body stabilization in this direction. The ground reaction force components obtained from the force plate were low-pass filtered with a cutoff frequency of 30 Hz using a fourth-order Butterworth filter. They were used to calculate the COP displacement, and the COP velocity (COPv) was identified using numerical differentiation of the COP displacement. The COM displacement and its velocity (COMv) were estimated using the Gravity Line Projection Method as described by Zatsiorsky and King [21]. The COM acceleration (ACC) was estimated using the horizontal force obtained from the force plate, according to:

$$ACC = \ddot{x}_{COM} \approx f_{AP}/m, \quad (1)$$

where f_{AP} denotes the horizontal force in the anterior-posterior direction and m denotes the subject's body mass M without his/her feet as modeled by $m = 0.971 \cdot M$ [22].

The EMGs of TA, SOL, and MG were rectified and smoothed using a fourth-order Butterworth filter with a low-pass cutoff frequency of 1 Hz. Then, the temporal phases, or periods, in the smoothed time series data were identified for which TA was either active (*TAon*) or inactive (*TAoff*). To identify the boundaries of these periods, we used several thresholds based on the TA resting level as obtained during seated posture. First, the standard deviation of the TA resting level (SD_{TA}) was calculated. Then, a range of thresholds was identified using the *average TA resting level* + *3, 5, 7, 9, or 11* · SD_{TA}. Finally, *TAon* and *TAoff* periods were obtained based on the smoothed EMG of TA being above or below the applied threshold, respectively. While we analyzed the experimental data using all five stated thresholds, we primarily present results for the *average TA resting level* + *3* · SD_{TA}, unless specifically mentioned, as we reached the same conclusions for other thresholds. Note that the applied threshold criterion was also used by Laughton et al. when examining muscle co-contractions during quiet standing [14].

2.4. Data analysis

The duration of *TAon* periods was expressed as a percentage of the entire period of standing (90 s). As this percentage was limited between 0 and 100%, whose parent distribution is non-normal, we compared *TAon* periods between the age groups using Wilcoxon's rank-sum test (non-paired). Subjects who exhibited TA activity for the entire period of standing (i.e., 100% *TAon*) were excluded from subsequent analyses. The variability of COP, COPv, COM, COMv, and ACC was quantified using the standard deviation. The amount of muscle activation of TA, SOL, and MG was quantified using the mean amplitude of each filtered EMG. Then, for each age group separately, the variability of COP, COPv, COM, COMv, and ACC as well as the mean amplitudes of TA, SOL, and MG were compared between *TAon* and *TAoff* periods using Wilcoxon's signed-rank test (paired) and Bonferroni correction, as we found non-normal presentation in 5 out of 32 sample distributions of the tested parameters (Kolmogorov-Smirnov tests). We also calculated