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Characteristic muscle activity patterns during gait initiation in the healthy younger and older adults

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ABSTRACT

It is thought that gait initiation (GI) might be an optimal task for identifying postural control deficiencies. Thus, the aim of this study was to clarify the strategies adopted by older subjects during this task. 16 healthy younger and 15 healthy older adults participated in the study. Subjects were instructed to begin forward stepping with their dominant limb in response to an auditory stimulus. The mean muscle activity, co-contraction index, and intra-subject coefficients of variation (intra-subject CVs) of dominant limb muscles in different phases of GI were measured. The level of association between the co-contraction index and intra-subject CV of muscles was also explored. This study showed that in the anticipatory phase, the younger group had larger amplitudes and more intra-subject CVs than older the group, particularly for the tibialis anterior muscle. However, the co-contraction index was greater in older subjects relative to younger subjects. During the weight transition phase, tibialis anterior, semitendinosus and vastus lateralis muscles of older adults had a lower amplitude as compared to younger adults. However, during the locomotor phase, the activity of tibialis anterior was greater in comparison to younger adults. Also, during this phase, similar to the anticipatory phase, the co-contraction index between tibialis anterior and gastrocnemius muscles was greater in older subjects relative to younger subjects. Additionally, the larger co-contraction index of some muscles was associated with smaller intra-subject CV. These findings suggest that muscle behaviors are altered with aging and older adults employ different strategies in the different phases of GI as compared to younger adults.

1. Introduction

Gait initiation (GI) is a transient phase between quiet stance and steady state walking and is the gait phase in which most falls occur [1,2]. The morbidity and mortality following falls are very important factors in the life of older people [3]. It is thought that GI could be an optimal task for identifying postural control deficiencies and thus may also be a suitable task to address when designing preventative approaches. Clarification of the postural control strategies adopted by older subjects during this task may be useful.

Due to the intrinsic sources of postural instability during GI, the central nervous system (CNS) needs to utilize effective and efficient mechanisms [4] for control. Some researchers believe the CNS governs initiation of gait through use of pre-designed motor programs [4–7]. These motor program define the detailed characteristics of the movement, which allows the CNS to precisely control the muscle sequences and coordinate muscle contractions. Coordination between muscles is a vital component of well-controlled movements and represents the ability of the muscles to work together, both in terms of the relative timing and relative magnitude of contractions [8]. Some investigators have observed a reproducible pattern of muscle activation during GI in healthy adults, which involves inhibition of gastrocnemius/soleus (GS/SOL) muscle activity followed by activation of the tibialis anterior (TA) muscle bilaterally [1,3,5,7,9]. Crenna and Frigon found a temporally invariant relationship between SOL inhibition and TA activation and represented it as a motor program which the CNS utilizes to control GI [10]. In addition, coordinated muscle activity

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of the hip adductors and abductors accelerates the center of mass (COM) toward the stance limb and allows the swing limb to be elevated [3,6,11]. Thus, any deficiency in the coordination of these muscle groups becomes important from the point of view of mechanics. Some studies have demonstrated that older adults with impairment of postural control use muscle co-activation as a strategy to maintain balance in steady state walking and stair descending situations [12,13]. However, the presence of such a strategy has not been clarified in GI. On the other hand, it has been suggested that the variability might be part of a motor-control strategy that allows individuals to adjust to changes. In fact, a certain amount of variability is expressive of health in biological systems [14] and enables the system to find the most appropriate solution in response to perturbations [15]. Thus, clarifying alteration of these strategies as a result of aging could be one step forward in designing the most effective type of assessment and treatment for postural control deficiencies. Therefore, the overall aim of this study was to compare muscle behavior and motor-control strategies in older and younger adults during GI. We hypothesized that older adults would present with a higher level of muscle co-activation as compared to younger adults. We also expected a lower level of variability in older compared to younger adults. Moreover, we hypothesized that muscle activity of both groups would show differences.

2. Method

2.1. Subjects

16 healthy younger and 15 healthy older adults participated in the study (Table 1). The inclusion criteria for healthy older adults were the following: Age ≥65 years old, Berg Balance Scale >40, Timed Up & Go ≤20 s, Activities-specific Balance Confidence Scale ≥50%, Mini-Mental State Examination ≥24, Hospital Anxiety and Depression Scale-depression subscale ≤7 and be free from any severe cardiopulmonary disease, neurological disorder, musculoskeletal impairment or any history of falls in the prior 6 months. Subjects were excluded from either group if had any dizziness, fatigue, undertook any vigorous physical activity or stress before testing. All subjects signed an informed consent approved by the Institutional Ethics Committee of the Tehran University of Medical Sciences.

2.2. Experimental protocol

The subjects stood barefoot and relaxed on the force platform, while eyes were open, both arms at the sides, feet were abducted at 10° and heels were separated medio-laterally by 6 cm [16] and weight was equally distributed. A pair of auditory stimuli was played with an inter-stimulus interval of 2 s. First stimulus (S1) and second stimulus (S2) were a warning and a response stimulus, respectively. Subjects were instructed to begin forward stepping with the dominant limb as soon as possible in response to S2. Subjects were given no specific instructions regarding the velocity or the length of steps to allow a behavior as natural as possible. Three experimental trials were performed before the main trials to familiarize the subjects with the test procedure, and overall 10 trials for each subject were collected. The force plate and the EMG recording systems were synchronized in time and acquisition of them was triggered 2s prior to the warning stimulus.

Table 1
Demographical and clinical characteristics.

Parameter	Subject			
	Younger (*N* = 16; F:10, M:6)		Older (*N* = 15; F:9, M:6)	
	Mean	SD	Mean	SD
Age (years)	26.12	3.1	71.03	3.7
Height (cm)	170.34	8.7	165.11	10.5
Weight (kg)	56.60	2.6	69.40	3.5
BBS (range 0–56)	56	0.0	54.3	1.1
ABC (range 0–100)	100	0.0	83.55	10.9
MMSE (range 0–30)	30	0.0	28.90	1.1
TUG (s)	8.1	2.3	13.00	4.14
HADS-D	4.3	2.8	5.5	2.6

Abbreviations: BBS: Berg Balance Scale; TUG: Timed-Up & Go Test; ABC: Activities-specific Balance Confidence Scale; MMSE: Mini-Mental State Examination; HADS-D: Hospital Anxiety and Depression Scale-depression subscale; F: Female, M: Male.

2.3. EMG recording

Surface electromyographic (EMG) activity of gluteus medius (GM), rectus femoris (RF), vastus medialis (VM), vastus lateralis (VL), biceps femoris (BF), semitendinosus (ST), tibialis anterior (TA) and gastrocnemius medialis (GS) of the swing limb (limb which would take the first step in GI) was recorded using integral dry reusable electrodes (SX230, Biometrics Ltd, Gwent, UK) (diameter: 10 mm, bipolar configuration and interelectrode distance: 20 mm) and an eight-channel EMG system (DataLog P3X8, Biometrics Ltd, Gwent, UK) (CMRR: >96 dB at 60 Hz, input impedance $>10^{12}\ \Omega$, gain: 1000 and band-pass filter: 20 Hz low cut-off, 450 Hz high cut-off). After shaving and cleaning the skin with alcohol, electrodes were placed on the belly of each muscle in line with fiber direction, according to SENIAM guidelines [17], and a ground electrode was attached to the subject's wrist. All electrode cables were tightly fixed to the skin to reduce any movement artifacts. Signals were acquired at a sampling frequency of 1 kHz.

2.4. Force plate recording

Ground reaction forces and center of pressure trajectories were recorded using a force platform (Bertec Corporation, Columbus, OH, USA) at a sampling frequency of 500 Hz.

3. Data analysis

3.1. EMG analysis

The raw data were high-pass filtered with a zero-phase shift, 6th-order Butterworth, with a cut-off frequency of 30 Hz to remove movement artifacts. Then, root mean square (RMS) values were taken with a moving window 50 ms. The data were time normalized using a piecewise linear temporal alignment [PLTA] method [18]. In this method, alignment was achieved using linear interpolation between events within the GI period. These events define boundaries for phases of GI (see Section 3.2). Then, the muscle activity in each phase was amplitude normalized to the mean of the respective muscle activity across the entire GI period, since in a pilot study it was found that normalization to the mean activity reduces the inter-subject coefficients of variation (inter-subject CVs) more than other methods (peak and rest normalization). The EMG data at 0% and each consecutive 1% were averaged across trials, generating an ensemble average EMG pattern for the subject and then were averaged across subjects, generating an across-subject ensemble average that represented an average EMG pattern for that group (Fig. 1). Subsequently, the mean amplitude of the normalized ensemble average during phases of GI was computed. Additionally, the intra-subject variability of the EMG trials was determined using the intra-subject coefficients of variation (intra-subject CVs). intra-subject CV is the square root of the mean squared error (MSE) across trials divided by the mean of EMG activities (x), (intra-subject CV = $\sqrt{\text{MSE}}/x$) [19]. Furthermore,