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# Functional implications of muscle co-contraction during gait in advanced age

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ABSTRACT

Older adults often exhibit high levels of lower extremity muscle co-contraction, which may be the cause or effect of age-related impairments in gait and associated falls. Normal gait requires intact executive function and thus can be slowed by challenging executive resources available to the neuromuscular system through the performance of a dual task. We therefore investigated associations between lower limb co-contraction and gait characteristics under normal and dual task conditions in healthy older adults (85.4 ± 5.9 years). We hypothesized that greater co-contraction is associated with slower gait speed during dual task conditions that stress executive and attentional abilities. Co-contraction was quantified during different phases of the gait cycle using surface electromyography (EMG) signals obtained from the anterior tibialis and lateral gastrocnemius while walking at preferred speed during normal and dual task conditions. Variables included the time difference to complete the Trail Making Test A and B (ΔTMT) and gait measures during normal or dual task walking. Higher co-contraction levels during the swing phase of both normal and dual task walking were associated with longer ΔTMT (normal: $R^2 = 0.25$, $p = 0.02$; dual task: $R^2 = 0.27$, $p = 0.01$). Co-contraction was associated with gait measures during dual task walking only; greater co-contraction levels during stride and stance were associated with slower gait speed (stride: $R^2 = 0.38$, $p = 0.04$; stance: $R^2 = 0.38$, $p = 0.04$), and greater co-contraction during stride was associated with longer stride time ($R^2 = 0.16$, $p = 0.03$). Our results suggest that relatively high lower limb co-contraction may explain some of the mobility impairments associated with the conduct of executive tasks in older adults.



## 1. Introduction

Aging is associated with a decline in mobility and balance, which may lead to falls and a loss of independent function [1]. One possible mechanism of these impairments in older adults is an increase in lower extremity muscle co-contraction. Muscle co-contraction is the simultaneous activation of agonist and antagonist muscle groups [2]. Older adults, compared to their younger counterparts, exhibit higher levels of lower extremity muscle co-contraction during walking [3] and standing balance [4]. In addition, older adults may unconsciously utilize co-contraction to stiffen joints in order to compensate for deteriorations in postural control and sensory processing [4]. However, high levels of co-contraction also appear to have negative consequences. Co-contraction increases energy expenditure and impedes movement [5], leading to a high cost of walking [6,7], fatigue, reduced physical performance, and falls [3,5,8]. Other potential negative effects include increased forces around joints causing cartilage and joint degeneration [9]. Therefore, it may be important to reduce lower extremity co-contraction in older adults in order to improve gait biomechanics and balance, and thereby reduce their risk of mobility disability and falls.

Recent studies have demonstrated that normal gait requires intact executive function [10] and lower extremity muscle activity can be altered by challenging the executive and attentional resources available to the neuromuscular system through the performance of a dual task [11]. The role of muscle co-contraction in this cognitive-motor interaction remains unknown, especially in older adults who rely heavily on co-contraction to maintain

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balance. Therefore, we examined the relationships between gait co-contraction and cognitive and physical performances in older adults and how cognitive stress can affect these relationships.

Previous studies have associated co-contraction with postural control during standing, revealing that higher levels of muscle co-contraction have a “deleterious” effect on the regulation of body sway [12]. However, there is a lack of information on lower limb muscle co-contraction during walking. Furthermore, balance control during walking is dynamic and phase dependent; different gait phases such as stance and swing appear to require different levels of cognitive and motor activation [13]. We therefore examined the patterns of muscle co-contraction not only during an overall gait cycle, but also during the different phases of gait.

We designed this study to determine the associations between lower limb co-contraction, functional performance, and gait under normal and dual task conditions in a group of very elderly adults living within supportive housing facilities – a rapidly enlarging, but often overlooked population that accounts for a large proportion of health care spending due to mobility disability. We hypothesized that greater lower limb co-contraction in this cohort is associated with poorer balance and slower gait speed, particularly during dual task conditions that stress executive control and attentional abilities.

## 2. Methods

A secondary analysis was performed on baseline data from a randomized controlled study [NCT01126723] of Tai Chi in elderly residents of senior housing facilities in the Boston area. Participants ranged from 71 to 95 years old. Exclusion criteria included the inability to stand or ambulate unassisted, the presence of symptomatic cardiovascular or respiratory disease, a history of myocardial infarction or stroke, self-reported painful arthritis, spinal stenosis, amputation, painful foot lesions or neuropathy, systolic blood pressure >160 or diastolic blood pressure >100 mm Hg, known abnormal cardiac rhythm or presence of a cardiac pacemaker, Parkinson's disease, metastatic cancer, or immunosuppressive therapy [14]. The study was approved by the Institutional Review Board of Hebrew SeniorLife and all participants provided written informed consent.

### 2.1. Protocol

All participants were assessed in their facility by trained research staff. The participants were interviewed to collect demographic, clinical, functional, and medication data. Physical and cognitive assessments included the Short Physical Performance Battery (SPPB), Berg Balance Scale (BBS), Activities-specific Balance Confidence (ABC) scale, and Trail Making Test (TMT). All participants then performed two randomized 90 s walks along an empty indoor hallway at: 1) normal walking speed (NW) and 2) normal walking speed while verbally performing serial subtractions of five from 500 (also known as a dual task walking condition (DT)).

Before the walking trials, surface electromyography (EMG) electrodes (Noraxon, Scottsdale, USA) were placed on the anterior tibialis and lateral gastrocnemius muscles. EMG signals were sampled at a frequency of 1500 Hz during the walking trials. The Noraxon equipment contained an EMG Sensor Data Acquisition system with a sample rate of 1500 Hz and a selectable low pass filter of 500 Hz. The EMG sensors had a 1st order high-pass filter set to 10 Hz +/− 10% cutoff. Wireless footswitches were placed on the heel and toe to record heel and toe contact and lift from the ground.

EMG signals were processed with MATLAB (Mathworks, Natick, USA) using a Butterworth bandpass fourth order filter of 20–400 Hz, full-wave rectification, and then a Butterworth lowpass fourth order filter of 6 Hz. A similar method was reported by Hallal and colleagues [8]. Walking stride was determined based on heel contacts recorded by the footswitches. Each stride EMG was resampled to 1000 points and a mean EMG signal of all the strides in the walk was obtained. The mean of the maximum EMG signal amplitude of each muscle group for all strides in a walking trial was also determined. The mean stride EMG for each muscle group was then normalized as a percentage of this mean maximum amplitude.

### 2.2. Measurement of muscle co-contraction and functional outcomes

EMG signals during each stride were averaged across all strides in a subject's walk to get an overall EMG stride pattern. Muscle co-contraction was quantified for this averaged stride. Muscle co-contraction was measured as the percentage of total muscle activity when antagonist muscle groups (the anterior tibialis and lateral gastrocnemius muscles) were simultaneously activated [3,15–17] and calculated using the following equation:

$$Percent\ cocontraction = 2 * \frac{common\ \ area\ \ A\,\&\,B}{area\ \ A\ +\ area\ \ B} * 100$$

Area A is the area under the EMG curve of muscle A, area B is the area under the EMG curve of muscle B, and the common area A & B is the area under the curves shared by both muscle A and muscle B during an average stride [3] (Fig. 1). The stance co-contraction was calculated from the heel strike to toe-off of the averaged stride EMG signal; the swing co-contraction was calculated from the toe-off to heel strike of the averaged stride EMG signal (Fig. 1).

Gait speed and phase times were determined for each 90 s walking trial under normal walking and dual task walking conditions. Gait speed was measured by dividing the total distance walked by the trial duration (90 s). Stride, stance, and swing times were calculated from the footswitch data. Stride time was measured as the time between each heel strike of the same foot. Stance time was measured as the time between the heel strike and toe-off of the same foot; this is the time during the gait cycle when the foot is in contact with the ground. The swing time was measured as the time between the toe-off and heel strike of the same foot; this is the time during the gait cycle when the foot is off the ground.

The TMT is a pen and paper test that is used to measure cognitive flexibility, processing speed, and set-shifting [18–20]. TMT contains two parts: TMT A and TMT B. TMT A required

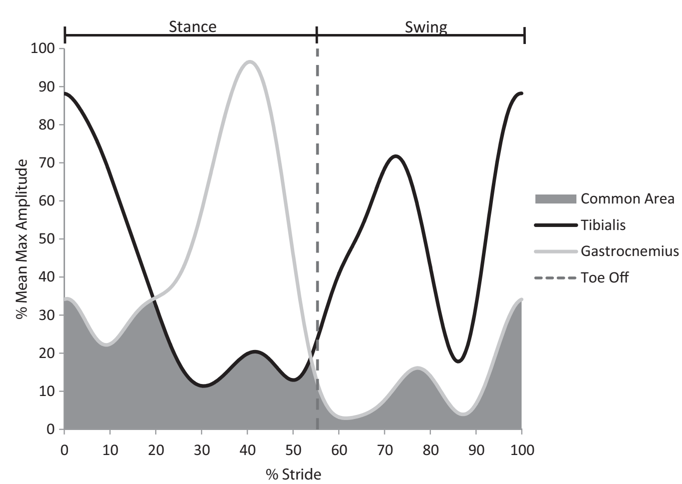


**Fig. 1.** Calculation of lower limb muscle co-contraction. The EMG signals of the anterior tibialis and lateral gastrocnemius muscles were extracted from each stride of each walking trial and normalized to 100%. The common area is the overlapping region under the curves of the EMG signals and represents the amount of muscle co-contraction. The toe off divides the stride into the stance and swing phases of the gait cycle.