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Soleus fascicle length changes are conserved between young and old adults at their preferred walking speed

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ABSTRACT

Older adults have been shown to naturally select a walking speed approximately 20% slower than younger adults. We explored the possibility that a reduction in preferred speed in older adults represents a strategy to preserve the mechanical function of the leg muscles. We examined this question in the soleus muscle in eight healthy young (25.8 ± 3.5 years) and eight healthy older adults (66.1 ± 2.3 years) who were paired so that their preferred speed differed by ~20%. Soleus muscle fascicle lengths were recorded dynamically using ultrasound, together with simultaneous measurements of soleus EMG activity and ankle joint kinematics while (a) older adults walked on a treadmill at a speed 20% above their preferred speed (speeds matched to the preferred speed of young adults), and (b) young and older adults walked at their preferred treadmill speeds. Analyses of mean muscle fascicle length changes revealed that, at matched speeds, older adults had a statistically different soleus fascicle length pattern compared to young adults, where the muscle's stretch-shorten cycle during stance was diminished. However, older adults walking at their preferred speed exhibited a more pronounced stretch-shorten cycle that was not statistically different from young adults. Conserving muscle length patterns through a reduction in speed in older adults may represent a physiologically relevant modulation of muscle function that permits greater force and power production. Our findings offer a novel mechanical explanation for the slower walking speed in older adults, whereby a reduction in speed may permit muscles to function in a mechanically similar manner to that of younger adults.

1. Introduction

One of the primary characteristics of gait in older adults (OA) is a reduction in preferred walking speed. Indeed, others have reported around 20% lower habitual walking speeds in healthy community dwelling older adults (1.0–1.3 m/s) compared to young adults (YA) (1.3–1.5 m/s) [1,2]. This age-related reduction in walking speed reflects a reduced motor capacity that may be linked to a greater incidence of falls [3] and a comparatively high metabolic rate in older adults for a given speed [4]. Examining the muscular mechanisms linked with a reduced walking speed in older adults may prove important for understanding and treating gait deficits associated with aging.

The underlying muscular mechanisms responsible for a reduced walking speed in OA compared to YA remain unclear. Previous literature has reported alterations in the structural and functional properties [5] of skeletal muscle and tendon linked with aging, such as a loss of muscle mass (sarcopenia), in particular in the lower limbs [6], reduced pennation angle and fascicle lengths [7] and lower tendon Young's modulus and stiffness [8]. These changes in muscle–tendon properties have important implications for the force and power capacity and efficiency of muscle during walking [9,10] and it is logical to assume that they contribute to the altered gait mechanics and control in OA [11]. Yet, exactly how these muscle–tendon characteristics influence speed selection in OA is not known. Is it possible, for instance, that a slower self-selected walking speed in OA represents a strategy to preserve the muscle's mechanical milieu at a level similar to those of YA? It has been proposed that humans and other species select speeds that lead to optimal

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function of skeletal muscles including minimization of force, mechanical power and energy expenditure [12–15]. A conservation of muscle function at preferred walking speeds across the age span would suggest that the slower speeds selected by OA may be a strategy to maintain optimal muscle mechanical function.

The focus of this study was to explore the aforementioned question by assessing how the soleus muscle functions (1) when OA walk at speeds matched to the faster preferred speed of YA and (2) during walking at preferred speeds in YA and OA. Specifically, we examined the differences in soleus muscle fascicle length changes between YA and OA given that this property is known to be intimately linked to muscle function [10]. We hypothesized that the soleus would lengthen less during the early part of stance (dorsiflexion) and shorten less during the latter part of stance and early swing when the muscle is active (plantar-flexion) in OA compared to YA when walking at matched speeds, similar to that reported for the stretch-shorten cycle of the medial gastrocnemius muscle [16], but that these differences would diminish when OA use their preferred walking speed. A corollary hypothesis was, therefore, that the muscle fascicle length change that occurs during stance in OA is greater when walking at their preferred speed compared to a faster-than-preferred speed. The soleus muscle represents a muscle of choice in addressing this question since it is amenable to dynamic *in vivo* imaging [17,18], because the plantar flexors, and the soleus in particular, have been identified as the primary source of mechanical work during gait [19], and finally due to the finding that the primary locus of gait impairment in OA is at the ankle plantar flexors [20].

2. Methods

2.1. Subjects

Sixteen healthy male subjects free from previous lower-limb injuries and musculo-skeletal disorders were recruited for this study. They were divided in two groups of eight by age: YA 25.8 ± 3.5 years, mean ± SD; OA 66.1 ± 2.3 years, mean ± SD. The YA group was composed of the same subjects recruited for a separate parallel study on soleus mechanics during walking and running [18]. Anthropometric characteristics including tibia length, weight and height were not statistically different between groups (0.41 ± 0.03 m, 1.75 ± 0.06 m and 70.3 ± 9.2 kg, mean ± SD for YA *vs* 0.40 ± 0.02 m, 1.74 ± 0.06 m and 72.1 ± 9.4 kg, mean ± SD for OA, respectively).

All subjects provided written, informed consent prior to participating in the study and all of the procedures were approved by the Human Research Ethics Committee at The University of Western Australia.

2.2. Self-selected walking speed and gait kinematics

Subjects performed over-ground and treadmill walking trials. Their preferred over-ground speed was assessed by timing participants walking 10 m along a carpeted surface. A minimum of 5 trials were used to assess mean preferred speeds. For the instrumented treadmill trials (Bertec, Columbus, OH, USA), preferred walking speed was assessed by permitting subjects to freely self-adjust the treadmill speed, starting at a speed 30% slower than their preferred over-ground speed and incrementing speed by 0.01 m/s until they reach their preferred speed. This procedure was repeated five times from which a mean self-selected treadmill speed was determined and used in subsequent tests. All participants attended a familiarization session on the treadmill prior to data collection.

Older adults were paired with younger adults so that the preferred walking speed between each pair differed by 19 ± 2%. Each subject was tested at their preferred treadmill speed, while OA were also tested at a speed 20% greater than their preferred speed, thus matching within 0.16 m/s the preferred speed of their paired YA. This permitted a case-matched comparison of the soleus muscle function (1) between preferred speeds in YA and OA and (2) between preferred speeds in YA and a 20% faster-than preferred speed in OA that matched the preferred speed of YA (thus controlling for relative speed in OA).

Three-dimensional gait analysis was performed on each subject during their treadmill walking trials. To-this-end, 22 retro-reflective markers were attached to the subject's pelvis and lower limb body landmarks and motion was collected using an 8-camera VICON MX motion capture system (Oxford Metrics, UK; 100 Hz). Marker placement and joint modeling were in accordance with the UWA lower body model [21]. All marker trajectories were filtered using a zero-lag 4th order low pass Butterworth filter with a 6 Hz cut-off frequency, which was defined using a custom residual analysis algorithm (MATLAB, The MathWorks Inc., USA). To determine the stance and swing phases, individual leg ground reaction forces were collected from the treadmill force plates at a frequency of 2000 Hz and synchronized with the motion data. Ankle joint angles were defined following the ISB guidelines [22] with negative values representing plantaflexion and positive values representing dorsiflexion (0° represents a neutral angle with the foot perpendicular to the tibia). Knee joint angles were defined with negative values representing extension and positive values flexion (0° knee fully extended).

2.3. Muscle length changes and activation

While the subjects walked on the treadmill, dynamic B-mode ultrasound images of the soleus muscle (Telemed, EchoBlaster128, Lithuania; image capture 70–80 Hz) were collected using a 7.5 MHz linear array low-profile probe (transducer field width = 60 mm) attached to their right calf using an elastic bandage (Elastoplast Sport, Beiersdorf, Australia). The probe placement was standardized across subjects using a location over the medial gastrocnemius (MG) where the MG muscle–tendon junction was visible in the distal portion of the scan [18]. Soleus muscle fascicle lengths were measured in the mid-region of the ultrasound scan and calculated as the distance between the fascicle endpoints, defined as the intersection of the fascicle with the superficial and deep aponeurosis. Fascicle endpoints were digitized manually using ImageJ software [23] by two investigators (one investigator analyzed all OA data). The digitized data were filtered using a 4th order zero-lag 5 Hz low-pass Butterworth filter (MATLAB, The MathWorks, Natick, MA). An analysis of muscle fascicle lengths across the stride on a sub-set of trials from all YA participants indicated minimal and non-significant differences between investigators; cross correlations were 0.97–0.99 with zero lag and the average difference in length from all data points was 0.9 mm. A rigid cluster composed of three non-collinear retro-reflective spherical markers was fixed to the ultrasound probe to verify that its movement relative to tibia was minimal during walking. The probe movement relative to the tibia across the stride was within 5.2°, 2.8° and 4.9° for movement in the tibia's sagittal plane, frontal plane and coronal plane, respectively. Fascicle lengths were normalized by dividing them by the length of the resting fascicle at 8° of dorsiflexion. This joint posture was selected as it represents the mean joint angle corresponding to the soleus muscle slack length (the length above which passive forces first appear) in YA [18]. Resting fascicle lengths were recorded with subjects seated in a dynamometer (Biodex, M3, Shirley, NY, USA)