Exploring the Functional Boundaries and Metabolism of Triceps Surae Force-Length Relations during Walking

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Introduction

Older adults exhibit reduced ankle push-off intensity and higher metabolic energy costs during walking than younger adults [1]. During walking, triceps surae (TS) muscle fascicles in young adults operate near the peak of their force-length (F-L) relation, which acts to maximize force capacity (i.e., the maximum possible force at a fascicle length) and minimize the active muscle volume necessary to meet force demands [2]. However, older adults tend to operate at shorter lengths that are associated with higher metabolic costs in isolated contractions [3]. Theoretically, increasing or decreasing activation should be capable of steering muscle fascicles to shorter or longer lengths, respectively, with implications for force capacity, active muscle volume, and thus metabolic energy cost. However, the relations between muscle activation, muscle mechanics, and whole-body metabolic energy cost in walking have yet to be fully elucidated. There are two translational implications that motivate this work. First, energetics models informed by such relations may help guide the personalized prescription of assistive devices. Second, clarifying the local muscle neuromechanical determinants of walking metabolism in young adults might provide a mechanistic framework to elucidate those in older adults. Thus, the purpose of this study was to establish cause-and-effect relations between volitional changes in TS activation prescribed using biofeedback and walking metabolic cost, muscle mechanics, and force capacity. We hypothesized that (1) increased TS activation would increase metabolic cost via shorter muscle fascicle operating lengths and thus reduced force capacity and that (2) decreased TS activation would decrease metabolic cost via longer muscle fascicle operating lengths and thus increased force capacity.

Methods

26 young adults (23±4 yrs., 12F/14M) walked on an instrumented treadmill at 1.25 m/s using electromyographic (EMG) biofeedback to match targets corresponding to ±20 and ±40% TS (medial gastrocnemius [MG] and soleus) activation during push-off (late stance). B-mode ultrasound imaged subjects’ MG. Subjects also performed maximal voluntary isometric plantar flexor contractions in a dynamometer at 5 joint angles to estimate individual F-L relations. We have thus far analyzed muscle data in n=9 participants using deep learning software [4]. We report net metabolic power, TA activation, MG force, force capacity, and MG fascicle lengths, averaged from the last two minutes of each walking trial, analyzed using repeated measures correlations [5].

Results and Discussion

In partial support of Hypothesis 1, subjects increased net metabolic power by up to 95% when targeting higher than normal TS activation (p<0.01; Fig. 1A). However, contrary to Hypothesis 2, they also increased net metabolic power by up to 23% when targeting lower than normal TS activation. At the instant of peak MG force (i.e., tpeak), MG fascicle length was 6% shorter (r=-0.60, p<0.001) and MG force was 5% larger (r=0.50, p=0.002) on average when targeting +40% TS activation. Not surprisingly, net metabolic power positively correlated with peak MG force (r=0.35, p=0.04; Fig. 1B). However, as hypothesized, and consistent with the association between activation and operating length, net metabolic power most strongly correlated with shorter fascicle lengths at tpeak (r=-0.55, p=0.001; Fig.1C). Consistent with prior work in isolated contractions [3], those results suggest that shifts to shorter fascicle lengths may mediate activation-induced increases in metabolic cost. More surprisingly, these determinants (i.e., MG force and fascicle length at tpeak) were not themselves well correlated (p=0.17; Fig. 1D). Finally, force capacity at tpeak and net metabolic power tended to positively correlate (r=0.32, p=0.06), alluding to higher metabolic cost of operating the MG at higher force capacity (Fig. 1E). This specific outcome is unlikely to apply to older adults who habitually operate further down the ascending limb.

Significance

We interpret our findings thus far to suggest that: (1) volitional changes in TS activation augment the metabolic cost of walking via relatively predictable alterations in muscle force and operating lengths but (2) activation-induced changes in muscle force and length, and their respective contributions to metabolic cost, may not be directly interdependent during complex, functional activities such as walking.

Acknowledgments

Supported by a grant from NIH (R01AG058615).

References

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Figure 1: (A) Metabolic responses to altered triceps surae activation in walking (n=26). *significant pairwise difference compared to normal walking. (B-D) Repeated measures correlations between muscle dynamics and energetic outcomes, where each color represents an individual subject (n=9). (E) MVIC MG F-L relation compared to physiological loading during walking conditions, averaged across subjects (n=9).