BJMB
Brazilian Journal of Motor Behavior

Current Opinion

The need for systems-based biomechanics to understand the causes and consequences of altered muscle-tendon unit function in elderly gait

JASON R. FRANZ[1] | TAIJA FINNI[2] | KOTA Z. TAKAHASHI[3] | BENEDICTE VANWANSEELE[4] | FRIEDL DE GROOTE[4]

[1] Joint Department of Biomedical Engineering, University of North Carolina at Chapel Hill and North Carolina State University, Chapel Hill, NC, USA.
[2] Faculty of Sport and Health Sciences, Neuromuscular Research Center, University of Jyväskylä, Finland.
[3] Department of Biomechanics, University of Nebraska Omaha, Omaha, NE, USA.
[4] Human Movement Biomechanics Research Group, Department of Movement Science, KU Leuven, Belgium.

Correspondence to: Jason R. Franz, Ph.D.
10206C Mary Ellen Jones Building, CB 7575, Chapel Hill, NC 27599
Phone: (919) 966-6119; Fax: (919) 966-2963
email: jrfranz@email.unc.edu
https://doi.org/10.20338/bjmb.v16i1.266

ABBREVIATIONS

PA	Plantar aponeurosis
PIMs	Plantar intrinsic muscles

PUBLICATION DATA
Received 31 10 2021
Accepted 30 11 2021
Published 01 03 2022

KEYWORDS: Achilles | Plantar flexor | Ankle | Foot | Neuromechanics | Older | Age

Active muscles, aided by series elastic tendons, power us through our activities of daily living. When the integrity of neural excitation, muscle mechanics, and tendon energy storage and return is preserved, their interaction is precisely tuned for effective and economical locomotion. Because muscle-tendon units spanning the ankle perform roughly 50% of the mechanical power needed to walk, age-related reductions in ankle power output have been one of the most prevailing biomechanical changes reported for elderly gait. The implications of reduced ankle power output among older adults include slower walking speeds and higher metabolic energy costs (i.e., worse “gas mileage”) than younger adults, reducing independence and accelerating fatigue. As biomechanists, we are generally trained to be reductionists; to leverage our understanding of neural control and musculoskeletal tissue mechanics to explain complex observational outcomes using changes we ascribe to constitutive components. We have for more than two decades used this reductionist approach to attribute age-related biomechanical changes to reduced ankle power output, and further to lesser plantarflexor muscle volume and strength.

This ankle-centric perspective has been important and extraordinarily influential. Yet, interventions designed to strengthen the plantarflexor muscles have generally failed to improve push-off power or walking economy. Recent work from our research groups and others has moved beyond muscle alone to improve our appreciation for series elastic tendon in precipitating age-related changes in plantarflexor muscle-tendon unit function [1-4]. However, older adults face substantial and, in many cases, inter-dependent declines in the structure, morphology, composition, and function of nearly all neuromusculoskeletal tissues and processes responsible for powering locomotion across all lower extremity joints. Thus, as we reflect on our current state of knowledge and opportunities for innovation and impact, we use this brief editorial to motivate a shift toward systems-based biomechanics (i.e., that which explicitly considers the interaction between relevant subsystems) in studies into the causes and consequences of altered muscle-tendon unit function in elderly gait. As a motivating example, we first expand our focus to include muscle-tendon function regulating performance of the foot-ankle complex before further expanding to discuss the more proximal implications of those changes.

The human foot plays a critical role in providing leverage to assist push-off in walking historically attributed solely to the plantarflexor muscles. Growing evidence suggests that foot stiffness regulates this leverage to meet the demands of walking through a complex combination of passive tension via the plantar aponeurosis (PA) and active contraction of the plantar intrinsic muscles (PIMs) [5]. Unfortunately, older adults exhibit reduced PIM size and strength, a thicker but more compliant PA, and a fat pad that dissipates more energy when compressed. Some researchers have started to suggest that those age-related changes undermine foot stiffness regulation during walking [6]. Moreover, anatomical studies suggest that a structural connection between the Achilles tendon and plantar aponeurosis may facilitate force transfer between the foot and ankle during walking. Indeed, some of our most recent ultrasound imaging data in young adults are highly consistent with this phenomenon [7]. However, cadaveric data and magnetic resonance imaging allude to age-related calcification of this contiguous tendinous structure and loss of a potentially important structural transmission system (e.g., [8]). Moreover, peripheral sensory changes due to aging can alter control of muscle and tendon mechanics spanning all lower extremity joints. In the case of the foot and ankle, understanding the interaction between such subsystems is critical because distal limb structures provide leverage critical not only for walking performance and economy, but also for stability. Shifting focus beyond ankle muscle-tendon units alone paves the way for feasible and cost-effective interventions and/or devices to modify foot structure and function in aging, such as carbon fiber insoles and stretching, strengthening, neuromuscular retraining, or even functional electrical stimulation of the PIMs and their associated tendinous structures. Moreover, this logical step toward ensuring that we include foot mechanics in our studies of muscle-tendon unit changes due to aging improves our ability to understand the time course of those changes and identify biomechanical phenotypes relevant to the personalized and more targeted prescription of these interventions.

However, even this shift from ankle-centric to foot-inclusive perspectives perpetuates the use of reductionist biomechanics and continues to oversimplify the complexities of the neuromusculoskeletal challenges faced by older adults. For example, in the study of altered muscle-tendon unit function in elderly gait, we collectively hypothesize that systems-based biomechanics will reveal that distal neuromusculoskeletal changes and interventions thereof precipitate a cascade of more proximal changes relevant to walking performance, economy, and stability in older adults. For example, in two independent studies from our groups [9,10], model predictions suggest that an insufficient push-off from the foot and ankle yields a redistribution to more proximal muscle-tendon units which, due to their relatively long muscle fascicles and short tendons, reduces walking economy in older adults. Those efforts highlight the potential for combined experimental and computational approaches to accelerate our understanding of cause-effect relations and the more rapid evaluation of novel interventions. However, the broader impacts of these approaches will be best realized in the hands of inter-disciplinary teams, including expertise in whole-body neuromechanics and motor control and with focus on the interaction between relevant subsystems. Ultimately, biomechanists must preserve the strengths of our reductionists practices to identify basic principles and mechanisms. However, only with team science approaches that shift focus to systems-based biomechanics will we accelerate discoveries into the causes and consequences of altered muscle-tendon unit function in elderly gait.

REFERENCES

1. Franz JR, Thelen DG. Depth-dependent variations in Achilles tendon deformations with age are associated with reduced plantarflexor performance during walking. *J Appl Physiol.* 2015;119(3):242-9. doi: 10.1152/japplphysiol.00114.2015
2. Krupenevich RL, Beck ON, Sawicki GS, Franz JR. Reduced achilles tendon stiffness disrupts calf muscle neuromechanics in elderly gait. *Gerontology*. 2021;16:1-11. doi: 10.1159/000516910
3. Stenroth L, Sillanpaa E, McPhee JS, Narici MV, Gapeyeva H, Paasuke M, et al. Plantarflexor muscle-tendon properties are associated with mobility in healthy older adults. *J Gerontol A Biol Sci Med Sci*. 2015;70(8):996-1002. doi: 10.1093/gerona/glv011
4. Delabastita T, Bogaerts S, Vanwanseele B. Age-related changes in achilles tendon stiffness and impact on functional activities: A Systematic Review and Meta-Analysis. *J Aging Phys Act*. 2018;1-12. doi: 10.1123/japa.2017-0359
5. Farris DJ, Birch J, Kelly L. Foot stiffening during the push-off phase of human walking is linked to active muscle contraction, and not the windlass mechanism. *J R Soc Interface*. 2020;17(168):20200208. doi: 10.1098/rsif.2020.0208
6. Krupenevich RL, Ray SF, Clark WH, Kashefsky HE, Takahashi KZ, Franz JR. Effects of age and locomotor demand on foot mechanics during walking. *J Biomech*. 2021;123:110499. doi: 10.1016/j.jbiomech.2021.110499
7. Krupenevich RL, Takahashi KZ, Kashefsky HE, Franz JR. Interaction between soleus and plantar intrinsic muscle length points to a structural transmission between the human foot and ankle, in American Society of Biomechanics Annual Meeting. 2021: Atlanta, GA.
8. Snow SW, Bohne WH, DiCarlo E, Chang VK. Anatomy of the Achilles tendon and plantar fascia in relation to the calcaneus in various age groups. Foot Ankle Int, 1995;16(7):418-21. doi: 10.1177/107110079501600707
9. Pimentel RE, Pieper NL, Clark WH, Franz JR. Muscle metabolic energy costs while modifying propulsive force generation during walking. Comput Methods Biomech Biomed Engin. 2021;24(14):1552-1565. doi: 10.1080/10255842.2021.1900134
10. Delabastita T, Hollville E, Catteau A, Cortvriendt P, De Groote F, Vanwanseele B. Distal-to-proximal joint mechanics redistribution is a main contributor to reduced walking economy in older adults. *Scand J Med Sci Sports*. 2021;31(5):1036-1047. doi: 10.1111/sms.13929

Citation: Franz JR, Finni T, Takahashi KZ, Vanwanseele B, Groote F. (2022). The Need for Systems-Based Biomechanics to Understand the Causes and Consequences of Altered Muscle-Tendon Unit Function in Elderly Gait. *Brazilian Journal of Motor Behavior*, 16(1):4-7.

Funding: There was no funding for this study.
Competing interests: The authors have declared that no competing interests exist.
DOI: https://doi.org/10.20338/bjmb.v16i1.266