Do differences in muscle efficiency explain the elevated energy cost of joint work redistribution?

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Summary

In this study, we measured the energy cost of the knee extensors and plantar flexors to perform positive mechanical work and compared that to the magnitude of internal muscle work performed. Participants (n=6) performed mechanical joint work on a dynamometer while we measured whole-body energy cost to calculate mechanical efficiency. We also quantified internal muscle work using ultrasonography to calculate muscle efficiency. This allowed us to ask whether mechanical efficiency was related to muscle efficiency. We found that mechanical efficiency was higher at the knee compared to at the ankle, whereas muscle efficiency was similar across joints. These results refute the notion that the elevated energy cost seen with joint work redistribution from distal to proximal joints is a result of higher mechanical efficiency of distal plantar flexors compared to proximal knee extensors.

Introduction

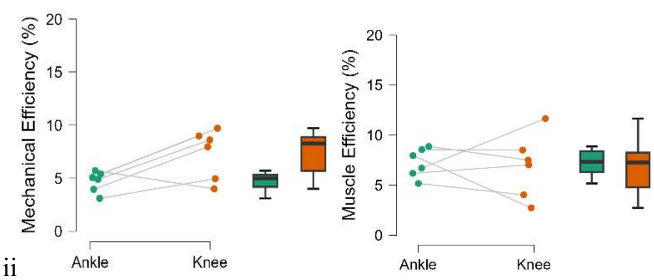
Mechanical joint work shifts from distal to proximal joints during prolonged running, elevating the metabolic cost of running [1]. This elevated metabolic cost is thought to be because muscles crossing the knee are assumed to be less efficient at producing mechanical work compared to muscles crossing the ankle [1]. This study sought to quantify the mechanical efficiency of the knee extensors (KE) and plantar flexor (PF) muscles while performing mechanical joint work. We simultaneously quantified muscle efficiency using a combination of dynamometry and ultrasonography. These data would allow us to determine a potential mechanism for elevated energy cost during prolonged running, when joint work is redistributed from distal to proximal joints.

Methods

6 recreationally active adults (22±2 years, 174±9 cm, 66.1±7.1 kg) performed positive mechanical work (W_{mech}^{+}) of the PF and the KE muscles, respectively, on an isokinetic dynamometer. W_{mech}^{+} was done by having participants perform 120 cyclic contractions at 0.5 Hz, while targeting 50% of maximum ankle plantar flexion moment over a angular displacement of 50% of participant-specific joint range of motion. Cyclic contractions were performed in both PF and KE in a random order. Metabolic energy cost (E_{met}) was quantified from whole-body indirect calorimetry. Positive internal muscle work (W_m^{+}) was calculated from the product of fascicle shortening of Gastrocnemius Medialis (GM) and Vastus Lateralis (VL) using ultrasound imaging and muscle forces, estimated from measured joint moments, moment arms and the relative contributions of GM and VL to total PF and KE force, respectively [3]. Mechanical (ε_{mech}^{+}) and muscle (ε_m^{+}) efficiencies were calculated as the ratio of W_{mech}^{+} to E_{met} and W_m^{+} to E_{met}, respectively. Participant-specific velocity associated with peak ε_m^{+} for each muscle group was determined from fascicle force vs. shortening velocity relations [2]. Muscle shortening velocities during cyclic contractions were compared to this optimal velocity across KE and PF muscles.

Results and Discussion

Cycle frequency was similar across joints (PF: 0.56±0.05 Hz vs KE: 0.52±0.03 Hz, *p*=0.11). Target moment was significantly lower in PF (57±16 Nm) compared to KE (76±35 Nm, *p*=0.04). W_{mech}^{+} per cycle was significantly lower in PF (19.6±2.4 J) compared to KE (32.8.6±4.3 J, *p*=0.01). ε_{mech}^{+} was significantly greater in KE (7.3±2.3%) compared to PF (4.7±1.0%, *p*=0.001). Both W_m^{+} and E_{met} were significantly higher in VL compared to GM (*p*<0.016). Conversely, ε_m^{+} was similar across muscles (7.2±1.5% for GM and 6.9± 3.2% for VL, p=0.693, Figure 1).



ii

Figure 1: Mechanical (left) and muscle (right) efficiencies across ankle (green) and knee joints (orange).

VL (0.34±0.07 V/V_{max}) and GM (0.35±0.04 V/V_{max}) shortening velocities were similar (*p*=0.718) but faster than the shortening velocity associated with peak ε_m^{+} (*p*<0.002).

Conclusions

While positive mechanical work and mechanical efficiency was higher in KE. muscle efficiency was similar between VL and GM muscles. These results therefore do not support the notion that differences in muscle efficiency between KE and PF are the cause for an elevated metabolic cost when joint work is redistributed from distal to proximal joints, such as seen in prolonged running.

Acknowledgments

We acknowledge the support of the *Natural Sciences and Engineering Research Council of Canada (NSERC)* and *Sigma Xi.*

References

[1] Sanno et al. (2018). *Med Sci Sports Ex.* ***50*****(12)**,2507
[2] Bohm et al. (2021) *Proc R Soc B* ***288***:20202784.
[3] Fukunaga et al. (1992) *J. Ortho research* ***10*****(6),** 926–934.