From Muscle-Tendon to Whole-Body Dynamics: Towards a Multi-Scale Empirical Understanding of Human Movement Biomechanics

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A grand challenge in the field of biomechanics is to develop a cohesive, multi-scale understanding of human movement that links muscle-tendon, joint and whole-body dynamics. Empirical and computational methods have been developed to estimate biomechanics at a single scale (e.g., joint work), and in some cases to bridge between scales (trans-scale, e.g., to link muscle-tendon to joint work). However, a critical challenge remains to overcome: biomechanical estimates at one scale often do not agree quantitatively with estimates at another. For instance, using traditional 3D analysis methods, net mechanical work computed about the joints when a person climbs a set of stairs overestimates the work performed to raise the center-of-mass against gravity [1]. Even for level ground walking, mechanical work discrepancies of 25-35% have been observed [2]. Likewise, muscle-tendon work derived from ultrasound and force transducers may not be fully consistent with joint work estimated from inverse dynamics. It is critical to resolve these trans-scale discrepancies in order to develop a comprehensive, multi-scale understanding of movement. This abstract summarizes our recent progress towards coalescing multi-scale estimates.

In one study we integrated various empirical estimates of work and energy in order to synthesize whole-body dynamics (from Fenn, and Cavagna traditions) with joint- and segment-level kinetics (from Braune & Fischer, and Elftman traditions). In a second study we focused on developing and validating an EMG-driven musculoskeletal analysis to partition joint kinetics into contributions from individual muscle-tendon units. We are now working to parse muscle fiber vs. tendon work by integrating ultrasound with motion capture and force measures.

We demonstrated, for the first time, that joint-segment estimates could reliably capture whole-body gait dynamics (work done on/about the center-of-mass, [1]). We found that the key to resolving trans-scale work discrepancies was using 6 degree-of-freedom (rotational and translational) analysis of the hip, knee, ankle and foot (Fig. 1); which revealed that the hip and foot contribute more to human gait kinetics than conventionally estimated. Next, we demonstrated that a new EMG-driven analysis could reproduce inverse dynamics sagittal ankle power with high fidelity during walking (R^2=0.98), while providing estimates of individual muscle-tendon unit contributions. Future work remains to validate this approach for different joints, activities, and additional planes. The next challenge is to parse muscle fiber vs. tendon work. We will discuss ongoing efforts (using ultrasound) to quantify muscle-tendon length changes and forces during movement, and to synthesize these with our multi-scale biomechanical understanding.

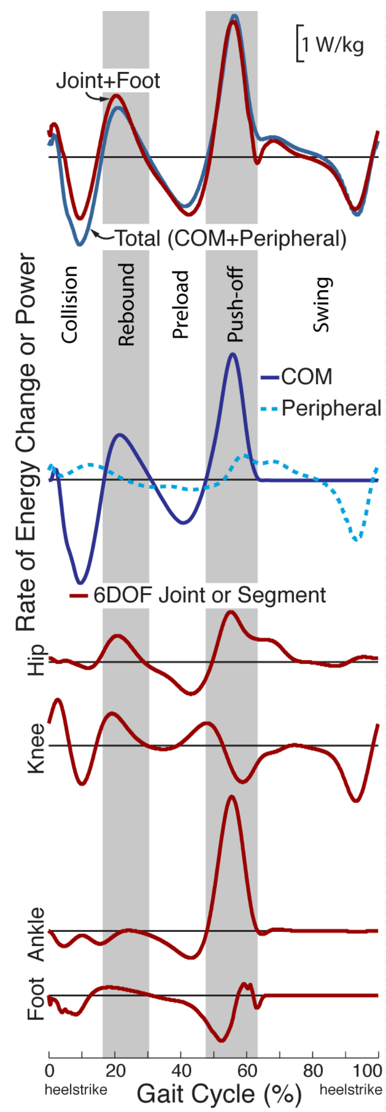

Figure 1: Energy Accounting analysis links joint and segment contributions to total energy changes of and about the center-of-mass (COM and Peripheral) [2].

References

1. Duncan et al. (1997). *Gait & Posture*. 5: 204-210.
2. Zelik KE, Takahashi KZ and Sawicki GS (2015). *J Exp Biol*. 218(6): 876-86.

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