Functional Interaction between Ankle Joint and Distal Foot Structures during Locomotion

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1 Motivation

The ankle joint muscle-tendon structures generate more mechanical energy than any other lower extremity joints during locomotion [1]. In an opposing manner, the 'distal foot' structures (e.g., foot muscles and plantar soft tissue) collectively absorb energy during foot-floor contact [2]. While the energy generation of the ankle joint is important for supplying the body with forward momentum [3], the biological role of the seemingly counteracting distal foot energetics is unclear. Therefore, the overall goal of this research is to explore the functional interaction between the ankle joint and distal foot structures during locomotion using a combined theoretical and experimental framework.

2 State of the Art

Over the last few decades, numerous 'bio-inspired' wearable ankle-foot devices have emerged – ranging from a motorized ankle-foot prosthesis [4], to a controlled energy storage and release exoskeleton [5]. Yet, these devices have specifically targeted the exclusive role of the natural ankle joint mechanics. We expect that exploiting the biological ankle joint-distal foot interaction will further advance the designs of wearable ankle-foot devices.

3 Own Approach

To elucidate the likely complex interplay between ankle joint and distal foot structures, we will utilize both modeling and experimental approaches. We are developing a simple musculoskeletal model, consisting of a single Hill-type muscle acting at an ankle joint (i.e., soleus muscle-tendon unit) and a rotational spring and damper acting distally at a toe joint. The model will systematically modify the toe joint spring and damping properties during a simulated gait movement to analyze the muscle-tendon level compensations at the ankle joint.

Experimentally, we will examine the ankle joint-distal foot interactions by modifying the mechanical properties of the distal foot structures (e.g., varying spring and damping via a wearable foot device), and by altering the mechanical demands of locomotion (e.g., varying gait speeds and slopes). Concurrent analyses will include joint/segment level mechanics, *in-vivo* muscle-tendon level dynamics of the ankle plantarflexors, and metabolic energy estimates.

4 Current Results (*Experimental Data*)

Across four walking speeds (in statures/s), increased speed led to an increased magnitude of mechanical energy generation by the ankle joint (Figure A), and an increased magnitude of energy absorption by the distal foot structures (Figure B). While the joint/segment level energy profiles reveal opposing functions, the influence of distal foot properties on the underlying muscle-tendon dynamics of the ankle plantarflexors is unknown.

Figure A)

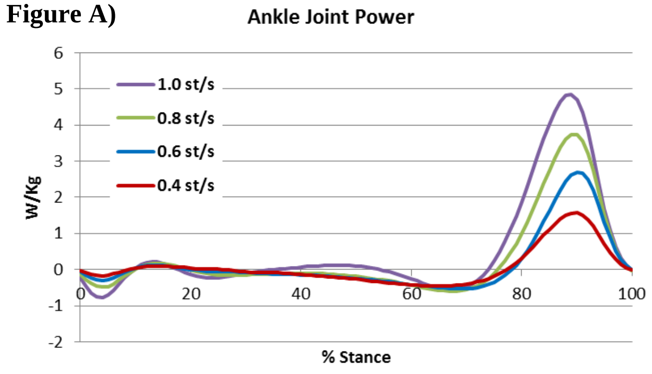
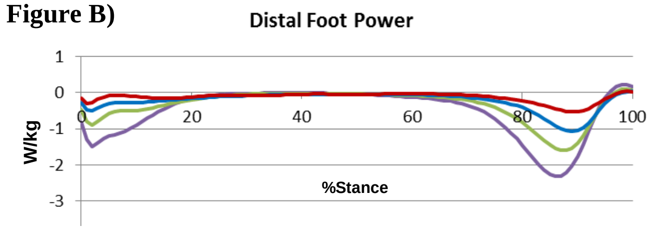


Figure B)



5 Best Possible Outcome

Our research will contribute to a more complete understanding of the ankle-foot dynamics during locomotion. This knowledge will form the foundation for analyzing normal and pathological ankle-foot mechanics, and will lead to new insights for 'bio-inspired' wearable devices.

References

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[5] Wiggin et al. (2012) IEEE Int Conf Rehabil Robot