RESOLVING THE DEBATE: ANKLE PUSH-OFF DURING HUMAN WALKING CONTRIBUTES TO ACCELERATING BOTH THE SWING LEG AND THE CENTER-OF-MASS

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INTRODUCTION

Muscle–tendon units about the ankle joint generate a burst of positive power during the step-to-step transition in human walking, termed ankle push-off. However, the functional role of this push-off has been debated for decades, without scientific consensus. One school of thought has emphasized that this push-off power primarily contributes to accelerating the swing leg, while another school of thought has emphasized the effect on accelerating the body's center-of-mass (COM). There is reasonable empirical evidence to support each perspective, yet these descriptions appear *prima facie* to be in contradiction. The purpose of this work was to unify these seemingly polarized perspectives, and to show that these two possibilities are not mutually exclusive. We demonstrate that both descriptions are valid, and that the principal means by which ankle push-off affects COM mechanics is by a localized action that increases the speed and kinetic energy of the push-off limb. This abstract summarizes findings from our recent JEB Commentary [1].

METHODS

We reanalyzed level-ground walking data from [2], and computed several energy change and work estimates. First, we partitioned Total (whole-body) mechanical energy change into (a) energy changes due to the motion of the body's COM (using individual limbs method), plus (b) energy changes due to motion relative to the body's COM, which we termed Peripheral energy change. Second, we used an alternative way to partition Total mechanical energy change, into contributions from individual body segments and segment groups. For simplicity, we identified three segment groups: (a) push-off limb (trailing limb thigh, shank, and foot), (b) leading limb and (c) head-arms-trunk. Third, we computed how much of the push-off limb segmental energy change also appears as COM energy change during the push-off phase of gait.

RESULTS AND DISCUSSION

We found that under normal walking conditions (1.4 m/s), the vast majority (>85%) of push-off limb energy change contributes directly to COM energy change during push-off (Fig. 1). This observation is consistent across gait speed: >80% at 0.9 m/s , and >90% at 2 m/s. Work provided by ankle push-off manifests principally as increased speed of the push-off limb. The push-off limb increases in segmental kinetic energy with little energy transferred to the torso through the hip. But because the limb is included in body COM computations, this localized segmental acceleration also accelerates the COM, and most of the segmental energy change also appears as COM energy change. Thus, ankle push-off primarily contributes to accelerating both the swing leg and the COM during human walking. It is, in fact, the same energy change in both the push-off limb and the COM, with only a small part of limb energy being purely Peripheral (non-COM). Thus, interpretation of ankle mechanics should abandon an either-or contrast of leg swing vs. COM acceleration. Instead, ankle function should be interpreted in light of both mutually consistent effects. This unified perspective informs our fundamental understanding of the role of ankle push-off, and has implications for the design of clinical interventions (e.g. prostheses, orthoses) that restore function to individuals with disabilities.

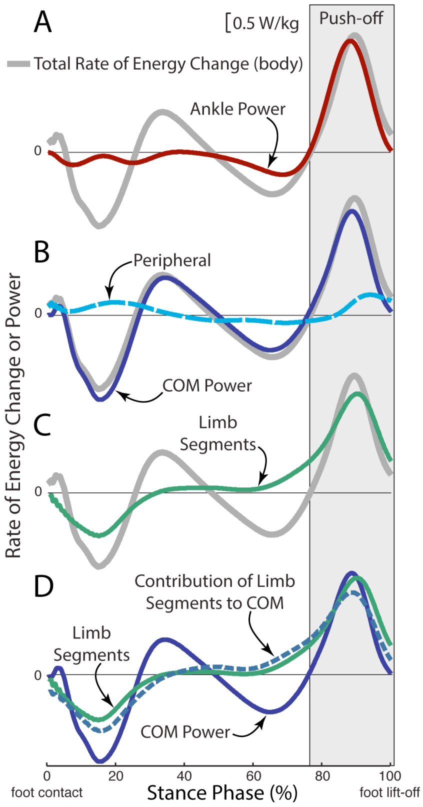

Fig 1. Estimates of the rate of energy change ($\dot{E}$) and power (work rate) for an individual limb during human walking. (A) Ankle power (red line) overlaid on Total $\dot{E}$ (gray line, due to motion of and about the COM). (B) The majority of Total $\dot{E}$ during Push-off (gray box) is attributable to COM $\dot{E}$ (blue line), and smaller contributions are from Peripheral $\dot{E}$ (due to segmental motion relative to the COM, dashed cyan line). (C) The majority of Total $\dot{E}$ during Push-off is also attributable to segmental $\dot{E}$ from the push-off limb (green line). (D) The contribution of limb segmental $\dot{E}$ (green) to overall COM $\dot{E}$ (solid blue) is shown here in dashed blue. During Push-off, the majority of the limb $\dot{E}$ goes into this contribution (dashed blue), which in turn accounts for the majority of COM $\dot{E}$. Data depicted are inter-subject means at 1.4 m/s (*N*=9, [1,2]).

CONCLUSIONS

The debate whether push-off from ankles
powers leg swing or COM rankles.
    But a unified view
    indicates both are true:
two effects inextricably tangled.

REFERENCES

1. Zelik & Adamczyk, *J Expt Biol*, 2016.
2. Zelik, Takahashi & Sawicki, *J Expt Biol*, 2015