

Quit being so rigid: How traditional gait analysis assumptions confound our understanding of ankles, feet, footwear and biomechanics

Karl E. Zelik and Eric C. Honert
Vanderbilt University, Nashville, TN, USA

Introduction

The human foot is traditionally modeled as a single rigid-body segment in gait analysis studies. This rigid-foot assumption dates back over 100 years, and is still commonly-used in contemporary gait analysis. However, mounting evidence indicates that structures within the foot (e.g., heel pad, arch, muscles) perform considerable mechanical work during locomotion; and these work sources are overlooked when the foot is modeled as rigid. There has been a lack of clarity in the literature around key questions: should we model the foot as a single rigid-body segment, is this adequate for addressing scientific questions that are commonly explored in gait analysis studies, or adequate for informing the design, prescription and evaluation of interventions (e.g., prostheses, footwear)? Here we present experimental evidence and analytical arguments suggesting that, in many cases, treating the foot as rigid (and thus neglecting power due to deformation/motion within the foot) is inadequate for scientific studies and can mislead clinical gait analysis and misinform the design or prescription of interventions.

Purpose of the study

The purpose of this work was two-fold. 1) To use case study examples in conjunction with analytical arguments and previously-published evidence to summarize *why* the foot should not be assumed rigid, and instead why power due to motion and deformation within the foot should be estimated in gait

analysis studies. 2) To address *how* to experimentally estimate (and interpret) foot and ankle power using less conventional inverse dynamics methods. Key implications will be discussed related to footwear design and evaluation.

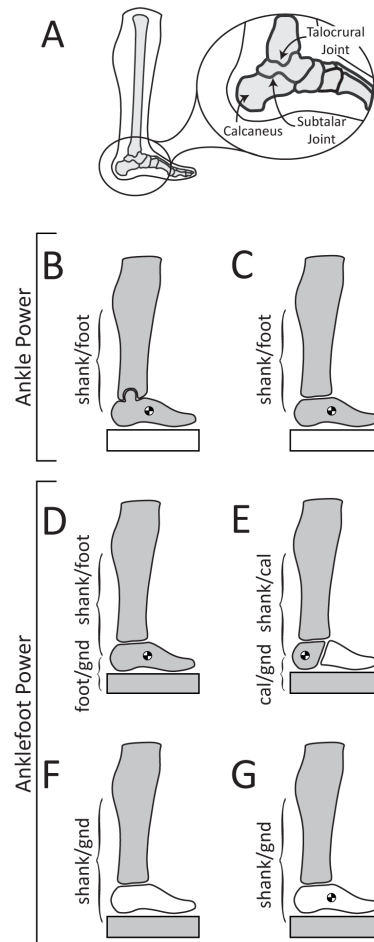


Figure 1. The physiological ankle joint complex (A) and various methods available to compute ankle (B-C) and combined anklefoot (D-G) power (Zelik & Honert 2018).

Methods

We performed two gait analysis case studies that exemplify how and why to compute foot power, and implications on ankle power estimates; then discuss and interpret these results in the context of broader literature. The first study was on a healthy control subject, and the second was on a person with transtibial amputation walking on different prosthetic feet. We compared and contrasted various estimates of ankle power, foot power, and combined ankle plus foot (termed anklefoot) power (Fig. 1). See Zelik & Honert 2018 for details on calculations.

Results

In the first study, we found that treating the entire foot as a rigid body (Fig. 1B-D) tends to overestimate ankle power. For instance, traditional ankle power (which assumes a rigid foot, Fig. 1B) was 77% higher than a power estimate that only assumes the calcaneus is rigid (Fig. 1E) during barefoot walking, and 20% higher during shod walking (Fig. 2). These case study findings are corroborated by multi-subject studies using multi-segment foot models, which reported that traditional methods overestimated peak ankle power by 27-74%.

In the second study, results indicated that modeling the entire foot as rigid can skew comparisons between prosthetic feet. For instance, when comparing two different prosthetic feet, using the conventional ankle power estimate (Fig. 1B) resulted in the first prosthesis having peak power 42 W higher than the second. However, when applying a more complete anklefoot estimate (Fig. 1F) we observed the opposite trend: the second prosthesis had peak power 56 W higher than the first.

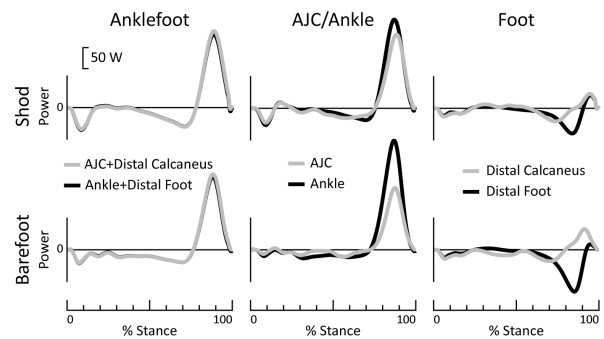


Figure 2. Power computed relative to rigid-foot (dark line) vs. relative to rigid-calcaneus (light line) ($N=1$, Zelik & Honert 2018).

Discussion and conclusion

The results suggest that traditional ankle power should generally be avoided, particularly when comparing interventions that affect the rigidity of the foot (e.g., orthoses, footwear, shoes with embedded plates). Otherwise, when comparing ankle power results between various interventions, the observed differences may simply reflect methodological errors due to assuming a rigid foot, rather than reflect actual biomechanical adaptations by the user.

Treating the entire foot as a single rigid-body segment can result in obscuring, or even completely missing, important gait dynamics. As such, it is recommended to compute foot power in gait analysis by using one or more of the methods outlined, and not to rely solely on conventional ankle power estimates (between rigid foot and shank).

References

- Zelik, K. E., & Honert, E. C. (2018). Ankle and foot power in gait analysis: Implications for science, technology and clinical assessment. *Journal of Biomechanics*, 75, 1–12.