Adaptability of human foot energetics and its relationship to foot shape

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Summary

We quantified the energetic function of the foot during uphill, level and downhill running, to determine if foot function is adjusted to meet relatively small changes in whole body work requirements. We also explored the relationship between foot shape features and foot energetics. The negative and positive work performed by the foot varied with incline, but no clear relationship between foot shape and energetic behavior across inclines was found. Despite wide variations in foot shape across our participants, similar adaptability to the different energetic demands suggests that structural differences in the foot may not influence energetic function.

Introduction

The human foot contributes to the energy generated and dissipated at the center of mass (COM) during level locomotion, jumping and landing [1,2]. However, it remains unclear if human feet retain similar energetic adaptability when faced with tasks of mixed energetic demands, such as uphill and downhill locomotion.

Furthermore, specific variations in the structure of the human foot have been associated with variations in its biomechanical function [3]. Yet, it remains unclear if foot morphology influences the energetic adaptability of human feet.

Therefore, we investigated how foot energetics vary during running at different inclines, and whether variations in foot energetics can be linked to variations in external foot morphology.

Methods

One hundred healthy adults (50 female, 50 male) were asked to run (1.00 Froude number) on a force-instrumented treadmill (AMTI, USA) at three different inclines (-10, 0, 10%). Lower limb and foot segment trajectories were recorded with a 3D motion capture system (Qualisys, Sweden), and the 3D external shape of feet captured using a 3D foot scanner (Elinvision, Lithuania).

The negative and positive work performed distal to the talus during the stance phase of each step was determined using a unified deformable segment approach [4]. We used principal component analysis of foot scan vertices to create a statistical foot shape model and identified the main modes of foot shape variation, or principal components (PCs). All PCs that explained at least 5% of total shape variation were included for analysis.

One-way repeated measures analysis of variance (ANOVA) was used to identify differences in negative and positive work, and the ratio of positive to negative work, between inclines. Correlations between the measures of foot energetics and scores for the first five PCs were used to determine the relationship between foot energetics and external shape characteristics. Present results are from a preliminary analysis of 30 participants.

Results and Discussion

All ANOVAs showed foot energetics varied significantly with running incline (all $p < 0.01$). Post-hoc comparisons showed only positive work during level and uphill running was not significantly different.

Like simpler tasks, such as jumping or landing [2], foot energetic behavior adapted to COM work demands. However, like positive foot work remaining constant across running speeds [1], it remained unchanged between level and uphill running (Figure 1).

Correlations between foot work and shape PCs were weak to moderate. The strongest correlation was between negative work during downhill running and shape PC5 ($r = 0.44$), which describes differences in lesser toe length and forefoot width.

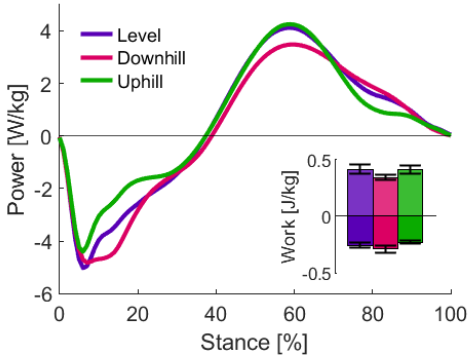

Figure 1: Stance phase power and work distal to talus.

Conclusions

While our feet adapt their energetic behavior to tasks with different energetic demands at the COM, the degree of adaptability does not appear related to features of external shape. Thus, distinctly shaped feet (presumably with different underlying passive and active structures) have a similar adaptive capacity for different locomotor tasks.

References

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