The mechanisms underlying enhanced running economy: an uphill versus level running paradigm

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Summary

Runners exhibit better running economy (RE) on level ground than untrained individuals, but the underlying mechanisms remain unclear. Using an indirect approach, we investigated whether optimized muscle-tendon interactions, facilitating energy-efficient muscle operating conditions, might explain this superior RE. We assessed RE and biomechanics in trained and untrained runners during level and uphill running. Unlike level running, uphill running requires net positive mechanical work, reducing the importance of fine-tuned muscle-tendon interactions for RE. Therefore, we hypothesized that the RE difference between trained and untrained runners would be smaller uphill. Our results confirmed that runners had superior RE on level ground but similar RE uphill. Furthermore, trained runners relied more on an ankle strategy, which might explain the better RE on level ground if this positive power is generated metabolically cheaper due to greater energy storage and return and/or more optimal muscle contraction conditions.

Introduction

Trained runners demonstrate better RE on level ground than untrained individuals. While the mechanisms underlying this advantage are unclear, biomechanical adaptations contribute substantially to this [1]. Running is a bouncing gait in which elastic tissues store and return energy with each step, allowing muscle fascicle length changes to be decoupled from length changes of the muscle-tendon unit [2]. Since muscles are most energy-efficient when operating isometrically and at optimal length, fine-tuned muscle-tendon interactions may enable more energy-efficient muscle contractions, thereby contributing to superior RE. To test this, we examined uphill running, which requires net positive mechanical work and reduces the importance of muscle-tendon interactions for RE. We hypothesized that if these interactions contribute to superior RE in trained runners, the difference in RE between trained and untrained runners would be smaller during uphill compared to level ground running.

Methods

14 (2F) trained and 15 (2F) untrained but physically active runners ran at two conditions with similar metabolic demands: level ground (3.5 m/s) and uphill (+14%, 1.7 m/s), each for 5 minutes. During each trial, we collected whole-body metabolic rate via indirect calorimetry, along with 3D motion capture data and ground reaction forces. RE was determined by averaging $\dot{V}O_2$ and $\dot{V}CO_2$ from the final 2 minutes of each condition. Lower limb joint angles and torque were calculate using OpenSim and used to compute joint powers. Average positive joint power was obtained by integrating the positive portion of the work rate-time curve and dividing by stride time. To evaluate each joint's contribution to total positive power, we calculated the ratio of the joint's positive power to the total positive power. A linear mixed effect model was used to analyse the effect of group, condition and group × condition interaction on RE and average joint power.

Results and Discussion

We observed a group × condition interaction effect for RE, indicating that trained runners had 9% better RE than untrained runners on level ground ($p < 0.01$; Figure 1). However, this difference disappeared during uphill running. Additionally, in both conditions runners generated higher average positive ankle joint power and relied more on the ankle to generate positive power ($p < 0.05$). This greater reliance on the ankle may contribute to superior RE on level ground in trained runners if positive power is generated metabolically cheaper due to greater energy storage and return and/or more optimal muscle contraction conditions. In contrast, during uphill running the advantage of an ankle strategy may be reduced as the need for net positive power diminishes its benefit.

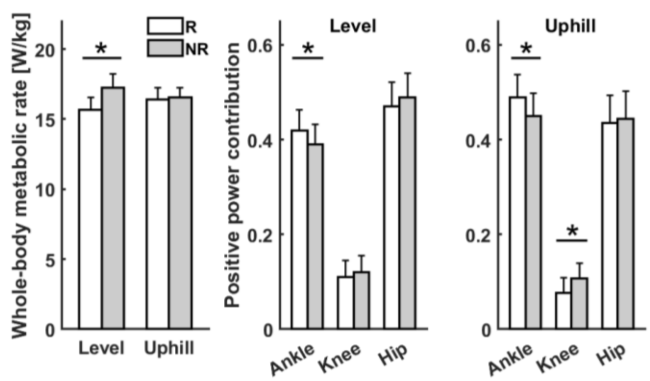

Figure 1: Metabolic rate and positive joint power contribution during level (3.5 m/s) and uphill (14%, 1.7 m/s) running in trained (white) and untrained (grey) runners.* $p < 0.05$.

Conclusions

While runners exhibit better RE than untrained runners on level ground, this metabolic advantage disappears during running uphill. The benefit on level ground may be attributed to a greater reliance on the ankle for generating positive power.

References

[1] Swinnen W et al. (2018). *Eur J Appl Physiol*, **118**: 1331-1338.

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