Lower Prosthetic Stiffness Minimizes the Metabolic Cost of Running for Individuals with Bilateral Leg Amputations

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INTRODUCTION

Non-amputee runners increase leg stiffness ($k_{\text{leg}}$) and decrease contact time ($t_c$) to achieve faster running speeds [1, 2]. Kram and Taylor [3] suggest that longer $t_c$ reduces the rate of muscular force production, thereby facilitating the recruitment of slower more economical muscle fibers which decreases the energetic cost of running. Thus, it is likely that a lower $k_{\text{leg}}$ (and longer $t_c$) reduces the metabolic cost of running.

While running with passive-elastic running-specific prostheses (RSPs), bilateral transtibial amputees have a lower $k_{\text{leg}}$ with faster running speeds [2]. Due to the singular stiffness of a given RSP, it is suggested that RSPs dominate $k_{\text{leg}}$, thus runners with bilateral leg amputations may be able to alter their metabolic cost of running by changing the stiffness of their RSPs. We hypothesize that using RSPs with lower stiffness will reduce the metabolic cost of transport (CoT) during running in runners with bilateral leg amputations. Also, we were curious how RSP model or height affect CoT, and due to insufficient evidence, we hypothesize that neither RSP model nor RSP height will influence CoT. To test our hypotheses we measured metabolic demand, ground reaction forces (GRFs), stride kinematics, and $k_{\text{leg}}$ from runners with bilateral leg amputations using RSPs that varied by model, stiffness category, and height.

METHODS

Three male runners with bilateral transtibial amputations participated. We obtained informed written consent, and then a certified prosthetist fit each subject with three RSP models (RSP1, RSP2, RSP3) at the recommended and ±1 stiffness categories. The height of each RSP was set to match the tallest allowed standing height as determined by the International Paralympic Committee [4] and ±2 cm. If the shortest attainable height for a RSP model was taller than recommended, the shortest height was used for that subject/model; then we altered RSP height by +2 cm, and +4 cm.

On days following the fitting session, subjects performed 5 min running trials on a force-instrumented treadmill at either 2.5 m/s (n=2) or 3.0 m/s (n=1). Each trial was completed using a different RSP model, stiffness category, and height combination. First, subjects ran using the recommended height while RSP model and/or stiffness categories were changed. Then, RSP height was altered ±2 cm (or +2 cm, +4 cm) at the optimal stiffness category; the stiffness category that elicited the lowest CoT. All trials were randomized.

We used indirect calorimetry to determine net metabolic power from the average metabolic rates during the final 2 min of each trial [5]. We converted average net metabolic power to work and divided by the product of mass and running speed, yielding CoT in J/kg/m.

We measured GRFs from 10 consecutive strides during the last 2 min of each trial. We combined the average GRFs from both legs, sampled at 1000 Hz, and processed them using a custom MATLAB script. We calculated $k_{\text{leg}}$ according to [6]. A statistical linear mixed model was used to determine the associations of RSP model, stiffness category, and height on CoT. We also compared the effect of RSP stiffness category on peak $k_{\text{leg}}$, peak vertical GRF (vGRF), and peak displacement of the leg-spring ($\Delta L$).

RESULTS AND DISCUSSION

For every one reduction in RSP stiffness category, CoT decreased by 5.1% (p<0.01) (Fig. 1).
Moreover, with our limited number of subjects (n=3), we were unable to detect significant effects from either RSP model (p=0.14) or height (p=0.59) on CoT. Based on our current sample size, our data support our hypotheses that RSP stiffness, but not model or height, influence CoT.

**CONCLUSIONS**

Runners with bilateral transtibial amputations had lower CoT, k_{leg}, and t_c when using RSPs with lower stiffness categories. However, neither RSP model nor height significantly affected CoT.

**REFERENCES**


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