INTRODUCTION

Effective storage and release of elastic strain energy will reduce muscle fiber mechanical work if the muscle fibers are able to operate at low contraction velocities, and thereby produce force at a lower rate of ATP consumption [1]. The forefoot (FF) running footfall pattern has been claimed to result in greater Achilles tendon elastic energy utilization [e.g., 2], resulting in a lower metabolic cost [3] compared with the rearfoot (RF) footfall pattern. Not only is there direct evidence to the contrary [2], but we have also found greater contractile element (CE) mechanical work in the gastrocnemius (GA) and soleus (SOL) in FF running than in RF running [4], despite greater series elastic element (SEE) work in FF running. These findings imply that FF running may not result in lower muscle metabolic energy expenditure compared to RF, but it is difficult to infer metabolic cost from force and work. Therefore, the purpose of this study was to expand on our earlier work and use a musculoskeletal model to predict metabolic energy expenditure of the GA and SOL in RF and FF running. It was hypothesized that FF running would result in greater muscle energy expenditure than RF running.

METHODS

Ten natural RF runners (7 males, 3 females, age = 28±5 yrs, mass = 70.6±9.8 kg, height = 1.8±0.1 m) and ten natural FF runners (9 males, 1 female, age = 26±8 yrs, mass = 70.5±7.1 kg, height = 1.8±0.1 m) participated after providing informed consent. Each participant performed ten trials of over-ground running with each footfall pattern (3.5 m·s⁻¹±5%). Inputs to a musculoskeletal model included sagittal plane knee and ankle joint angles and moments averaged over the 10 trials of each participant. Musculoskeletal geometry parameters were scaled to each participant. A two-component Hill model of the GA and SOL was used to calculate MT, CE, and SEE forces, powers, and work. CE metabolic power (CEₘₚ) was predicted as a function of CE velocity and activation [5]. CE metabolic energy expenditure (CEₘₑ) during the entire stance phase and the push-off phase was calculated by integrating CEₘₚ with respect to time. The push-off phase was defined as the time between the first instant the MT produced positive power in the second half of stance through toe-off. A mixed-factor ANOVA was used to detect differences in CEₘₑ between footfall patterns and groups during stance and push-off phases (α = 0.05).

RESULTS AND DISCUSSION

No significant group by pattern interactions or group main effects were observed for GA or SOL CEₑₑ during stance or push-off (P>0.05). Thus, all results were collapsed across groups. There was no significant difference in GA CEₑₑ between footfall patterns during stance or push-off (P>0.05: Figure 1D). However, FF running resulted in 28% greater SOL CEₑₑ than RF running during the stance phase and 33% greater SOL CEₑₑ than RF running during push-off (P<0.01; Figure 1D).

Although the elastic energy mechanism does augment the mechanical output of the GA and SOL in FF running compared to RF [4], FF running resulted in greater SOL CEₘₑ but similar GA CEₘₑ than RF running (Figure 1D and E). Therefore, the hypothesis that FF running would result in greater CEₘₑ than RF running was supported for the SOL but not the GA.

GA CE work and CEₘₑ (Figure 1C and E) were similar between patterns because of the offsetting mechanical and metabolic effects of CE shortening.
velocity and force generation: FF running required greater activation in order to generate greater GA force (Figure 1A and B) but it was produced more economically as a result of slower contraction velocities compared to RF running [4].

In the first ~65% of stance, SOL CE ME was similar between patterns (Figure 1D) as a result of offsetting metabolic effects of contraction velocity and force production. Similarly to the GA, RF running resulted in higher SOL CE shortening velocities [4], but lower activation and force production than FF running during this period (Figure 1A and B). During push-off, however, FF running resulted in greater SOL CE work and CE ME (Figure 1C and E) as a result of greater activation (Figure 1A) and shortening velocities [4] compared to RF running, despite similar SOL force production between patterns during this period (Figure 1B).

CONCLUSIONS

Although we found that FF running does result in greater elastic energy utilization of the GA and SOL [4], consistent with previous suggestions [2,3], metabolic energy expenditure of the triceps surae was greater in FF running compared with RF running. These findings can be understood largely in terms of the CE force-velocity relation: a higher force or higher shortening velocity will favor more mechanical work, but will also cost more due to the necessity of higher muscle activation. In the GA, force and velocity offset each other in FF versus RF running, but in the SOL during late stance they do not, resulting in greater SOL energy expenditure in FF running.

REFERENCES