

A TEST OF THE METABOLIC COST OF CUSHIONING HYPOTHESIS IN BAREFOOT AND SHOD RUNNING

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INTRODUCTION

Advocates of barefoot running assert that it is more metabolically efficient than shod running. This idea makes sense because wearing shoes adds mass to the feet, and this increases energetic cost. Frederick et al. [2] showed that $\dot{V}O_2$ increases by approximately 1% for each 100 grams of added mass per shoe. Previous studies that controlled for foot/shoe mass suggest that shoe cushioning may provide an energetic advantage over running barefoot [1, 2, 3]. Further, running in lightweight shoes has about the same metabolic cost as running barefoot [1, 4], suggesting that the positive effects of shoe cushioning may counteract the negative effects of added mass (Figure 1).

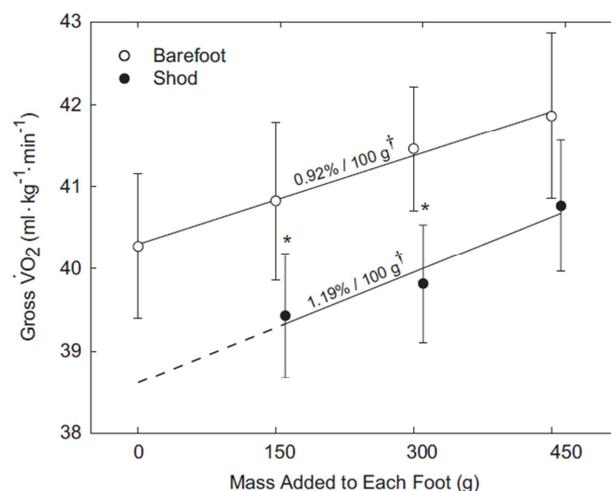


Figure 1. Oxygen consumption data from Franz et al. [1]. When mass is controlled for, other factors make shod running more economical. Asterisks (*) indicate significant difference between barefoot and shod conditions of equal mass. † indicates significant main effect of added mass.

Based on these findings, we hypothesized that: 1) barefoot running would have the same metabolic cost as running with lightweight, cushioned running shoes and 2) the metabolic cost of barefoot running would be less on cushioned surfaces.

METHODS

Ten experienced barefoot runners (mean \pm SD, age: 30.2 ± 9.1 yrs) ran at 3.35 m/s with a mid-foot strike pattern on a Quinton 18-60 motorized treadmill modified to have a calibrated digital readout of speed. This classic treadmill has a rigid steel deck. All subjects gave written informed consent as per the Univ. of Colorado IRB. The inclusion criteria were: >18 years of age, mid-foot strike preference both barefoot and with shoes, run at least 25 km/week, including at least 8 km/week barefoot or in minimal running footwear (e.g. Vibram Five Fingers) for at least 3 months out of the last year, injury-free, self-reported ability to sustain 5 min/km (3.3 m/s) running pace for at least 60 minutes, and meeting the criteria of the ACSM for minimal risk of exercise. To verify that subjects preferred a mid-foot strike pattern, they ran at their typical 10 km training pace across a 30m runway equipped with a force platform (AMTI, Watertown, MA) to which a sheet of paper was affixed. To orient foot placement with the force platform origin, we taped small pieces of marker pen felt to each subject's right foot at 90, 70, and 33% of foot length (measured along the line between the heel and distal end of the second toe). We classified subjects as mid-foot strikers if the center of pressure at initial contact was between 33% and 70% of foot length.

Subjects ran barefoot (BF) and in lightweight cushioned running shoes (SH) (Nike Free 3.0; ~211 g/shoe). Subjects also ran barefoot on the same treadmill with 10 mm and 20 mm thick slabs of ethylene-vinyl acetate (EVA) foam affixed to the treadmill belt (Figure 2). The foam was identical to that used in the running shoes. Prior to testing, subjects completed a 10 minute treadmill acclimation trial. The 4 conditions consisted of: shod, barefoot, barefoot on 10 mm foam, and barefoot on 20 mm foam, performed in random order. A 3-minute rest period separated each of the

running trials. We calculated metabolic power (W/kg) from rates of oxygen consumption and carbon dioxide production using the Brockway equation [5]. We calculated stride kinematics from high-speed digital video recordings (210 FPS, Casio EX-FH20).

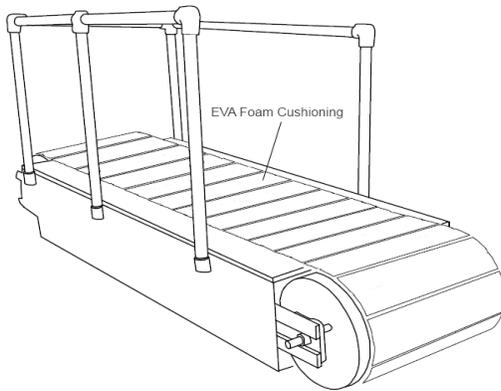


Figure 2. Cushioned treadmill

RESULTS AND DISCUSSION

As hypothesized, on the rigid treadmill surface, metabolic power requirements for running barefoot and in lightweight running shoes were not significantly different (Mean \pm SD, BF: 13.65 ± 1.31 W/kg, SH: 13.66 ± 1.15 W/kg; $p=0.95$). The data (Figure 3) also support our second hypothesis; metabolic cost for barefoot running was 1.91% cheaper on the 10 mm foam compared to the rigid surface ($p=0.018$). The reduction in metabolic cost on the 20mm thick surface was not statistically significant (1.70%, $p=0.056$).

Stance times for each of the conditions were: 0.231 ± 0.02 sec (BF), 0.225 ± 0.01 sec (BF 10mm), 0.23 ± 0.015 sec (BF 20mm), and 0.242 ± 0.015 sec (SH). The stride frequencies for each condition were: 1.671 ± 0.14 (BF), 1.666 ± 0.129 (BF 10mm), 1.651 ± 0.136 (BF 20mm), and 1.628 ± 0.124 (SH).

Based on the “1% rule”, we would expect that running in 210g shoes to be 2.10% more expensive than barefoot running. However, according to our data, it was essentially the same. 10 mm of foam cushioning (approximately the thickness of the forefoot shoe midsole) afforded a benefit of 1.91%. Thus, it appears that the positive effects of shoe cushioning counteract the negative effects of added mass, resulting in a metabolic cost for shod running approximately equal to that of barefoot running.

Kerdok et al. [3] found that the cost of running on an elastic compliant treadmill steadily decreased with greater compliance. However, we did not find that the metabolic cost of running decreased with thicker cushioning. A possible explanation for this discrepancy is the fact that Kerdok et al.’s treadmill surface acted as a leaf spring, and therefore, provided greater energy return with increased compliance. In contrast, our cushioned treadmill used a material with significant damping.

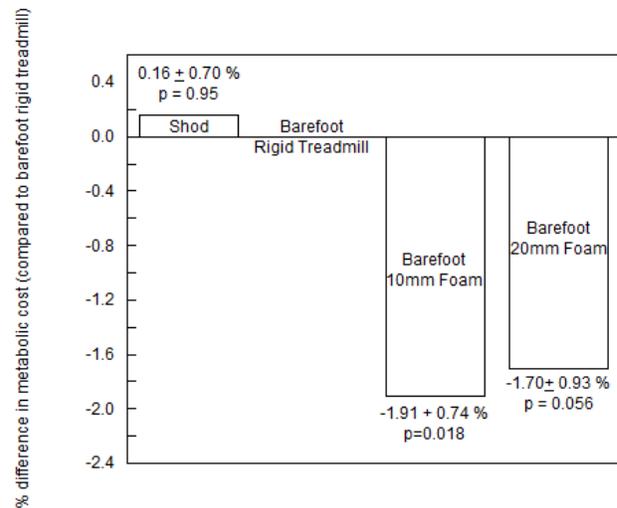


Figure 3. Percent difference (mean \pm standard error of the mean) in metabolic power for each running condition with respect to the cost of barefoot running on rigid treadmill surface.

CONCLUSIONS

Cushioning reduces the metabolic cost of running. Further research is needed to identify the metabolically optimal amount of cushioning.

REFERENCES

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