Reducing the metabolic cost of downhill walking through passive dissipation

I. INTRODUCTION

Humans dissipate mechanical energy during downhill walking to offset the positive work done by gravity. Whereas active muscles are thought to be responsible for this dissipation [1], it could also occur passively by deformation of soft tissues such as the viscera and the heel pad. There may be a trade-off between the metabolic cost associated with active muscle use, and the risk of overuse injury or damage associated with energy dissipation through passive tissues [2]. It might be possible to reduce metabolic cost of downhill walking by increasing the dissipative capacity of passive elements. We tested whether humans take advantage of artificial passive dissipation added to the body, to decrease the metabolic cost of downhill walking.

II. METHODS

We measured the metabolic cost of walking at a range of slopes, with and without added dissipation, achieved through camping-grade air pumps mounted under the feet. Although walking with air pumps may reduce the contribution of active muscle dissipation to metabolic cost, it may increase other contributions (e.g., for carrying additional weight, ground/leg clearance, maintaining balance). We therefore compared added dissipation against a non-dissipative control condition, where the pump’s valves were opened so that air could easily escape (weight-matched control). Because costs other than active muscle dissipation may be independent of slope, we predicted that at steep declines, metabolic cost would be lower for added dissipation than for weight-matched control. For normal walking, the metabolic cost is usually lowest at shallow declines, where gravitational power offsets the total dissipative power. The metabolic cost increases at steeper declines due to the need for additional active dissipation, giving rise to a bowl-shaped metabolic cost landscape [1]. We expect that the energetic minimum in this landscape will occur at steeper declines when adding artificial dissipation, as larger gravitational power would be required to offset the dissipation. We therefore predicted a shift of the energetic minimum towards steeper declines for added dissipation vs. normal walking (shod control). For level and uphill walking, the added dissipation would require more positive work, at higher metabolic cost than either control condition.

We tested these predictions on preliminary data from a healthy human subject (N=1) walking on a treadmill with a constant speed (1 m/s) at various slopes (-0.26 to +0.10 rad). We estimated metabolic power from respirometry data, averaged over the last 3 minutes of each 5-minute trial.

III. RESULTS & DISCUSSION

Added passive dissipation increased the metabolic cost of level and uphill walking compared to shod control, while it decreased the metabolic cost of downhill walking compared to weight-matched control (Fig. 1). The latter supports our hypothesis that adding passive dissipation can decrease the metabolic cost of downhill walking. Added dissipation did not decrease the metabolic cost compared to shod control, probably due to the weight and other encumbrances of the apparatus. The difference between added dissipation and shod control did decrease with greater downhill slopes (Fig. 1), which may reflect a larger increase in active muscle dissipation and associated metabolic cost in shod vs. added dissipation condition. Although current data is inconclusive, added dissipation seemed to result in shifting the energetic minimum towards steeper slopes compared to both control conditions, in line with predictions.

Figure 1. Metabolic power vs. slope for added dissipation walking and control conditions. The cost for added dissipation walking (blue) decreased below the cost for weight-matched control (yellow) at steep declines, but sharply increased above the cost for shod control (red) during level- and uphill walking.

CONCLUSION

Artificial passive dissipation has nearly opposite effects on metabolic cost of walking downhill vs. walking uphill. Whereas passive dissipation greatly increases the cost of uphill walking, it may allow humans to reduce active muscle dissipation and associated metabolic cost during downhill walking.

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REFERENCES