The Metabolic and Mechanical Costs of Step-Time Asymmetry in Walking

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INTRODUCTION

Asymmetry is a major feature of numerous gait pathologies. Restoring gait symmetry has therefore been used as a clinical outcome variable for individuals recovering from stroke, amputation, joint replacement and physical trauma [e.g. 1]. Despite this, this is yet no evidence that gait symmetry is optimal even in healthy adults. Indeed, recent modeling studies suggest that the costs of small asymmetries may be minimal [2]. It has already been shown that step times both slower- and faster-than-preferred are mechanically and metabolically more expensive than preferred steps [3]. Here we ask: is there an inherent cost to gait asymmetry beyond that imposed by slow or fast steps? We also explore the mechanical power generated during asymmetric walking.

Hypothesis 1: The metabolic cost of walking with asymmetric steps will be greater than for walking with symmetric steps.

Hypothesis 2: This increased metabolic cost can be explained by greater mechanical power production.

METHODS

10 healthy subjects (5M/5F, 174±20cm, 68±10kg, 26±6yrs) each completed 9 walking trials at 1.25 m/s on a dual-belt force treadmill. Each trial involved walking at different symmetric and asymmetric step time combinations. Throughout the protocol, subjects received both auditory cues and visual feedback of their step time symmetry ratio, calculated as:

We define a step as from heel strike of the contralateral foot to the heel strike of the ipsilateral foot (e.g. right step time is left heel strike to right heel strike). Because of how we calculated SR, the right leg was always the ‘slow’ leg, with a step time greater than the left leg and slower than preferred (Fig 1). Correspondingly, the left leg was the ‘fast’ leg for all subjects. Our symmetric conditions had steps times +25, +12.5, 0, -12.5, -25% faster or slower than preferred (SR 1.0). Of our 4 asymmetric conditions, 3 had similar, less asymmetric SR’s (1.25, 1.29 and 1.33) with right and left step times +25/-0, +12.5/-12.5, and +0/-25% different from preferred. One condition had a higher SR (1.66), with steps +25/-25% from preferred.

We used expired gas analysis to calculate subject’s metabolic power. We calculated the mechanical power from measured ground reaction forces using the individual limbs method [4].

RESULTS AND DISCUSSION

Our symmetric results confirmed that faster and slower symmetric steps are more expensive than preferred steps. Our +25% condition resulted in a ~0.97 W kg⁻¹ (+30%) increase in the net metabolic power while our -25% condition resulted in a 1.35 W kg⁻¹ (+42%) increase in metabolic power (Fig 2A).

Fig 1: Average ground reaction forces for the +25/-25 condition. DS= double support. SS=single support. Right step time was longer than left step time, resulting in a symmetry ratio, resulting in a SR > 1.00.
We also observed a modest (-0.10 W/kg) increase in the mechanical power required for our three less asymmetric conditions, which was significant for all but the +12.5/-12.5 condition. We observed a large amount of variability in the strategies employed by our subjects to complete the task. Interestingly, some subjects performed less positive and negative mechanical work for an asymmetric stride than for a symmetric stride under each of the +12.5/-12.5, +25/-0 and +0/-25% conditions.

We also observed a substantial shift in when during the stride this work was performed, as well as a shift in the function of each leg. On average, the ‘fast’ leg performed more than half of the positive work per stride. Further, both legs had redistributed when they were producing power relative to normal walking. For example, the ‘fast’ leg produced net power during single support while also absorbing more power as the leading leg during each step-to-step transition.

**CONCLUSIONS**

Step-time asymmetry resulted in a clear metabolic penalty, which increased with increasing asymmetry. In our specific paradigm, we observed a reorganization of how when during the stride each leg was producing and absorbing power. The ‘slow’ leg produced net positive power while the ‘fast’ leg primarily absorbed power, which was distributed differently across the stride than we observed for symmetric walking. We suggest that the greater metabolic cost of walking asymmetrically is caused both by an increase in positive work performed on the center of mass and by an unequal distribution of this work between the legs and across a stride. Overall, we find that symmetry is optimal for healthy, generally symmetric individuals, as it requires less metabolic power, although this does not endorse the idea of imposing symmetry on individuals with pathological gait asymmetry.

**REFERENCES**