OXYGEN CONSUMPTION AND THE PREFERRED FREQUENCY SPEED RELATION IN HUMAN WALKING

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INTRODUCTION

It has long been recognized that, at different speeds, an individual will, roughly, select the step length and step frequency that minimizes energy expenditure per unit distance travelled. We discovered (Bertram and Ruina 2001) that, roughly, an individual will also choose the speed and step frequency that minimizes energy expenditure if step length is constrained, or the speed and step length that minimizes energy expenditure if step frequency is constrained. A schematic of the three preference curves and their relation to a prototypical set of oxygen consumption contours are shown in Fig. 1.

How might an individual control walking to minimize metabolic cost? One possibility is that the neural system constantly monitors the energetics of walking, processes that derived information and implements an appropriate optimization. This direct internal control seems to formidable task for big-brained bipeds. Alternatively, the neural system could implement a simpler control strategy that has evolved so that it has the observed minimization property.

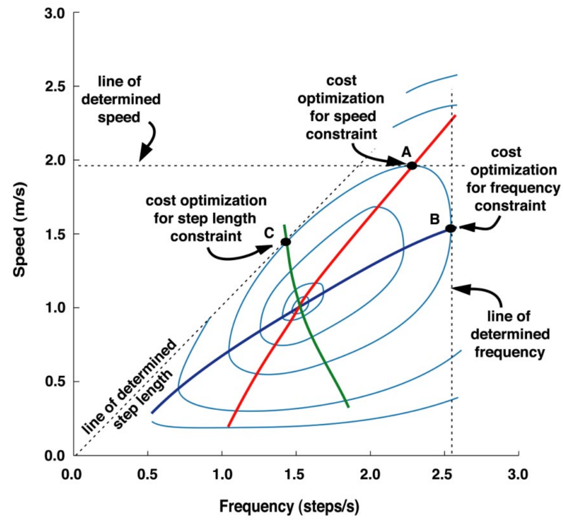

Figure 1: Description of the constrained optimization hypothesis. The concentric blue lines indicate iso-cost curves that have greater magnitude as they expand outward.

Here we further investigate the relation between oxygen consumtion and the various constrained preference tests for several subjects. Rather than using published VO2 data this work uses VO2 data from the same subjects as are used in the preference tests.

METHODS

A metabolic cost surface is generated from oxygen consumption rate at 49 speed-frequency conditions for 10 subjects. Energy optimization using this surface predicts the results of the preference tests, which we can compare to the results of the actual preference tests for the same individuals (constrained speed walking on a standard treadmill; constrained frequency level walking to a metronome beat; constrained step length level walking on evenly spaced markers).

RESULTS

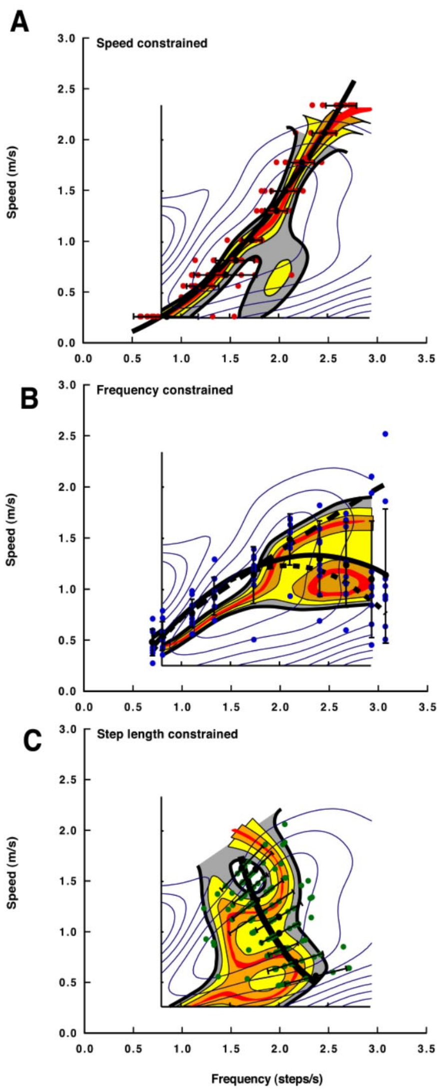

Figure 2: Observed walking of 10 subjects compared to the predictions from metabolic cost of movement (blue contours). Shaded areas show ranges around optimum: red ± 1%, orange ± 5%, yellow ± 10%, gray ± 15%. Solid black circles indicate mean (±1 sd). Plots A and C are fit with least-squares power function regressions (applied to the independent variable and mathematically manipulated to match the variables shown in these plots). Plot B is fit with least-squares quadratic regressions, solid line, all data; long dashed line, the subgroup that selected high speed optimum; short dashed line, subgroup that selected low speed optimum.

DISCUSSION

The correlation between the preference tests and energy optimization observed in Bertram and Ruina (2001) is maintained when VO2 data is used for the same subjects as are used in the preference tests (as opposed to old published VO2 data). Although minimization of cost per distance appears to dominate walking control, differences from predicted behavior suggest that other factors are also relevant.

REFERENCES

Bertram, J.E.A., Ruina, A. (2001) *J. Theor. Biol.* **209**, 445-453.