Is there a reaching speed that minimizes metabolic cost?

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1 Motivation

Human movement is remarkably similar across individuals. A prime example of such stereotypy is the conserved natural reaching speeds observed in healthy young adults. However, movement speeds become slower with increasing age and certain movement disorders such as Parkinson's Disease. A better understanding of the mechanisms underlying the decision to move at a given speed would allow the design of improved rehabilitation techniques for a variety of movement disorders.

2 State of the Art

In human locomotion, it generally accepted that metabolic cost is a primary determinant of the choice to walk at a given speed. Interestingly, this seems to not be the case for arm-reaching movements. Models that minimize terms such as error, jerk, and reward can simulate observed movement behavior [1-3]. Minimization of energy or effort is also often included in these models. However, they predict that minimizing energy alone cannot result in a non-zero optimal reaching speed (i.e. the optimal speed is to move as slow as possible). This is despite little experimental evidence for how the brain represents effort, or even what the actual metabolic (energy) requirements are for the task. Here we sought to measure the actual metabolic demands of a reaching task, and determine whether there is a metabolic minimum when reaching at different speeds. We hypothesized that metabolic rate (J/s) would increase with reaching speed but that metabolic energy expended per movement (cost per movement, J/mvt) would have a U-shaped relationship with reaching speed.

3 Own Approach

Seated subjects ($n = 8$) reached horizontally towards a target 20 cm away using a robotic arm at different speeds, including their preferred speed. We used expired gas analysis to measure their O_2 and CO_2 rates and calculate metabolic power [4]. We then subtracted out the baseline sitting metabolic power to get net metabolic power. We calculated net cost per movement by multiplying net metabolic power by movement duration (J/s * s = J/mvt). Two other groups of 8 subjects completed the experiment at target distances of 10 cm and 30 cm.

4 Current Results

Metabolic power increased with faster reaching speeds. For the 20 cm reach, the metabolic power for each subsequent faster speed was significantly higher (p's < 0.05, 1-tailed paired t-test). For the 10 cm and 30 cm reaches, the metabolic power for the three and two slowest speeds, respectively, were not significantly different. Surprisingly, these curves exhibit a constant offset of ~0.23 J/kg-s, independent of reach distance (Fig 1A). This offset is not included in traditional effort-based cost functions and indicates that there is a constant metabolic cost associated with the reaching task, above the cost of sitting, which penalizes slow movements.

Cost per movement had a U-shaped relationship with average velocity for all 3 distances (Fig 1B). The minimum cost per movement was significantly less than the cost per movement for the neighboring speeds (p's < 0.05). The preferred speeds were slightly slower than the metabolically optimal speeds ($p = 0.42$ and $p = 0.24$) for the 10 and 20 cm reaches The preferred speed for the 30 cm reach was significantly slower than the metabolically optimal speed ($p < 0.046$).

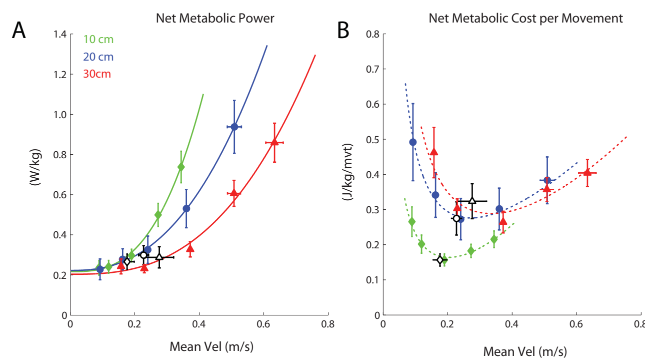

Figure 1 Net Metabolic Power (A) and Net Metabolic Cost per Movement (B), averaged across subjects, for each reach distance. Black symbols represent average preferred reaching speed. Solid lines in A represent best fits to the data. The dotted lines in B indicate the cost per movement according to the derived functions in A.

5 Best Possible Outcome

We found that metabolic power (J/s) increases with faster reaching speeds and there is a metabolic minimum in terms of cost per movement (J/mvt). This metabolic minimum results from a previously unobserved constant metabolic cost that penalizes slow movements. Although the source of this metabolic offset is not clear, future modeling efforts should consider including it in their cost functions. Overall, these findings suggest that people may reach with a given speed in part to minimize metabolic cost. Consequently, an individual's valuation of metabolic cost, and how it varies with fatigue, age and/or disease may provide a novel window for movement rehabilitation.

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References

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