External power as a proxy for energy cost: Walking entrainment with machine oscillations

Ryan T. Schroeder
Faculty of Kinesiology
University of Calgary
Calgary, AB, Canada
ryan.schroeder@ucalgary.ca

James L. Croft
Faculty of Kinesiology
University of Calgary
Calgary, AB, Canada
james.croft@ucalgary.ca

John E.A. Bertram
Cumming School of Medicine
Biomedical Engineering Program
University of Calgary, Calgary, AB, Canada
jbertram@ucalgary.ca

I. INTRODUCTION

Active exoskeletons are often applied to specific joints to assist muscle-tendon units during locomotion (e.g. at the ankle [1]). However, actuation about specific joints ultimately affects center-of-mass dynamics and thus energetics, sometimes as a primary goal [2]. Given this, wearable assistive machines can be used to apply forces directly to the body without adding burdensome load to the peripheral limbs. An experimental mechatronics device was designed to provide periodic vertical forces to human subjects while they walked on a treadmill. Multiple oscillation frequencies and amplitudes were prescribed as experimental conditions, and energetics and mechanics of the subject-oscillation interaction were measured, particularly with regards to subjects’ chosen force alignment in the step cycle.

II. METHODS

The custom mechatronics system used two electric motors and a series of pulleys and cables to pull on a body harness worn by subjects. The motors were activated with a sinusoidal current to apply periodic vertical forces. Experiments involved walking with and without active oscillations and opportunities to entrain (i.e. synchronize) steps at prescribed frequencies. Harness forces were measured throughout experiments via transducers and the timing of peak upward force was compared to gait events measured with accelerometers. Oxygen consumption was also measured, and average metabolic power was compared for subjects entrained vs. not entrained to the oscillation frequency. Linear mixed-effects models were used to assess cost differences statistically.

III. RESULTS & DISCUSSION

Metabolic power was not significantly different when subjects entrained vs. when they did not entrain their steps to the oscillations. However, energetic cost was reduced when subjects aligned forces with toe-off events (−0.25 of step cycle), on average (Fig. 1A). The energy-minimal force alignment was also associated with maximal net mechanical work per step from the external forces (Fig. 1B). While positive mechanical work per step was correlated with reduced energy cost during entrainment, it is unclear if this relationship is causal, in particular since the timing of peak forces was an outcome of subject preference rather than an experimental manipulation. Positive power from external forces in the environment are often highly correlated with reduced energetic cost, perhaps since individuals can down-regulate costly positive muscle work and dissipate excess energy with relative economy. Future work could explore the utility of external mechanical power as a proxy for energetic cost, given that it can be measured more quickly than metabolic data (nearly instantaneous vs. minutes).

ACKNOWLEDGMENT

Supported by an Eyes High Doctoral Recruitment Scholarship from the University of Calgary, and the National Sciences and Engineering Research Council of Canada (312117-2012 and 04823-2017).

REFERENCES
