ADAPTATION OF STEP-TO-STEP MECHANICAL WORK ON CENTER OF MASS DURING SPLIT-BELT TREADMILL WALKING

1,2 Gloria Cho, 2 Montakan ‘Ploy’ Thajchayapong, 2 Megan E. Toney and 1,2 Young-Hui Chang

1 Georgia Tech MSPO Program, School of Applied Physiology, Atlanta, GA, USA
2 Comparative Neuromechanics Lab, School of Applied Physiology, Georgia Tech, Atlanta, GA, USA
email: ploy@ap.gatech.edu, web: http://www.ap.gatech.edu/Chang/Lab/CNL/home.html

INTRODUCTION

The purpose of this work is to try to understand how the body adjusts mechanical work on the center of mass (COM) due to external perturbation. Much of COM work is performed to redirect the center of mass from a downward to an upward velocity during transitions from one step to another, termed step-to-step transitions. In this study, step-to-step transition starts from the minimum center of mass velocity and ends at its maximum.

Split-belt treadmill has been previously used for study walking adaptation. Here we termed adaptation as the ability to adjust the body function from changes in environment.

We hypothesize that external mechanical work on COM would demonstrate adaptation to eventually match with the baseline condition.

METHODS

Subjects were asked to walk on a treadmill consisting of 2 separate belts and each belt can be controlled independently. During different testing periods, subjects walked on the treadmill with the 2 belts either moving at the same speed (“tied” condition) or at different speed (“split-belt” condition). During baseline period, subjects walked on the treadmill with belt tied at 0.5, 1.0 and 1.5 m/s. During adaptation period (10 minutes), treadmill belt speeds were set at 0.5 and 1.5 m/s. The leg was assigned randomly on each belt. At the end of testing session, the treadmill belt was tied and the speed was set at 0.5 m/s.

We used a six camera motion analysis system (120 Hz, Vicon motion system) to determine the sagittal plane positions of the body segments. Mechanical work was calculated from

\[ P = \vec{F} \cdot \vec{v}_{COM} \] (1)

\[ W = \int P \, dt \] (2)

RESULTS AND DISCUSSION

When walking in the split belt treadmill condition, there were two types of transitions recorded and analyzed. When transitioning from the fast belt to the slow belt, the fast leg trails, providing propulsion and the slow leg leads, providing breaking forces to slow the COM velocity.

Figure 1. Transitioning from fast to slow belt, the leading leg (red/magenta) requires more steps to reach a steady state compared to the trailing leg (blue/cyan).

During this transition, the leading leg requires more steps to reach a steady state than the trailing leg, demonstrating a typical adaptation. In 2010, Reisman et al. suggested that variables with this typical exponential decay curve (Lam et al, 2006)
are generally controlled via feedforward, predictive mechanisms. Because leading leg collision kinetics are dominated by the initial conditions prior to contact, it follows that leading leg control would be governed by feed-forward mechanisms. During transitions in which the body steps from the fast to the slow belt, stance kinetics of the fast leg inform the body that it is walking at 1.5 m/s. When the slow leg then encounters the belt moving at 0.5 m/s, in early adaptation the walker has not yet established appropriate feedforward expectations for controlling leading leg collisions. As a result, leading leg collisions of the slow leg (pink triangles, Fig 1) are much larger than what would be expected from slow tied belt, baseline walking (red diamonds, Fig 1).

The leading leg also provides afferent sensory feedback about the encountered conditions, which may inform behavior for the trailing leg. As a result, the trailing leg can make online adjustments to account for unexpected perturbations. When transitioning from fast to slow conditions, the trailing leg positive work undershoots what would be expected from the 1.5 m/s baseline (blue squares, Fig 1). The trailing leg also reaches a steady state condition for positive work in fewer steps than the leading leg, indicating that trailing leg propulsive work is likely governed by feedback control mechanisms.

When transitioning from the slow to fast belt, the fast leg leads and produces less negative work than would be expected from the baseline trials. The reduced negative work appears close to the work necessary to achieve smooth transitions, and little adaptation is observed. The trailing leg correspondingly produces smaller positive, propulsive work, reaching a steady state in fewer steps similarly to what was previously observed in the fast to slow transitions.

The final steady state value does not consistently match external mechanical work calculated for the respective baseline trials. It appears that the body attempts to match positive and negative braking forces within a transition rather than matching baseline values. This final steady state value may indicate that human walkers attempt to stabilize (make consistent) some larger goal over successive steps over the course of adaptation.

CONCLUSIONS

The results presented here demonstrate that human walkers adapt kinetic parameters when walking in a split belt environment. It appears that leading leg collision kinetics are mediated by feedforward mechanisms, demonstrating a typical adaptation curve. Trailing leg propulsive forces then make online adjustments informed by afferent feedback from the leading leg dynamics. Contrary to our hypothesis, external mechanical work did not return to a recorded baseline value, but instead appeared to match braking and propulsive work within a single step. This trend provides some evidence that human walkers attempt to stabilize some greater whole-body goal when walking in an unusual environment.

REFERENCES