Temporal Interactions between Stability and Energetics during Human Locomotor Learning

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1 Introduction

In recent years, split-belt treadmill adaptation has emerged as a model paradigm used to study the neuromechanics of human locomotor learning. This paradigm is typically characterized by an adaptation period where one belt is driven to move 2-4 times the speed of the other, and a post-adaptation period used to assess how much a participant has "learned" from exposure to the split condition. During early adaptation, the abrupt change in belt speeds usually produces an asymmetry in step lengths, and this asymmetry is gradually reduced over 10-15 minutes of adaptation.

This process is commonly described as an error-based learning process, whose goal is to reduce step length asymmetry (error). As an alternative to the error-based learning framework, recent studies have begun to examine how energetics influences this learning process (Finley et al., 2013). Although this study demonstrated that adaptation is associated with reductions in net metabolic cost, it remains to be seen if this is a goal or byproduct of adaptation. Another possibility is that adaptation results from a desire to adopt a locomotor pattern that is perceived to be most resistant to falling. To this end, we examined whether adaptation was associated with changes in dynamic margins of stability and whether these changes are correlated with changes in step length asymmetry or net metabolic cost.

2 Methods

Each experiment began with three baseline periods where both belts moved at either 0.5 m/s, 1.0 m/s, or 1.5 m/s. This was followed by a split-belt condition where participants adapted their walking pattern while the left and right belts moved at 0.5 m/s and 1.5 m/s, respectively. Storage of a newly adapted walking pattern was assessed during a post-adaptation period where each belt moved at 1.0 m/s. Full body kinematics were recorded using a Qualysis Oqus motion capture system. Oxygen consumption and carbon dioxide production were measured using a ParvoMedics TrueOne 2400 metabolic cart.

Step length was computed as the fore-aft distance between the ankle markers at heel strike. Dynamic margins of stability (MoS) were quantified by computing the distance between the vertical projection of the body's extrapolated center of mass (XCoM) and the boundary of the body's base of support (BoS). Lastly, net metabolic power was estimated from expired gas analysis using standard equations.

3 Experimental Results

As participants adapted to walking on the split-belt treadmill, we observed a gradual reduction in step length asymmetry and concomitant reductions in net metabolic power. Furthermore, there was a significant increase in step length and the MoS for the leg on the fast belt during late adaptation relative to early adaptation (Figure 1). These changes were temporally correlated with changes in metabolic cost ($r = 0.51$) and changes in the fast step length ($r = 0.7$). Similar results were observed during post-adaptation, but for the leg formerly on the slow belt.

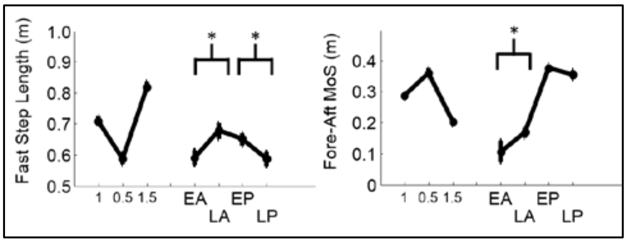

Figure 1: Changes in step length and fore-aft MoS for the leg on the fast belt

4 Conclusions and Future Directions

This study provides support for the notion that split-belt treadmill adaptation results from a complex interplay between stability, energetics, and movement errors. We are also exploring a model-based approach to better understand the role of passive mechanics during adaptation. We believe that this analysis will be especially enlightening as analysis of passive dynamic walking models has proved useful for informing our understanding of the interactions between mechanics, energy expenditure, and stability during human gait (Donelan et al., 2004; Kuo, 2005).

References

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