MECHANICAL AND METABOLIC REQUIREMENTS OF LATERAL STABILIZATION IN HUMAN WALKING

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INTRODUCTION

Human walking is passively unstable in the lateral direction (Kuo, 1999). Humans appear to actively stabilize lateral motion using medio-lateral foot placement (Bauby & Kuo, 1998). While this stabilization mechanism is effective, it is not without cost—precise control of the swing leg is required and variability in foot placement increases mechanical work (Donelan et al., 2001). Our purpose was to study the mechanical and metabolic requirements of active lateral stabilization in human walking. We hypothesized that external lateral stabilization would reduce the amount of active stabilization required to walk, resulting in less variability of medio-lateral foot placement and a lower metabolic cost.

METHODS

Ten healthy adults (6 male, 4 female) participated in the study after providing informed consent. They walked on a treadmill at 1.25 m/s, both with and without external stabilization (Fig. 1). To control for the effects of average step width, we instructed subjects to walk on a single line marked on the treadmill belt. We chose to enforce zero step width because our device stabilized the body about a trajectory with zero lateral movement. Subjects walked with arms crossed to prevent differences in use of arms to stabilize balance. Subjects practiced the experimental protocol prior to data collection.

The external lateral stabilizer consisted of lightweight elastic cords attached to a padded waist belt pulling in both lateral directions. The relatively long (8 m) cords insured that any non-lateral forces exerted by the apparatus were negligible. The device exhibited an effective spring constant of 1700 N/m and negligible damping (14 N-s/m).

Figure 1.

We developed a mathematical model, based on passive dynamic walking, to characterize the effect of the external stabilizer. The model predicted that the cords were sufficient to passively stabilize the body laterally, suggesting that the subject need not actively adjust medio-lateral foot placement with each step, as is normally necessary. The model therefore predicts lowered medio-lateral foot placement variability, as well as lowered metabolic cost due to the decreased active foot placement.

We measured center of pressure under the feet using a force treadmill (Kram, et al., 1998). We analyzed the first 200 steps after the subject had been walking for 150s. Step width for each step was defined as the lateral distance between consecutive centers of pressure, averaged over the single stance phase. We calculated variability in step width and length as a function of external stabilization. We also measured net metabolic power using standard methods of indirect calorimetry (Donelan et al., 2001).

RESULTS AND DISCUSSION

When stabilized, variability in step width decreased by 35% while metabolic cost decreased by 6% when compared to unstabilized walking (p= 0.0003 and 0.025, respectively). For comparison, step length variability decreased by a smaller amount (14%, p=0.01) than step width variability. Mathematical models predict this slight coupling between lateral and fore-aft dynamics. Average step width and length were not affected by stabilization (p= 0.80 and 0.69, respectively).

These results support our hypotheses that (a) lateral foot placement is used to actively stabilize walking, (b) external lateral stabilization reduces the need for this active stabilization, and (c) the reduced active stabilization results in slightly lower metabolic demand. Stability and energy consumption are concerns for groups such as amputees and the elderly. Mathematical modeling and empirical testing may lend insight into possible interventions for these groups.

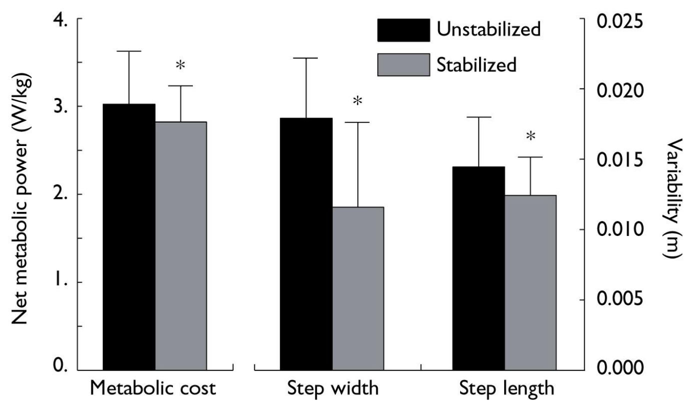

Figure 2. a) Metabolic cost, step width variability and step length variability decreased with stabilization.

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