CONTROL MECHANISMS OF LATERAL BALANCE DURING HUMAN WALKING

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MOTIVATION

Simple bipedal walking models suggest that walking is more unstable in the lateral direction [2]. The primary means of stabilizing balance appears to be foot placement, which exhibits greater variability laterally than fore-aft. That variability also serves as a predictor of falls in the elderly [1], perhaps because it indicates a degraded ability to control balance. It is likely, however, that other control mechanisms are also employed for balance. This is evidenced by tightrope walking, which is possible despite essentially eliminating foot placement and ankle torque for lateral stabilization. Alternative balance mechanisms might normally be less conspicuous than foot placement, making it a challenge to quantify their contributions.

STATE OF THE ART

Studies to date have largely focused on foot placement for control of balance, or on torques exerted by the stance leg's ankle on the ground [3]. In the case of tightrope walking, it is clear that other body motions can stabilize the body, even if they are not obviously employed during normal walking. Few studies have examined the contribution of these body motions in walking, nor the conditions under which they might become more apparent.

OUR APPROACH

We propose that multiple stabilization mechanisms contribute to lateral balance, and that their contributions may be made more evident through the application of constraints. Similar to the example of the tightrope walker, removal of foot placement as a control mechanism should lead to greater use of alternative mechanisms. By applying a succession of constraints, we hope to identify these mechanisms and determine the preferential degree to which they are used.

A simple dynamic walking model suggests several possible mechanisms for controlling lateral balance [2]. In addition to lateral foot placement and ankle torque, the torso and other body segments can be rotated to aid balance. We believe humans use these methods to correct for the variability inherent in walking due to, for example, noise in neurological systems. A passive walking model suggests that a noise-free system can walk using the same trajectory each step. However, in the presence of noise, the walker must laterally balance using a combination of mechanisms each step. Therefore, we interpret increased step-to-step variability in a balance mechanism to indicate additional usage in balance control.

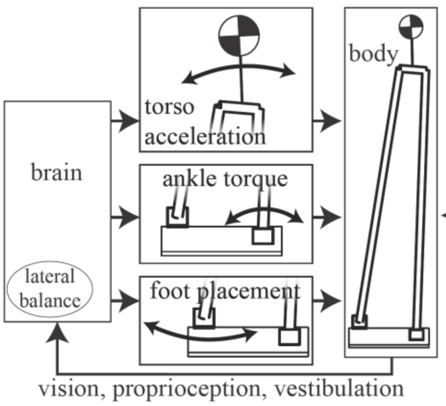

Figure 1: Conceptual model of walking. Noise inherent to walking disturbs the body's balance, which the brain senses and corrects using three potential mechanisms of lateral balance.

We experimentally tested the roles of several proposed mechanisms of lateral stability in normal human walking. The stability mechanisms studied are lateral foot placement, stance ankle torque, and torso roll acceleration. Subjects walked under several conditions on a treadmill: normal, step width constrained, and ankle constrained (figure 2). Step width was constrained by projecting lines onto the treadmill along the walking direction and asking subjects step on the lines. The ankle was constrained to reduce torques along the walking direction using an ankle roll brace. To measure the use of lateral foot placement, we calculate the lateral foot placement step-to-step variability. To measure the use of ankle torques, we calculate the ankle roll torque variation around average. Torso acceleration is measured as an excursion of average torso angular acceleration throughout a stride. If the three proposed lateral stability mechanisms are indeed used in walking, we expect that constraining each will increase the use of the other two proposed mechanisms on a step to step basis.

CURRENT RESULTS

Preliminary results suggest constraints on step width and ankle roll torque reduce the intended measure of lateral control, and generally increase other lateral balance methods (figure 2).

BEST POSSIBLE OUTCOME

We expect further experimentation to show the basic finding of variability in balance mechanisms to be experimentally controllable using simple constraints. Humans have more methods to balance laterally than the three proposed here, potentially including inertia from non-torso body segments, and step timing, and ideally these could be controlled for or measured as well. We will also investigate correlations between each balance mechanism and simple measures of lateral stability on a step-by-step basis, exploring how each balance mechanism effects lateral balance each step. This could lead to a sensitivity analysis for each balance mechanism and center of mass balance, as well as strategies of how individuals cope with loss of a balance mechanism. This may help indicate important measures of balance in people diagnosed with balance impairments in a specific mechanism, or those operating with environmental or physical constraints.

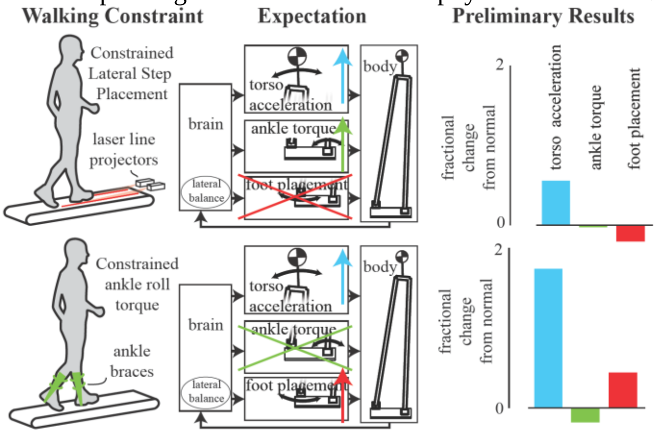

Figure 2: Experimental setup, expectations, and preliminary results. Each condition constrains a proposed lateral balance mechanism, which predicts a decrease in the associated balance metric and increase in the others.

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