The Role of Body Rotations in Control of Lateral Balance during Walking

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Motivation

Gymnasts and tight rope walkers may be observed to move their arms, lean their trunk, or swing out their legs to effectively maintain lateral balance while walking on a beam or rope. Untrained people sometimes also make similar body motions to stay balanced, although normally step placement appears to be a preferred means of stabilization. Perhaps body motions occur under more challenging circumstances where step placement is insufficient or constrained. Here we examine the conditions that favor additional body movement, and how it helps to maintain lateral balance.

State of the Art

One of the primary strategies for maintaining lateral balance during human walking is to adjust the location of the center of pressure (COP). One means of adjustment is step placement, where the foot should be placed laterally relative to the center of mass to reject mediolateral perturbations during walking. The COP can also be adjusted through application of ankle torque during stance [1]. Ankle torque is, however, less controllable in cases such as transtibial amputees and persons with arthrodesis. They may balance through wider step placement [2] among other strategies. Few studies have examined what other strategies should be and how they should be applied.

Own Approach

We propose that the observed rotations of the arms, torso, and leg are a strategy to counteract the perturbed motion of the center of mass, similar to a reaction wheel. If the body is falling in, say, the clockwise direction, the limbs should also be rotated clockwise, to induce a ground reaction force that will tend to restore the body to upright (Figure 1). We measure body rotations that walking human subjects perform about the antero-posterior axis, in response to lateral perturbations. Starting with the base case of normal walking, we introduce perturbations of various magnitudes. We then apply increasing constraints on known and potential balancing mechanisms, such as limiting lateral step placement location to reduce its ability to adjust COP. The response of body rotations is measured through motion capture and inverse dynamics of the various body segments. We expect that body rotations will be quite small for small perturbations to normal walking, but become quite large under higher perturbation forces and with the addition of constraints on normal stepping responses.

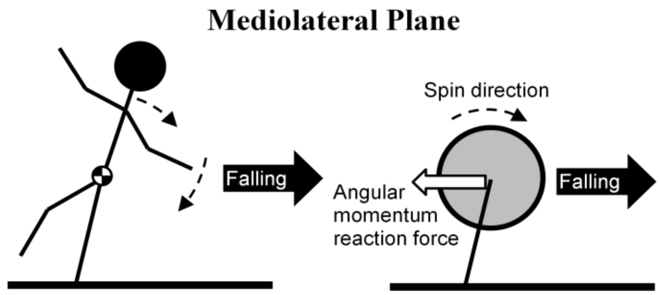

Figure 1: Movement of the arms, trunk, and swing leg in the mediolateral plane (left), referred to as body rotations, are analogous to a spinning reaction wheel (right).

Current Results

Pilot testing with lateral step placement constraints revealed significant arm, torso, and leg movement, with increased motion as perturbation force increased. The segments appear to rotate about the body in the mediolateral plane, and in the angular direction of the impending fall (Figure 1). We also observe shorter step times immediately after perturbations medial to the stance leg, and longer step times with more dramatic motions after perturbations lateral to the stance leg (when a preferred crossover step is prevented due to constraint). We theorize that body rotations help delay falling after perturbations where stepping is slowed by the need to cross medially around the stance foot.

Best Possible Outcomes

1. Humans complement step placement with body rotations to control lateral stability.
2. Humans can reason with angular momentum. The motions of the arms, torso, and leg after perturbation are consistent with reaction wheel control.
3. Body rotations can delay falling in the case of impeded step placement.

Acknowledgements

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References

[1] Hof et al. (2010) J Exp Biol
[2] Segal et al. (2012) GCMAS 2012