From Humans to Robots and Back: Role of Arm Movement in Medio-lateral Balance Control

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1 Introduction

In passive dynamic walking, it has been argued that bipedal walking is intrinsically unstable in the medio-lateral (ML) direction. Thus, body and in particular arm movements need to be actively controlled to maintain upright balance. Despite this important role in maintaining ML stability, arm movements have found relatively little consideration. With the goal of developing control policies in humanoid robot locomotion, this study investigated how humans control their arms to maintain stability in the ML direction.

To address this question, this study examined 3D body kinematics of humans walking on a narrow beam (3.4cm wide, 5m long). The limited support surface increased the instability in the ML direction compared to overground walking. To further examine how much the human control strategy depended on multi-joint arm movements, the degrees of freedom of the arms were constrained. Comparison of constrained and unconstrained balancing movements aimed to reveal the aspects of control that changed and those that remained unaffected by the kinematic model.

2 Methods

Sixteen healthy individuals participated in this experiment. In each trial, the subject walked along the beam at a self-selected speed. A trial was deemed successful, if the participant remained on the beam for its entire length. In the control condition, no constraints were applied and all participants completed as many trials as necessary in order to complete 20 successful trials. In the constrained condition, subjects performed the task with their arms constrained by rigid tubes to prevent movements in elbows and wrists (Figure 1). Subjects again performed as many trials as necessary to complete 20 successful trials.

We evaluated each trial by quantifying not only standard kinematic measures of gait, such as step period and length, and trial duration, but also individual segmental movements, indices of symmetry between limbs, and deviations of the center of mass (COM). In addition, whole-body angular momentum was computed, as prior studies suggest that angular momentum is a critical controlled variable in normal human locomotion.

3 Results

Preliminary results revealed kinematic differences between the constrained and unconstrained arm conditions. Counter to expectation, reducing degrees of freedom in the arm did not decrease stability in the ML direction. In fact, for subjects who were unstable in the control condition, the constrained arms improved their stability as indicated by less failed trials and deviations of the COM in the ML direction. Analyses of moment of inertia and natural frequency of the inverted pendulum of the body will quantify how extended arms may decrease the sensitivity to lateral variability and thereby increase ML balance. Identifying the invariance in control objectives across different kinematic models should indicate potential control objectives to improve stability in humanoid robotic locomotion.

Figure 1: Subject walking along a narrow ridge in the control condition (right) and with restricted elbow and wrist joints (left).