

## ASSESSMENT OF STABILIZING FEEDBACK CONTROL OF WALKING, A TUTORIAL

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### ABSTRACT

Walking without falling requires stabilization of the trajectory of the body center of mass relative to the base of support. Model studies suggest that this requires active, feedback control, especially in the mediolateral direction. In older adults and in individuals with neurological or orthopedic disorders that affect walking ability, falls during gait are a common cause of injuries, hospitalization and loss of independence. In this tutorial, we illustrate how gait analysis can be used to assess the stabilizing feedback control of gait. We present methods ranging from those that require limited input data (e.g. position data of markers placed on the feet and pelvis only) to those that require full-body kinematics and electromyography. Analyses range from simple kinematics analyses to inverse dynamics. These methods assess stabilizing feedback control of human walking at three levels: 1) the level of center of mass movement and horizontal ground reaction forces, 2) the level of center of mass movement and foot placement and 3) the level of center of mass movement and the joint moments or muscle activity. We show how these can be calculated and provide a GitHub repository (<https://github.com/VU-HMS/Tutorial-stabilizing-walking>) which contains open access Matlab and Python code to calculate these. Finally, we discuss what information on feedback control can be learned from each of these.

### 1. INTRODUCTION

Preventing a fall while walking requires stabilization of the position of the body center of mass over the base of support. The common occurrence of falls in toddlers who learn to walk, illustrates the difficulty of this control process. Falls are quite common also in older adults and in people with orthopedic or neurological disorders (Lord et al., 2001; WHO, 2007) and more importantly in these groups the consequences of falls are often severe (MacIntyre & Dewan, 2016; Talbot et al., 2005; Wenning et al., 1999).

From a mechanical perspective, it is not surprising that falls are common during walking. In human bipedal gait, the base of support is formed by those parts of the feet that are in contact with the floor. The base of support during walking is small, particularly in single stance. In addition, a large part of the total body mass is located high above the base of support. Consequently, even small deviations of the center of mass position can result in substantial gravitational moments that accelerate the center of mass out of the base of support. Both internal sources of noise (e.g. sensory noise and motor noise) and external perturbations (e.g. uneven terrain, gusts of wind) can cause deviations in center of mass position with respect to the base of support. Given that walking is inherently unstable, ongoing (intermittent or continuous) stabilization is needed, to avoid cumulative effects of small perturbations over time. When major perturbations occur, which are here defined as external mechanical events that disturb the relation between center of mass and base of support beyond the variance observed in unperturbed gait, the need for stabilizing control is evident.

Stabilization of gait can be achieved by passive and active mechanisms. Passive stabilization relies on the passive mechanical properties (stiffness, damping and inertia of the human body), whereas active

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