At What Speed does Walking Become “Dynamic”? Interplane Coupling as a Measure

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I. Introduction

Walking speed is considered by some to be the 6th vital sign because it is a valid, reliable and sensitive measure that can predict rehabilitation outcomes, cognitive decline, disabilities, and cardiovascular events [1]. Healthy individuals generally walk at self-selected speeds of 1.0 to 1.4 $\frac{m}{s}$, depending on age and sex. The speed of “community ambulation,” typically considered 0.44 $\frac{m}{s}$, indicates the walking speed threshold below which an individual is unable to participate actively in society and have a healthy lifestyle [2]. Over 800,000 individuals in the U.S. cannot achieve this speed of walking, so they are not considered community ambulators. Traumas such as spinal cord injury, stroke, and lower limb amputation often contribute to slow walking speed, and the return to community ambulation is a common rehabilitation goal.

Is walking at speeds below the community ambulation threshold dynamic? Regardless, what is the threshold for walking to be “dynamic”? These are semantic questions, but the kinematics and kinetics of walking at very slow speeds are quite different from those at self-selected speeds. For example, the mediolateral displacement of the mass center at slow speeds is more than twice that at self-selected speeds, while the vertical displacement is only about half [3]. See Fig. 1. Flat foot posture at touchdown as opposed to rolling on the heel in early stance, a reduction in knee flexion during this same phase of gait, absence of ankle plantar flexion at toe off, and reduction of EMG amplitudes are other key differences. While these difference are clear, there is no obvious demarcation of (or Froude number equivalent to predict) the transition from very slow to dynamic walking, and a better understanding of that transition could inform rehabilitation strategies.

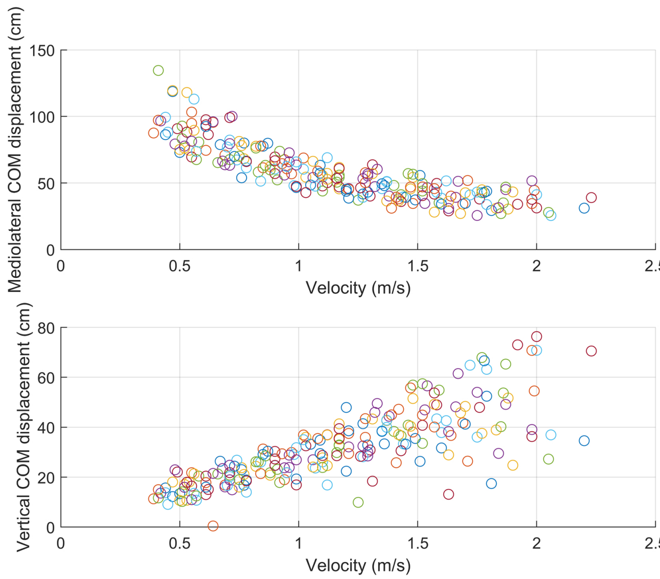

Fig. 1. Mediolateral & vertical displacements of mass center as function of speed for 27 subjects walking on treadmill. (Data from [4].)

II. Dynamic Coupling

This work proposes that a measure of the coupling between the dynamics in the frontal and sagittal planes marks the transition from slow to self-selected-speed walking mechanics. The amount of this coupling changes nonlinearly with speed, which has been previously exploited to design controllers for underactuated biped robots that are more robust to external disturbances [5]. Applying this to human locomotion, the coupling metric can quantify how the sagittal plane motion favorably contributes to stabilizing the frontal plane dynamics at higher walking speeds. It can likewise quantify how the absence of the stabilizing coupling effects at slow walking speeds contributes to the different gait strategy to maintain balance. The speed at which the “elbow” in the nonlinear coupling metric curve can be found marks the transition from slow to dynamic walking. In this way, the coupling provides a quantitative measure of the speed at when walking is truly dynamic. Future work will examine how the use of various ambulatory assistive devices (AADs) influence the coupling metric via their impact on gait mechanics.

References

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