ANALYSIS OF AMPUTEE GAIT USING CENTER-OF-MASS VELOCITY

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INTRODUCTION

Clinical gait evaluation in a laboratory produces abundant data regarding kinematics, moments, and powers at the joints. Although joint motion is critical to walking, there are few measurements that evaluate motion of the body center of mass (COM). Such measures could potentially augment joint data and contribute to understanding of gait abnormalities. Here we show that a cyclic plot of the COM's trajectory in velocity space, called a COM *hodograph*, exhibits distinct features that differ between normal and pathological gait. The features arise from abnormalities such as asymmetric work output and impaired push-off. They can be linked to unilateral leg function for highlighting gait asymmetry, and can be quantified for objective comparison.

METHODS

We measured ground reaction forces (GRF) while unilateral transtibial amputees (n = 4) and non-amputees (n = 10) walked over two in-floor force plates. From the measured GRF and walking speed, we computed COM velocity over a complete stride cycle (Cavagna, 1975). We plotted the COM hodograph as the vertical component of COM velocity versus its fore-aft component (Fig 1; Greenwood,1988). We noted prominent features differentiating the hodographs of amputees (Fig 2) and non-amputees (Fig 1). We compared these features to the underlying GRF in order to determine the functional abnormalities that caused them.

A typical COM hodograph for a non-amputee is shaped like a rounded letter D, with one counter-clockwise loop for each leg's stance phase (Fig 1). Double support spans the right (highest-speed) portion of each loop and single support spans the left portion. Just before heel strike, the trailing leg commences push-off, reducing the downward COM velocity and giving the bottom of the D an upward slope. During double-support both legs redirect the COM velocity upward, forming the rounded portion of the D. The maximum up-

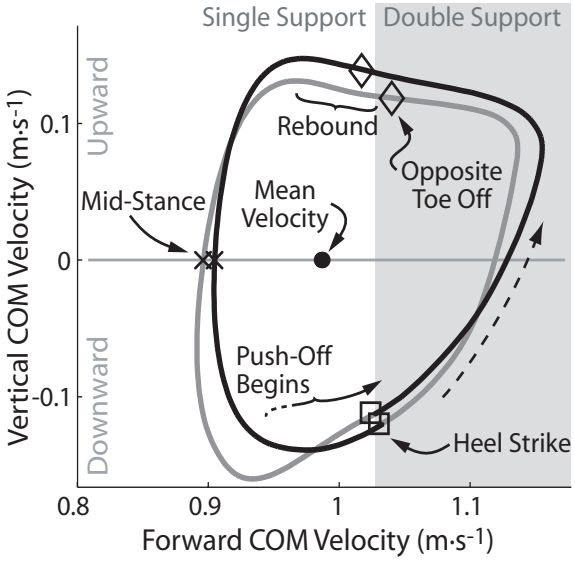

Figure 1: Sample COM hodograph for a complete stride cycle of a non-amputee walking at 1.0 m·s^{-1}. Labels indicate mean velocity and the timing of heel strike, opposite toe off, rebound, mid-stance (defined as zero vertical velocity), and early push-off. Light: Left Stance; Dark: Right Stance

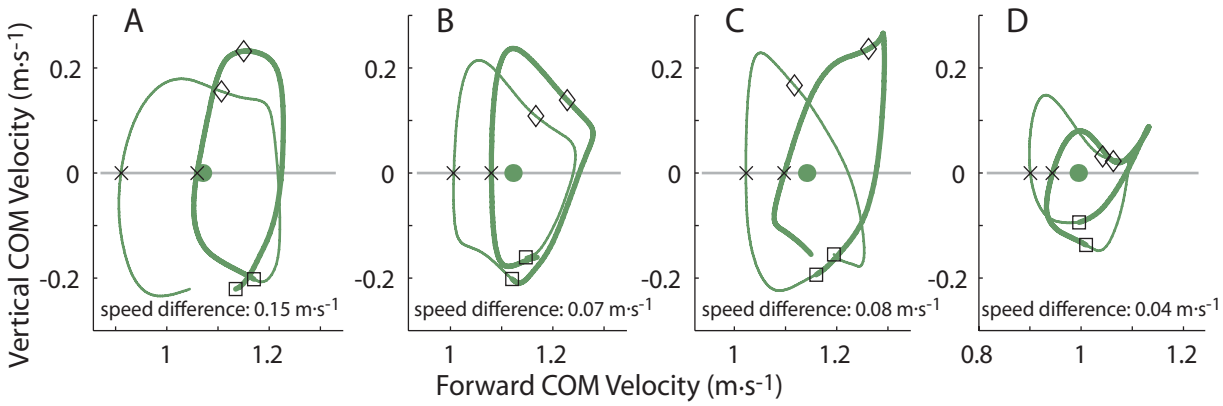

Figure 2: COM hodographs from four unilateral transtibial amputees. One abnormality is that mid-stance forward speed is higher during prosthetic stance than during intact stance, indicating asymmetric acceleration and deceleration of the COM (A-D; speed difference is given for each subject). Other features such as asymmetric forward speed range (A), downward acceleration at intact heel strike (A,C,D), and negative vertical acceleration during late double-support (C-D) may yield additional subject-specific insight. Thin lines: Intact Leg Stance; Thick lines: Prosthetic Leg Stance. Gait events denoted by symbols as in Fig 1.

ward COM velocity occurs after toe-off as a "rebound" from leg compression. Finally, the middle portion of single-support is characterized by a smooth downward acceleration.

RESULTS AND DISCUSSION

One feature of the amputee COM hodographs is substantial asymmetry in walking speed. We quantified this by comparing the forward COM velocity at mid-stance for the two legs. Intact subjects had only slight speed asymmetry (Fig 1; absolute value of speed difference 0.0123 ± 0.0125 m·s^{-1}, mean ± S.D.), while amputees exhibited speed asymmetry of 0.04 to 0.15 m·s^{-1} (intact-affected speed difference, Fig 2A-D). This may be due to a reduced ability to push off with the prosthetic leg and compensations such as increased push-off with the intact leg.

Additional features of the amputee COM hodographs may provide additional insight into the specific gait of each individual. For example, three amputees exhibited downward (rather than normal upward) acceleration at the time of intact heel strike (Fig 2 A,C,D). For these amputees, prosthetic side vertical push-off GRF does not exceed body weight before heel strike as it does in most intact limbs. Other features include asymmetries in speed fluctuation (Fig 2A) and unusual downward acceleration during late double-support (Fig 2 C-D). These features may be helpful for understanding how a wide variety of gait impairments influence COM motion, and could potentially be quantified as with speed asymmetry.

The hodograph provides a simple summary of COM motion that can complement traditional gait rehabilitation techniques. It highlights abnormal gait patterns in ways that cannot be observed visually. It does not require extensive equipment, and can be constructed with as little as a single force plate.

REFERENCES

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