Center of Mass Mechanics in Amputees – Asymmetric Gait for an Asymmetric Body

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SUMMARY
Amputees have reduced capacity for ankle push-off work due to lost leg musculature. Dynamic walking predicts kinetic and energetic consequences for asymmetric push-off based on center of mass (COM) mechanics. Unilateral changes in push-off alter the step-to-step transition, which then affects the next step. We demonstrate consequences of asymmetric push-off on COM mechanics in amputees.

INTRODUCTION
Symmetry of the non-amputee body yields a fairly symmetric gait. In unilateral amputees, reduced push-off affects gait symmetry and COM motion. Many asymmetry studies of amputees focus on uneven gait timing or joint mechanics, but a simple mechanical view of the effects of reduced push-off has been largely overlooked.

Unimpaired gait is often studied through the motion of the COM. Dynamic walking studies have shown that much of the energetic cost of gait can be attributed to work performed on the COM [1] as a mechanical consequence of non-pendular COM velocity changes [1,2]. We have used the COM *hodograph*, a plot of COM velocity components (Fig. 1A), to show that COM velocity fluctuation patterns are affected by changes in gait [3]. Here, we investigate asymmetric COM work and COM velocity fluctuations in unilateral transtibial amputees.

METHODS
Seven male unilateral transtibial amputees walked at comfortable speed (1.00 to 1.25 m·s^{-1}) over two in-ground force plates to yield ground reaction forces (GRF). We integrated GRF to estimate COM velocity and COM work rate, assuming periodic gait [1]. We integrated COM work rate to find total positive and negative COM work performed during each push-off and collision, and during the whole stride. We compared COM work and COM velocity fluctuations during prosthetic and intact steps.

Dynamic walking principles suggest three consequences of unilateral reduced push-off. The first is a greater collision on the contralateral (intact) side. This may be accompanied by reduced forward speed during the ensuing step. Second, a person could compensate with greater push-off work on the intact side. Differences in push-off would cause differences in the vertical change in COM velocity during the step-to-step transition. Finally, another possible compensation is to "pull" the body through stance with the hip muscles. This strategy would reduce the total negative work the prosthetic side performs, and may reduce the decrease in forward speed before mid-stance.

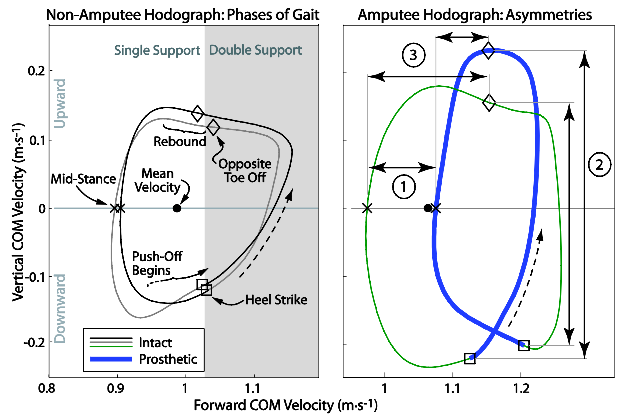

Figure 1: **A)** A typical non-amputee has a nearly symmetric hodograph, progressing counterclockwise through the phases of gait. **B)** A typical amputee exhibits notable asymmetry in (1) mid-stance forward velocity, (2) vertical velocity change during double support, and (3) forward velocity reduction in early single stance.

Results are compared to non-amputees, and normalized to mass M and walking speed v. $P < 0.05$.

RESULTS AND DISCUSSION
Changes in COM work and COM motion were consistent with collision and hip-pull adaptations, but not increased intact push-off (Fig. 1B). First, COM work in collision was higher for the intact than the prosthetic side (0.14 vs. 0.07; control 0.11Mv^2). As expected, COM velocity at the following intact side mid-stance was lower than at prosthetic mid-stance (0.89 vs. 0.98; control 0.93v; Fig. 1B, (1)). Second, COM work in push-off was higher for the intact side than the prosthetic side (0.16 vs. 0.08), but less than controls (0.19Mv^2). The associated double-support increase in vertical COM velocity (from falling to rising) was greater for intact side push-off than prosthetic push-off (0.46 vs. 0.30; control 0.23v; Fig. 1B, (2)). Finally, prosthetic side work outside the step-to-step transition was more positive than intact side work (0.05 vs. -0.11; control -0.08Mv^2). There was also a smaller decrease in forward velocity during early prosthetic single support (0.10 vs. 0.16; control 0.12v; Fig. 1B, (3)).

Weak push-off in amputees appears to be compensated by ipsilateral single stance work. Dynamic walking principles help assess this functional asymmetry in COM mechanics.

REFERENCES
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