How do we start from standing to walking?

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1 Motivation

Maintaining balance in steady states/gaits (i.e. walking, quiet standing) and especially for transitions is important for humans and bipedal robots. Walking gait initiation is a common gait transition in daily life. It requires 1) propulsive forces which generate forward movement, and 2) stepping leg control which lifts the leg and puts it in front of the center of mass (CoM) to catch up the falling. Several studies have been done to describe the characteristics of walking initiation [1, 2]. The goal of this study is to investigate human lower limb joint functions and underlying mechanisms during the walking gait initiation.

2 Method

Walking initiation experiments with three different self-selected target speeds (slow, normal, and fast, 8 repetitions each) were conducted. Eleven young healthy subjects (one female, ten males, age 26.6±3.9 years, body mass 73.3±8.6 kg, height 1.8±0.1 m) were instructed to stand and walk barefoot on an instrumented walking track (6m long, 1m wide, 7 force plates, Kistler, Switzerland). Ground reaction force (GRF) was recorded at 1kHz. Full body kinematics were recorded by 10 high-speed cameras (Qualisys, Sweden) at 500Hz. Subjects were instructed to start with the left leg (see Figure 1). Joint torque and power were computed based on inverse dynamics. The CoM positions were computed by combining both kinematics and GRF. The starting of initiation was defined as the moment when the displacement between the center of pressure (CoP) and the CoM in walking direction is larger than 2cm. The end of initiation is defined as the lift-off moment of left leg.

3 Prelimiarly results and discussions

Target speeds were 1.00±0.09 m/s for slow, 1.48±0.15 m/s for normal, and 2.21±0.16 m/s for high. The results (Figure 1) show that at the beginning of initiation the vertical force of the left leg first increases, whereas it decreases in the right leg. This indicates that subjects try to move the CoM to the right side while keeping the CoM vertical position constant. Gait initiation time is almost the same for all three speeds (start at 0.34s, end at 1s). Both left and right ankle torques decrease at the beginning of the initiation. For normal and fast speed, ankle torques decrease to almost zero, which makes the movement of CoM similar to an inverted pendulum. There is almost no power output from both ankles before left leg lift-off. These results indicate that the lifting leg ankle of prostheses or exoskeletons could stay passive during gait initiation.

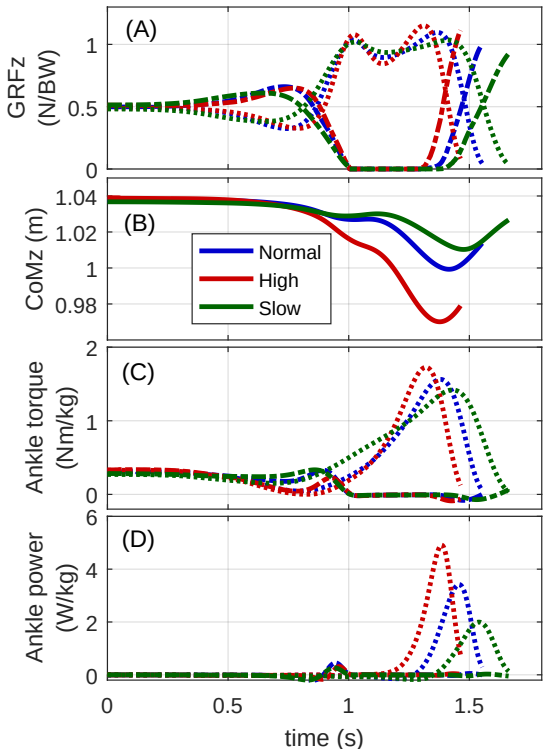

Figure 1: Dashed line and dotted line denote left and right leg. (A) Vertical GRF normalized to body weight. (B) CoM height. (C) and (D) are ankle torque and power normalized to body mass. All trials are synchronized to the lift-off of the left leg (t=1s).

For all three different speeds, the transition from standing to walking is initiated by shifting the total CoP to the left-backward side (Figure 2(A)). This results in a CoM velocity towards right-forward direction (Figure 2(B)) and makes it possible to lift left leg afterwards without falling to the left side. The maximum mediolateral velocity for all three speeds are quite similar. And the magnitude of the mediolateral velocity at the left leg TO and TD across all speeds are also consistent. This suggests that, although the dominant locomotion of human walking is in the sagittal plane, the frontal plane leg movement might play a key role to the overall leg control.

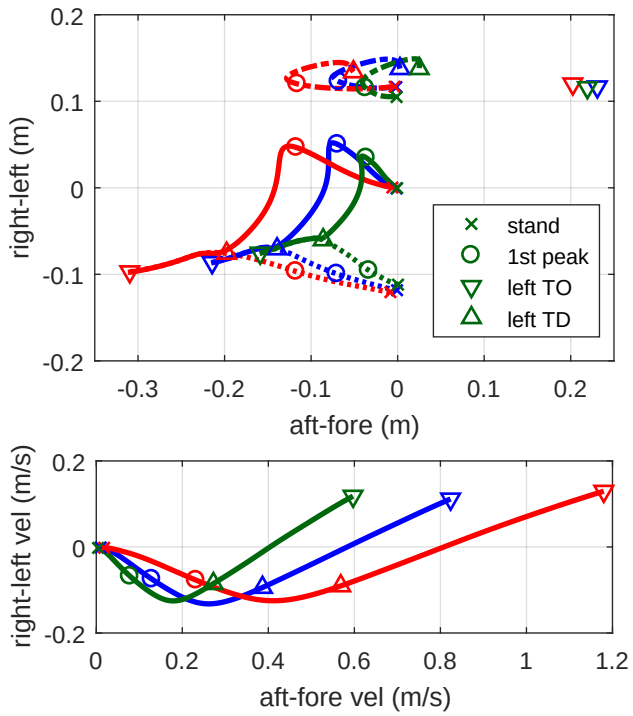

Figure 2: From quite standing to the first TD of left leg. Green, blue and red color denote slow, normal, and fast speed. Left and forward direction are defined as positive. TO and TD denote toe-off and touch-down. (A) Displacement from CoP to CoM in the transverse plane. Dashed, dotted and solid line denote left, right and total CoP. (B) Fore-aft velocity vs. mediolateral velocity.

References

[1] Brenire Y and Do MC (1986) When and how does steady state gait movement induced from upright posture begin? *J. Biomechanics*, 19(12):1035-1040.

[2] Brenire Y and Do MC (1991) Control of gait initiation. *J Mot Behav*, 23(4):235240.