Leg stiffness increases with load to achieve resonance-based CoM oscillation

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1 Motivation

Oscillatory behavior of the center of mass (CoM) was reasonably well represented by mass-spring walking model. In addition, the gait frequency was reported to be highly correlated with the resonant frequency of the mass-spring model [1]. To examine whether the observed high correlation is a robust gait characteristic, we varied the loading condition and see if the leg stiffness was adjusted to maintain the speed-dependent resonant frequency.

2 State of the Art

Stiffness increase in loaded gaits was consistently reported [2, 3], mostly using the approach of estimating the stiffness based on the regression of static force-displacement relationships, such as vertical stiffness, joint stiffness, or average stiffness over the finite gait phase. Therefore, the previous reports on increased leg stiffness have limitations in directly being interpreted as gait dynamics perspective.

3 Own Approach

Therefore, we calculated the leg stiffness based on the kinetics of CoM oscillation [1] and examined whether the resonant-based gait characteristic was consistently observed in various loading conditions. Seven healthy subjects participated over ground walking with and without wearing a 25-kg backpack at three different walking speeds. Ground reaction force and position of markers on each joints data were measured by three force plates and six motion capture cameras. Leg stiffness was estimated from spring constant of mass-spring-damper walking model that best matched empirical data of ground reaction force (GRF). To confirm suggested presumption that the change of stiffness would relate to CoM oscillation frequency, we compared the duration of single support phase with natural frequency of leg stiffness.

4 Current Results

The result showed that leg stiffness increased with load and leg stiffness normalized by total weight (body mass added backpack) was well approximated to each loading conditions. Resonant oscillation period has high correlation with the duration of single support phase. The result showed that optimal leg stiffness that maximized propulsion energy was well approximated to empirical leg stiffness for both loading conditions, implying that resonant-based gait dynamics has energetic benefit.

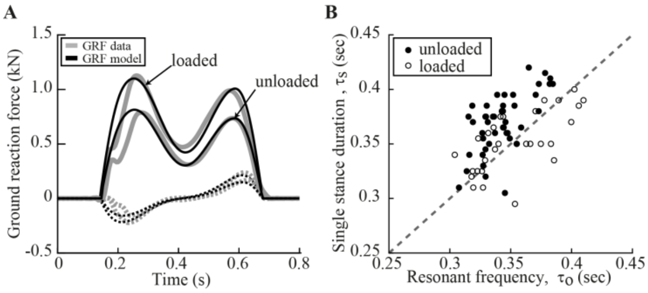

Figure 1 (A) Comparison of the simulated and empirical GRFs and (B) resonant frequency (τ_o) and single stance duration (τ_s).

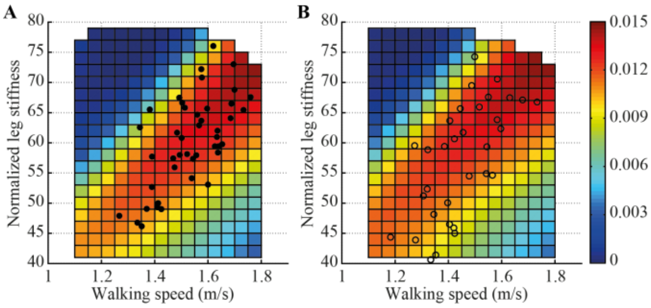

Figure 2 Propulsion energy stored at the end of single support phase for (A) unloaded and (B) loaded conditions. The magnitude of propulsion energy was represented by color code at the right side of plots. The estimated leg stiffness was plotted on top of the energy level (filled circles for unloaded, hollow circles for loaded conditions)

5 Best Possible Outcome

We expect to observe resonant-based gait characteristic from non-steady gait trials such as transient, asymmetric, walking trials.

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References

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