Gait strategy changes with walking speed to accommodate biomechanical constraints

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SUMMARY

To maintain steady state walking, ankle push-offs dominantly provide positive works against impulsive loss during heel strike. However, at higher gait speed which requires greater compensatory ankle push-offs, biomechanical constraints on maximum plantar flexion would require alternative gait strategy. Subjects walked along the 10 m walkway with randomly ordered five different, slower to the maximum, gait frequencies. The magnitudes of impulsive push-offs saturated while heel strike impulse increased with gait speed. The mechanical energy increase during the swing phase approximately compensated the impulsive deficit by the push-offs, implying that biomechanical constraints induce gait strategy change from ankle to hip strategy.

INTRODUCTION

Steady state human locomotion at level ground needs compensatory energy input against impulsive energy loss during heel strike. Ground push-off by the stance leg right before the onset of double support phase appeared to be four times energy efficient than the an active hip torque generation during the swing phase [1]. However, if there is biomechanical constraint applied to the maximum allowable ankle push-off, despite its cost effectiveness, the nervous system may need to employ active hip torque to compensate heel strike energy loss to maintain steady state walking, as similar to the postural strategy changes from ankle to hip strategy to accommodate biomechanical constraints in response to backward perturbation [2]. In this study, we hypothesized that the gait strategy changes from ankle strategy (that compensates heel strike energy loss mostly by the ankle joint push-off impulse) to hip strategy (that generates additional energy input using active hip joint torque during the swing phase) to accommodate biomechanical constraints at ankle joint torque.

METHODS

Eight healthy male volunteers aged 23-27 participated in this study after signing informed consent approved by KAIST IRB. Subjects walked along the 10m walkway with randomly ordered five different gait frequencies given by the auditory cues while having almost constant step lengths. The uniform interval of gait frequencies was obtained by the one third of gait frequency difference between the self-selective and maximum gait frequency. Ground reaction forces of each foot and joint kinematics were measured by dual force plates and optical motion capture system, respectively. Collision impulse was calculated by an integral of ground reaction forces measured from the force platform over the duration of collision. Mechanical energy was calculated by the sum of potential and the kinetic energy of the center of mass using a sacral marker.

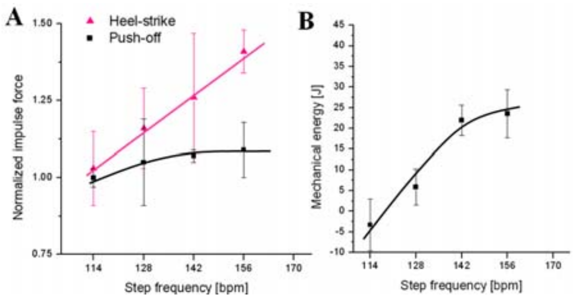

Figure 1: (A) Impulsive force of the ankle push-off and heel strike at double support phase. (B) Increase of mechanical energy during swing phase.

RESULTS AND DISCUSSION

Peak impulsive force of both push-off and heel strike were not significantly different in magnitudes at slow step frequency, but push-off impulsive forces appeared to saturate for the higher step frequency trials. The magnitudes of the impulse were almost similar with each other at slower gait speed while the push off impulse was significantly smaller than the heel strike impulse at higher step frequency due to the saturated push off impulsive forces. The differences in the mechanical energy between the beginning and the end of the swing phase were negligible at slower step frequency, while they monotonically increased with step frequency

Biomechanical constraints on ankle joint torque was demonstrated by the saturated ankle joint push-offs. Increased mechanical energy during the swing phase implies that the nervous system employs active hip torque to compensate heel strike energy loss to maintain steady state walking despite its higher energy cost than the ankle push-offs. As was observed in the postural strategy change [2], the results suggest that biomechanical constraints induce gait strategy change from ankle to hip strategy.

REFERENCES

1. Kuo, AD, *J Biomech Eng*. **124**, 113-20, 2002.
2. Park, S., et al. *Exp Brain Res*. **154**, 417-27, 2004.

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