THE OPTIMAL RELATIONSHIP BETWEEN ACTUATOR STIFFNESS AND ACTUATION TIMING FOR A PASSIVE ANKLE EXOSKELETON: AN OPENSIM SIMULATION

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Introduction

The passive ankle exoskeleton developed by Collins et al. (2015) reduced the metabolic cost of walking with an actuation-timing of ~16% of stance [1]; however, other actuation timings have not been extensively investigated. Therefore, the purpose of this study was to determine the optimal relationship between actuator-stiffness and actuation-timing for a passive ankle exoskeleton by using musculoskeletal modeling.

Methods

Kinematics and ground reaction forces were recorded while a healthy-young male walked on overground force-plates, and these data were exported to a musculoskeletal modeling software (OpenSim) for simulation. A passive ankle exoskeleton model was designed and integrated with a default OpenSim lower-limb model. A total of 2000 simulations were performed to test all combinations of 20 actuator stiffnesses (5.5-17.5 kN/m) and 10 actuation timings (15-60% stance) across 10 walking steps. The Umberger probe [2] was used to estimate the metabolic rate of each muscle and the integrals of the metabolic rates for all the lower extremity muscles were used to estimate the total metabolic cost of walking.

Results and Discussion

The greatest reduction in metabolic cost (Δ -2.67% ± 0.83%, $p<0.01$) occurred at an actuation-timing of 15% of stance and an actuator-stiffness of 5.5 kN/m. These data support the results of Collins et al. and indicate that other actuation timings may not be effective at reducing the total metabolic cost of walking. These results can be directly applied to the development of passive ankle exoskeletons.

References

[1] Collins et al., “Reducing the energy cost of human walking using an unpowered exoskeleton,” Nature., vol. 522, no. 7555, pp. 212–215, 2015, doi:10.1038/nature14288.
[2] Umberger BR. Stance and swing phase costs in human walking. J R Soc Interface. 2010;7(50):1329-1340. doi:10.1098/rsif.2010.0084