A bird-inspired passive-elastic ankle-toe exoskeleton induces digitigrade (toe) walking in humans

Brekke A. Green
Biomechanics Lab
Penn State University
University Park, USA
bag5269@gmail.com

Greg S. Sawicki
PoẆer Lab
Georgia Tech
Atlanta, USA
sawicki@me.gatech.edu

Jonas Rubenson
Biomechanics Lab
Penn State University
University Park, USA
jonas@psu.edu

***Abstract*—A passive-elastic ankle / metatarsophalangeal exoskeleton induced digitigrade (toe) walking in human subjects. Engaging the spring reduced the metabolic cost of walking in the exoskeleton in three of seven participants. Passive contributions to ankle and toe work likely contribute to energy savings.**

Keywords—exoskeleton, walking, bio-inspired, mechanical work, passive-elastic

I. Introduction

Passive-elastic lower-limb exoskeletons aim to reduce the metabolic cost of walking by taking advantage of elastic springs that provide both assistive passive torque and mechanical work. [1]. We propose that further advances in passive-elastic assistive exoskeletons can be achieved by drawing inspiration from non-human species that exemplify elastic gait mechanics. Unlike humans, the majority of cursorial species walk and run on their toes (digitigrade). This mode of locomotion facilitates elastic energy storage and return in muscle-tendon units that cross both the ankle and the metatarsophalangeal (MP) joint. For example, the ostrich has been shown to produce fifty percent of the positive mechanical work of the stance phase of running through elastic recoil at the tarso-metatarsophalangeal joint [2].

The purpose of the present study was to design and test a biologically-inspired human exoskeleton prototype that emulates the storage and return of elastic energy at both the ankle and MP joints typical of the gait mechanics of efficient non-human cursorial species.

II. Methods

The exoskeleton (EXO) consisted of three segments: (1) a shank frame; (2) a rear-foot frame mounted to a running shoe; and (3) a fore-foot plate that was mounted to the running shoe under the toe box (Fig. 1). A spring cord ran across a pulley situated on the rear-foot frame behind the ankle and continued across a second pulley on the rear-foot frame to terminate on the fore-foot plate. Two parallel linear steel springs (7 kN/m each) were positioned in the spring cord line behind the calf. Two strain gauge load cells (Omega) measured spring force.

Metabolic cost was measured in seven subjects (Cosmed K4 / K5) during treadmill walking (1.25 m s^{-1}) without the EXO; with the EXO but with no elastic component engaged; and with the EXO fully functional. Overground joint mechanics were recorded in the same conditions at a similar speed (1.25 m s^{-1} ± 5%; 8-camera Motion Analysis Corp; two AMTI force plates).

III. Results & Discussion

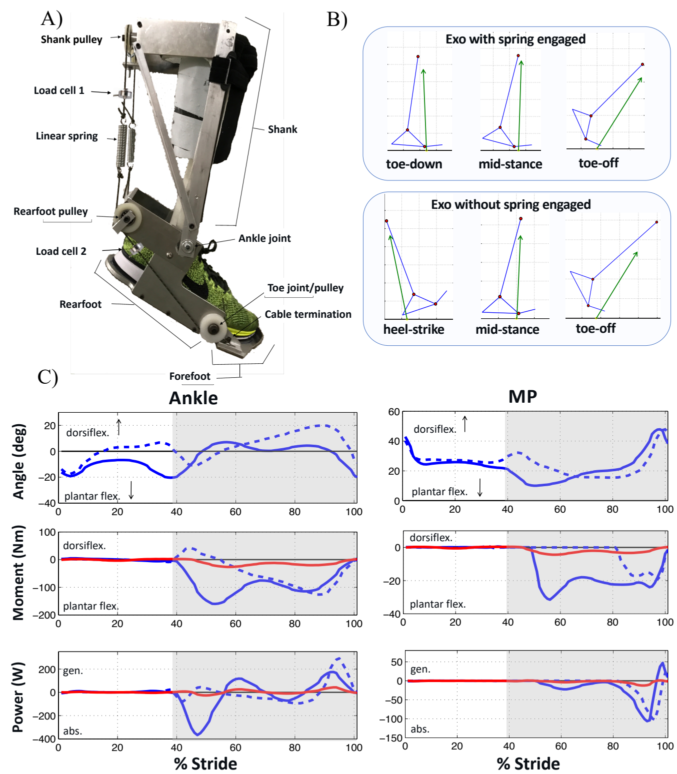

Fig. 1. A) EXO design; B) Center of pressure and ground reaction forces during the stride; C) Gait mechanics with EXO spring assist (solid blue), without spring assist (dashed blue) and the EXO spring contribution (red).

The EXO resulted in a center of pressure anterior to the MP joint. The EXO spring contributed to 20% and 15% of the peak ankle an MP moments, respectively, and 25% of the ankle work. Metabolic cost was reduced by engaging the EXO spring in three subjects, remained constant in one and increased in three subjects. A two-joint passive ankle-toe EXO can repurpose the MP joint to function more spring-like during walking.

References

[1] S.H.. Collins, M.B Wiggin, G.S. Sawicki "Reducing the energy cost of human walking using an unpowerede exoskeleton". Nature, vol 522, pp.212–5, 2015.

[2] J. Rubenson, D.G. Lloyd, D.B. Heliams, T.F. Besier, P.A. Fournier. "Adaptations for economical bipedal running: the effect of limb structure on three-dimensional joint mechanics." J. R. Soc. Int, vol 8, pp. 740–55, 2011.