Project Title: Optimizing Ankle Exoskeleton Assistance for Walking Across the Life Span

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Study Protocol

We used commercially available bilateral ankle exoskeletons (Dephy Inc, Boxborough, MA) with custom controllers to provide plantarflexion assistance to each user. The exoskeletons have on-board encoders and inertial measurement units to enable state-based control.

Participants walked in six conditions: (1) without ankle exoskeletons (NoExo), (2) ankle exoskeletons without assistance (NoTorque, (3) exoskeletons with springlike assistance (Spring), and exoskeletons with three motorized assistance strategies with increasing peak torque: (4) 10 N-m (MotorLow), (5) 20 N-m (MotorMed), (6) 30 N-m (MotorHigh). The spring-like assistance used impedance control without damping to apply torque with a spring stiffness of 70 Nm/rad. The assistance began in the foot-flat position after heel strike and ended at toe off mimicking a spring and clutch mechanism than enabled storage and release of elastic energy in stance and free foot motion during swing. The torque profile for the motor assistance conditions was specified by a spline generated from four nodes: peak time, rise time, fall time, and peak torque. The spline settings were based on a previously published study that used human-in-the loop optimization to minimize metabolic cost for a group of younger adults walking at medium speed. For this experiment, we scaled the HiLO torque pattern to match our desired low, medium and high peaks values at preset values of 10, 20, and 30 N-m.

Participants completed testing over three sessions walking at 1.25 m/s on an instrumented split-belt treadmill (CAREN, Motek, Netherlands). The sessions were conducted in a set order: 1) habituation, 2) gait mechanics, and 3) steady-state metabolic energy consumption. Waiting periods between sessions were minimized to allow for learning and retention of walking patterns with exoskeleton assistance (2-7 days on average).

Session 1 – Habituation.

Previous work has shown the importance of habituation for the acceptance of assistance from exoskeletons. In the first session, each participant walked with spring-like assistance for three, seven-minute intervals for a total of 21 minutes. They also walked with motorized assistance for three, seven-minute intervals while increasing peak torque (10, 20, 30 Nm) with each bout.

Session 2 - Gait Mechanics.

The primary goal for the second session was to obtain biomechanical measurements. Reflective markers were placed on participants' lower limbs and torso to collect motion of the hip, knee and ankle joints and an instrumented treadmill was used to collect ground reaction forces form each limb. We instrumented participants with surface electromyography to record muscle activity on the right leg [tibialis anterior (TA), lateral gastrocnemius (LG), soleus (SOL), rectus femoris (RF), biceps femoris (BF), gluteus medius (GMd), and gluteus maximus (GMx)]. Participants were re-habituated to the exoskeleton assistance for 6-minutes prior to walking with exoskeletons without assistance, with spring-like assistance, and with motorized assistance. During the motorized assistance habituation period, we increased the peak torque every 2 minutes. After each condition's habituation trial, participants walked for a 2-minute data acquisition period. The exoskeleton assistance order was randomized for each participant.

Session 3 - Steady-State Metabolic Energy Consumption.

Participants began the third session with a five-minute standing trial to record their metabolic resting baseline. Participants were fitted to a portable indirect calorimetry device (COSMED K5, Rome, Italy) to collect energy expenditure for each condition. We repeated the habituation process conducted during Session 2 - Gait Mechanics. The participants walked for six minutes in each of the six conditions in a randomized order with the respective habituation trial preceding a measurement trial.