Project Title: Improving Community Ambulation for Stroke Survivors using Powered Hip Exoskeletons with Adaptive Environmental Controllers

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Study Protocol

Over the last decade, research groups have explored methods to optimize different assistance strategies to maximize the human exoskeleton performance in different environmental settings. However, these studies were often conducted at a specific condition and did not capture what a user would experience in a realistic setting. Previous study indicated that, for a given environmental setting, there is an optimal assistance that can maximize the energetic benefit of using an exoskeleton. This optimal assistance level is dictated by the user's underlying biomechanical demand, mainly the user's biological joint moment during different locomotor activities. For example, during the extension movement, providing a relevant extension torque in the same direction of the user's leg is important. Additionally, setting the timing of these different assistance can easily change the overall performance of the exoskeleton. From this study, we have developed a powered hip exoskeleton that optimized assistance timing and magnitude based on previous literature findings. The benefit and advantage of this controller is that it is capable of providing assistance in different ambulation settings such as ramps and stairs.

To test the effect of our controller, we utilized a lightweight autonomous powered hip exoskeleton that can provide hip flexion and extension assistance bilaterally in the sagittal plane (Gait Enhancing and Motivating System, Samsung Electronics, South Korea). The device has an actuator at each hip joint that can provide a joint torque up to 12 Nm. The device has an additional passive joint at the hip for free abduction and adduction in the frontal plane. Overall exoskeleton system had a mass of 2.1 kg. We controlled our exoskeleton system utilizing a biological torque controller to ensure consistent and continuous assistance throughout the gait cycle. The onset and peak assistance timing of hip flexion and extension were based on the values from our previous hip exoskeleton study, which showed the largest metabolic cost reduction for able-bodied subjects. The hip assistance was provided bilaterally in both flexion and extension in the same region that is relevant to the user's biological joint demand.

The assistance can be adjusted depending on the user's locomotion mode: 1) Level-Ground (LG), 2) Ramp Ascent (RA), 3) Ramp Descent (RD), 4) Stair Ascent (SA), and 5) Stair Descent. For LG, the assistance timing was set to 82%, 12%, 32%, 42%, 59.5%, 79.5% (flexion onset, flexion peak, flexion offset, extension onset, extension peak, and extension offset defining toe-off as 0%) within the gait cycle with the assistance magnitude set to 5.8 Nm for both extension and flexion, respectively. For RA, the assistance timing was set to 92%, 7%, 27%, 37%, 67%, 87% within the gait cycle with the assistance magnitude set to 10 Nm for extension and 3.5 Nm for flexion, respectively. For RD, the assistance timing was set to 67%, 12%, 37%, 52%, 57%, 62% within the gait cycle with the assistance magnitude set to 3.6 Nm for extension and 7.2 Nm for flexion, respectively. For SA, the assistance timing was set to 97%, 27%, 37%, 47%, 62%, 87% within the gait cycle with the assistance magnitude set to 7.1 Nm for extension and 4.3 Nm for flexion, respectively. For SD, the assistance timing was set to 77%, 7%, 27%, 32%, 57%, 72% within the gait cycle with the assistance magnitude set to 2.8 Nm for both extension and flexion, respectively.

The experimental protocol consisted of 10 trials per each locomotion mode (5 modes total) where the subject walked across a defined path. The ramp incline was set to 9.2 degrees and the stair height was set to 15.24 cm, which was within the ADA building accessibility guideline. First, the subject donned and was fitted to the exoskeleton with an adjustable waist belt, thigh interface, and thigh straps. For each mode, the subject walked in two different conditions: 1) without the exoskeleton, 2) exoskeleton with the corresponding assistance. We recorded the time that the user took to walk across the defined distance for each locomotion mode. We measured the user's self-selected walking speed at a given mode by dividing the defined distance by the recorded time per each trial.