GAIT KINEMATICS WHEN LEARNING TO USE A WHOLE-BODY POWERED EXOSKELETON

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Robotic exoskeletons (EXOs) have received increasing attention as potential interventions to reduce physical demands in industrial applications (Huysamen et al., 2018; Otten et al., 2018; von Glinski et al., 2019). However, there is still limited understanding of how users react to EXO systems, how (human) motor adaptation evolves over time (i.e., EXO learnability), and associated training effects. Several studies in the field of rehabilitation and military applications have considered motor adaptation or learnability when users initially adapted/learned to use robotic EXOs (Bequette et al., 2020; Gordon & Ferris, 2007), but existing studies are largely limited to single joint or simpler EXO systems (i.e., ankle or lower limb EXOs).

Understanding motor adaptation and learnability during the early adaptation to EXOs may be more critical for a complex system, such as a whole-body powered exoskeleton (WB-PEXO). In this context, we conducted a preliminary study to investigate how novice users learn to operate a WB-PEXO prototype (Guardian™ XO, www.sarcos.com) over multiple level-walking sessions. Spatiotemporal gait parameters and lower limb joint angles were examined to quantify changes in motor adaptation between sessions. We hypothesized that novices would take shorter steps, be slower, and have discrepancies in joint-kinematics in walking compared to experts, but that these differences would decrease over time.

Eleven healthy male participants (six novices and five experts) completed the study. Prior to the experiment, informed consent was obtained from all participants following procedures approved by the Virginia Tech Institutional Review Board (IRB). A repeated-measures design was used that involved three walking sessions with WB-PEXO and one session without the WB-PEXO. Each walking session involved four walking trials along a 10 m linear gait track at a preferred walking speed. Whole body kinematics were measured at 60 Hz during each walking trial using an inertial motion capture system (Xsens Technologies B.V., Enschede, The Netherlands), which consisted of 17 inertial measurement units.

To extract dependent measures, a gait cycle was defined from sequential right heel strikes, and data for each gait cycle were resampled to 100 normalized time points (i.e., 0–100% of the gait cycle). At each normalized time, we computed four spatiotemporal gait measures (i.e., step/stride time and length) and six joint angle measures (i.e., peak hip flexion/extension and the timing of peak hip flexion/extension occurrence; peak knee flexion and the timing of peak knee flexion occurrence). For each participant and each dependent measure, the mean from each walking session was obtained and used to describe overall changes in gait kinematics across the sessions. Linear regression analysis was used to examine how difference scores (i.e., novice – expert) for each of the dependent measures varied over the sessions. All statistical analyses were completed using JMP® Pro 15.0 (SAS Institute Inc., Cary, NC) with statistical significance determined when $p<0.05$.

For temporal measures (i.e., right step time and right stride time), there were no clear trends over sessions when novices were compared to the experts. Both step and stride time for novice users were relatively shorter (~3.6%) in the first session compared to the experts, but the time measures increased in the latter sessions. Larger changes were observed in the spatial measures. Novice users showed reduced step and stride lengths in their first session, by up to ~25% when compared to experts, and the magnitude of reduction in both step and stride lengths decreased over the sessions (~7% reduction in session 3 when compared to experts).

Results from the linear regression analyses exhibited similar trends. Stride time had a non-significant intercept, suggesting that there were initially no differences between the novices and experts. Significant negative slopes for step/stride time and step/stride length indicated that the difference between novices and experts decreased over the sessions.

In terms of peak knee flexion and hip extension, the largest differences between novices and experts were observed in Session 1, and these differences decreased in later walking sessions: peak (SD) knee flexion was 53.4° (8.03°) degrees among novices in Session 1 vs. 61.05° (7.4°) degrees among experts; peak hip extension was -1.97° (5.1°) degrees vs. 10.63° (6.5°) degrees among novices and experts, respectively. Relatively small differences (~10%) were observed in the timing of peak joint angle occurrences as a percent of the gait cycle.

Our results from this preliminary investigation indicated that novice users began to exhibit gait kinematics similar to that of experts within a few training sessions (i.e., two or three). We found similarities in gait kinematics in terms of both spatiotemporal measures and hip/knee joint angles. Results from this study will help guide further improvements in exoskeleton design and help in the development of effective training protocols for exoskeleton deployment in the industry. However, more work is needed to identify the specific factors that contribute to the learnability of a WB-PEXO (e.g., muscular effort, WB-PEXO torques, and postural stability being some potential candidate variables). Whether gait kinetics also show similar effects, and to what extent our observations translate to more complex tasks, need to be further examined. Future research in this direction will help enhance our understanding of the motor control and adaptation strategies that evolve while performing industrial tasks using WB-PEXOs.

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