Characterizing Intent Changes in Exoskeleton-Assisted Walking Through Onboard Sensors

Taylor M. Gambon, James P. Schmiedeler, and Patrick M. Wensing

I. Introduction

Robotic exoskeletons present the opportunity to restore mobility and independence following musculoskeletal injury. Existing exoskeleton control strategies provide varying levels of user-intent matching and comfort, from finite state machines that identify discrete gait modes [1] to continuous strategies that amplify user-initiated actions [2]. While human gait mechanics are well characterized at different walking speeds [3], it is unclear how gait changes are expressed when the human interacts with an exoskeleton and its control strategy. The hypothesis in this work is that human intent can be deciphered based on the human's interactions with the exoskeleton as measured by the onboard sensors.

II. Methods

Two human subjects with experience using the EksoGT exoskeleton (Ekso Bionics) participated in the study; one had a chronic spinal cord injury (SCI), while the other was able-bodied. Subjects donned the EksoGT and used Lofstrand crutches as stability aids to walk several lengths of a 6m long motion capture arena to get familiar with the exoskeleton's settings. To begin a trial, subjects walked naturally in the exoskeleton before being given a pseudo-randomized command to speed up, slow down, or make no change in gait. Trials continued until three repetitions of each command were completed for each of two gait assistance modes: Free and Adaptive. In Free mode, the exoskeleton provided constant support, similar to gravity compensation. In Adaptive mode, it employed predefined gait trajectories, providing corrective input at the joints when the user deviated from the trajectories. Exoskeleton data included joint torques, joint positions, estimates of the absolute position of each hip, and foot contact sensors determined heel-strike events. Data were filtered and separated into pre- and post-command heel-strike-to-same-leg-heel-strike gait cycles. Stride time and hip progression were defined as the differences in time and in forward progression of the ipsilateral hip, respectively, from the start to end of each gait cycle.

III. Results and Discussion

The exoskeleton sensor data indicated that measurable changes following an intent change depend on the exoskeleton settings, user ability, and temporal considerations. In Free mode, both subjects exhibited more statistically significant differences in joint kinematics (Fig. 1 for able-bodied subject) than motor currents. To speed up in Free mode, subjects significantly decreased stride time, but did not significantly increase hip progression. This result is consistent with unassisted humans altering step frequency more than step length to modulate walking speed [4]. To slow down in Free mode, subjects significantly increased stride time, decreased hip progression, or did both. The No Change command had no effect on stride time or hip progression.

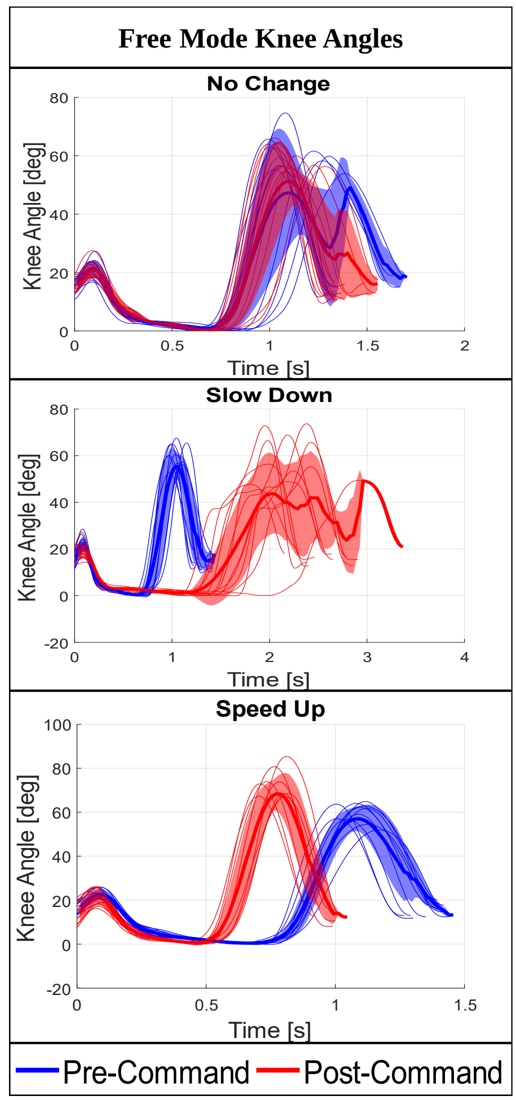

Fig. 1. Knee angle trajectories for No Change, Speed Up, & Slow Down trials of able-bodied user in Free mode. Pre- & post- command trajectories are in blue & red, respectively. Solid lines & shadowed regions indicate mean ± one standard deviation.

*This work was supported in part by the National Science Foundation and was done in collaboration with EksoBionics

*Authors are with the Department of Aerospace & Mechanical Engineering, University of Notre Dame, Notre Dame, IN. tgambon@nd.edu

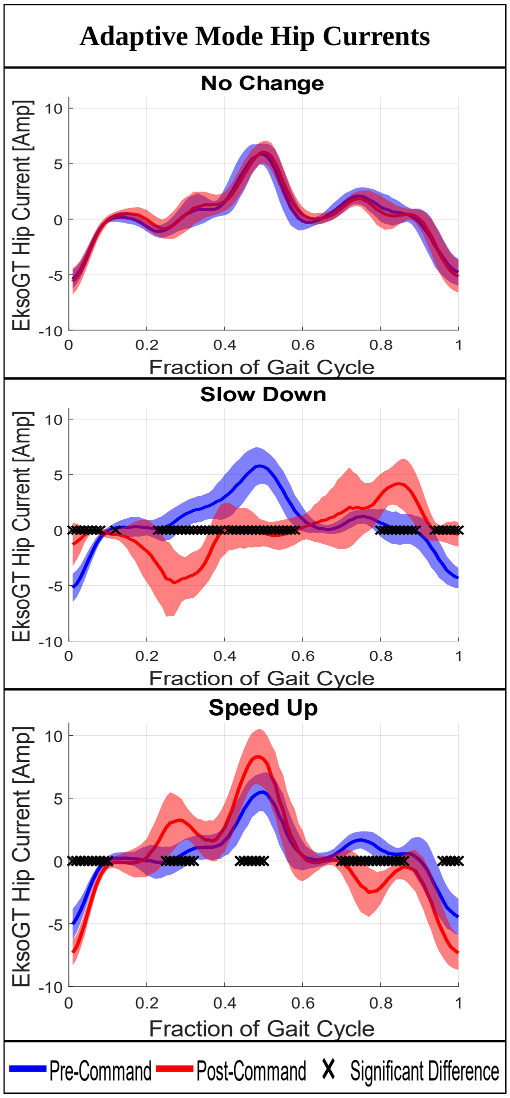

Fig. 2. Hip current trajectories for No Change, Speed Up, & Slow Down trials of able-bodied user in Adaptive mode. Pre- & post- command trajectories are in blue & red, respectively. Solid lines & shadowed regions indicate mean ± one standard deviation.

In Adaptive mode, both subjects exhibited more statistically significant differences in motor currents (Fig. 2 for able-bodied subject) than joint kinematics. Before any commands were given, subjects walked with reduced hip progression and reduced stride time in Adaptive mode compared to Free mode. This may indicate that the trajectory tracking constrained subjects to different-than-self-selected gait parameters. To speed up in Adaptive mode, subjects significantly increased hip progression, but did not significantly decrease stride time. Since subjects were already walking with decreased stride time, the hip progression increase had two results - it achieved the intended gait change and brought the gait parameters closer to those exhibited in Free mode. To slow down in Adaptive mode, subjects significantly increased stride time, decreased hip progression, or did both. The No Change command again had no effect on stride time or hip progression.

The Slow Down command caused increased hip extension/flexion current draw in the first/second half of the gait cycle. It also caused generally decreased range of motion for both the hip and knee joints. The Speed Up command caused the opposite changes to both current draw and joint range of motion, but to a lesser degree. Compared to Slow Down, the intent to Speed Up was not as easy to detect in both Free and Adaptive mode perhaps because the subjects' self-selected speeds early in each trial were already near their highest possible speeds.

While statistically significant differences were found throughout, more were found at 0-10%, 30-50%, and 90-100% of the gait cycle, i.e., at transitions to and from stance. The stance phase is functionally important for modulation of both stride time and stride length, one or both of which must change to realize a change in gait speed. To modulate stride time in unassisted walking, humans modulate stance duration more than swing duration [3], and stance duration is set at late stance/early swing by the timing of swing initiation. Stride length is set at late swing/early stance by placing the swing foot on the ground. For changes in gait speed, it is logical that these portions of the gait cycle are most affected.

Overall, the subject with SCI required larger motor currents and achieved smaller gait changes following commands than did the able-bodied subject. Both findings indicate that the user's ability to contribute to a gait may affect the viability of exoskeleton-sensor-based intent detection. The step-to-step variation was greater for both subjects in Free mode, which reflects the more restrictive nature of Adaptive mode control.

IV. Conclusions

When the EksoGT exoskeleton was in gravity compensating Free mode, user intent was more easily detectable via kinematic changes than exoskeleton motor current changes because the user was more "free" to impose those changes on the exoskeleton. In contrast, the gait-trajectory-based Adaptive mode imposes a nominal gait trajectory, so user intent was more easily detectable via current draw than kinematics as the exoskeleton resisted deviations from the nominal trajectory. Both current and angle measures were more sensitive to intent changes at transitions to and from stance, and both subjects were able to cause significant changes to their gait in response to the intent command. Future work will leverage these user intent signals in adjusting the exoskeleton control strategy to better align with the user's desired gait.

References

[1] Z. Zhang and F. Sup, "Activity recognition of the torso based on surface electromyography for exoskeleton control," *Biomed Signal Proces*, vol. 10, no. 1, pp. 281–288, 2014.

[2] A. Young, H. Gannon, and D. Ferris, "A biomechanical comparison of proportional electromyography control to biological torque control using a powered hip exoskeleton," *Front Bioeng Biotechnol*, vol. 5, no. June, 2017.

[3] C. Kirtley, M. Whittle, and R. Jefferson, "Influence of walking speed on gait parameters," *J Biomed Eng*, vol. 7, no. 4, pp. 282–288, 1985.

[4] D. Grieve and R. Gear, "The relationships between length of stride, step frequency, time of swing and speed of walking for children and adults," *Ergonomics*, vol. 9, no. 5, pp. 379–399, 1966.