CHANGES IN KINEMATICS AND MUSCLE ACTIVITY WHEN LEARNING TO USE A WHOLE-BODY POWERED EXOSKELETON FOR STATIONARY LOAD HANDLING

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Powered/active exoskeletons (EXOs) are emerging as potential ergonomic interventions to control exposures to physical risk factors for work-related musculoskeletal disorders and enhance work performance. However, little is known about how users react to such EXO systems over time and develop expertise (e.g., motor adaptation). This knowledge gap is important, since task-specific expertise can have substantial effects in the context of industrial manual material handling strategies and their resulting biomechanical effects (e.g., Authier et al., 1996; Gagnon, 2003; Goubault et al., 2020; Lee et al., 2014; Plamondon et al., 2014). To our knowledge, though, no previous studies have examined motor adaptations to EXO use during manual material handling.

We explored how novice users adapted to operating a whole-body powered exoskeleton (WB-PEXO) prototype (Guardian^{TM} XO, www.sarcos.com) when performing one-hand stationary load handling task over multiple sessions. During the task, we monitored upper limb kinematics and muscle activity from the novice users, which were compared to the same measures obtained from experts performing the same task using the same EXO. We hypothesized that there would be significant initial differences between novices and experts in: 1) shoulder and back kinematics; and 2) muscle activation levels. We further hypothesized that such differences would decrease as novice users adapted over time to WB-PEXO use.

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. The load-handling task required participants to lift/lower a bag with mass = 11.3 kg, and do so three times between three levels of a storage rack. The task was done using the dominant arm (right, for 10/11 participants). A repeated-measures design was used that involved three load-handling sessions with the WB-PEXO and one session without the WB-PEXO.

Surface electromyography (EMG) signals from the anterior deltoid, upper trapezius, and the back (thoracic + lumbar) of the dominant side were measured at 1.5 kHz using a telemetered system (Ultium, Noraxon, AZ, USA). Muscle activity was measured during sessions 1, 3, and No-EXO sessions for novices, and EXO and No-EXO sessions for experts. EMGs were normalized to values from maximal constraction. Whole body kinematics were measured at 60 Hz using an inertial motion capture system (Xsens Technologies B.V., Enschede, The Netherlands).

Task completion time, median and peak (95th %ile) shoulder and torso flexion angles on the dominant side were extracted as dependent measures. Additionally, empirical cumulative distribution functions (ECDFs) were obtained for muscle activity, from which median and peak values were determined. Independent-sample *t*-tests were performed separately in the four phases of the stationary load handling task (1 = lift from the middle to the top shelf, 2 = lower from the top to the middle shelf, 3 = lower from the middle to the bottom shelf, 4 = lift from the bottom to the middle shelf). Statistical significance was determined when $p<0.05$.

Novices had significantly longer completion times in all four load-handling phases, though these differences between novices and experts decreased over time. Both novices and experts exhibited similar median and peak flexion angles at both the shoulder and torso when using the EXO. Novices had significantly lower peak shoulder flexion in phases 1 and 2, which persisted in session 3.

Novices generally exhibited higher median back muscle activity compared to the experts in all load handling phases. However, peak back muscle activity was mostly similar between novices and experts. For the upper trapezius, novices had significantly lower median muscle activation levels in all sessions. However, they had higher peak upper trapezius muscle activity in session 1 and lower peak muscle activity in session 3.

Our results from this preliminary investigation indicate that novices and experts employed similar load-handling kinematics using the WB-PEXO, but that novices had a much slower pace (up to ~2.5x longer completion time) and they did not completely adapt to the EXO over the three sessions studied. Our hypotheses – that novices will initially employ significantly different upper limb and back kinematics, but that such differences will decrease with EXO use – were not supported. This outcome, though, is consistent with our earlier investigation of motor adaptation in a powered exoskeleton in the context of walking (Park et al., 2022). However, unlike that prior study, where we observed significant initial differences between novices and experts in all kinematic variables, we did not observe significant initial differences here in shoulder and torso flexion angles.

Results regarding back muscle activity, however, generally supported our other hypothesis: despite similar kinematics, back muscle activity was higher among novices and they exhibited differences in the relative contributions of the trapezius vs. anterior deltoid muscles. Future research in this direction will help better understand the motor control and adaptation strategies exhibited by individuals performing industrial tasks using WB-PEXOs, and help to determine what adaptation periods or training approaches are needed for safe and effective EXO use.

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REFERENCES

Authier, M., Lortie, M., & Gagnon, M. (1996). Manual handling techniques: Comparing novices and experts. *International Journal of Industrial Ergonomics*, *17*(5), 419–429.

Gagnon, M. (2003). The efficacy of training for three manual handling strategies based on the observation of expert and novice workers. *Clinical Biomechanics*, *18*(7), 601–611.

Goubault, E., Martinez, R., Assila, N., Monga-Dubreuil, É., Dowling-Medley, J., Dal Maso, F., & Begon, M. (2020). Effect of Expertise on Shoulder and Upper Limb Kinematics, Electromyography, and Estimated Muscle Forces During a Lifting Task. *Human Factors*, *1*, 1–20. https://doi.org/10.1177/0018720820965021

Lee, J., Nussbaum, M. A., & Kyung, G. (2014). Effects of work experience on fatigue-induced biomechanical changes during repetitive asymmetric lifts/lowers. *Ergonomics*, *57*(12), 1875–1885. https://doi.org/10.1080/00140139.2014.957733

Park, H., Kim, S., Nussbaum, M. A., & Srinivasan, D. (2022). Effects of using a whole-body powered exoskeleton during simulated occupational load-handling tasks: A pilot study. *Applied Ergonomics*, *98*(September 2021), 103589. https://doi.org/10.1016/j.apergo.2021.103589

Plamondon, A., Delisle, A., Bellefeuille, S., Denis, D., Gagnon, D., & Larivière, C. (2014). Lifting strategies of expert and novice workers during a repetitive palletizing task. *Applied Ergonomics*, *45*(3), 471–481. https://doi.org/10.1016/j.apergo.2013.06.008