EFFECTS OF PASSIVE UPPER-EXTREMITY EXOSKELETON USE ON MOTOR PERFORMANCE IN A PRECISION TASK

Kelson. Denean M., Kim, Sunwook, Nussbaum, Maury A., Srinivasan, Divya
Virginia Polytechnic Institute and State University, Blacksburg, VA, USA
Email: sdivya1@vt.edu

Upper-extremity exoskeletons (UEXO) are promising interventions for reducing the physical demands of work performed with arms elevated (e.g., overhead work). In this study, we investigated the effects of passive UEXO use on motor performance and physical demands in a repetitive precision overhead task. Eleven participants completed repetitive tapping of targets in both vertically-aligned (targets above/below shoulder level) and horizontally-aligned (targets at shoulder level) configurations, using two UEXOs (Levitate Airframe™ and Eksobionics EksoVest™) and in a no-device (control) condition. Median levels of muscle activity in the upper trapezius and anterior deltoid muscles decreased using both UEXOs compared to the control. However, the two UEXOs caused distinct effects on end-point precision. End-point precision was similar between devices in the horizontal configuration, but using the EksoVest significantly decreased precision in the vertically-aligned task. These results indicate that task performance may be device-specific, and should be considered when using industrial exoskeletons in diverse tasks.

Working at or above shoulder height poses complex and concurrent physical demands (Grieve & Dickerson, 2008), and is a well-documented risk factor for shoulder-related musculoskeletal disorders (Nordander, Hansson, Ohlsson, et al., 2016; Roquelaure, Ha, Rouillon, et al., 2009). Exoskeletons are wearable devices that augment worker performance and provide assistive torques (Yang, Zhang, Chen, et al., 2008). Use of an upper-extremity exoskeleton (UEXO) – designed to offset shoulder demands – can be a potential occupational application for overhead work. Previous research has demonstrated that UEXOs reduce muscle loading during overhead manufacturing-related tasks (Gillette & Stephenson, 2017; Huysamen, Bosch, de Looze, et al., 2018; Kim, Nussbaum, Mokhlespour Esfahani, Alemi, Alabdulkarim, et al., 2018; Theurel, Desbrosses, Roux, et al., 2018). However, with UEXO use, unintended consequences have also been reported, such as decreased joint range of motion (Kim, Nussbaum, Mokhlespour Esfahani, Alemi, Jia, et al., 2018). This study aimed to investigate the effects of passive UEXO use on motor performance in a precision task, and to quantify the effects of differing exoskeleton designs while completing overhead precision work.

Eleven participants (7 males and 4 females) completed the study. Participants completed a precision, repetitive pointing task using a powered hand drill (5kg). Pairs of targets were placed 40 cm distance apart in two configurations: vertically-aligned (VA; i.e., Top and Bottom targets), and horizontally-aligned (HA; i.e., Left and Right targets). Participants completed 15 cycles of repetitive tapping at 40 beats per minute in three device conditions: no device control (ND), Levitate Airframe™ (AF) and EksoBionics EksoVest™ (EV). Sufficient rest was provided between tasks. For the UEXO conditions, arm-support level was individually selected after a short training.

Raw surface electromyography (EMG) data was collected from the dominant upper trapezius (UT) and anterior deltoid (AD) using a telemetered system (TeleMyo Desktop DTS, Norazon, AZ, USA) at a sampling frequency of 2 kHz. The raw EMG signals were band-pass filtered (20-450 Hz, 4th-order Butterworth, bidirectional), RMS-converted, and normalized to maximum voluntary exertions. Reflective markers placed on the drill bit were monitored at 120 Hz, using a 6-camera optical motion capture system (Vicon Vero, Los Angeles, CA, USA); marker data were subsequently low-pass filtered (6 Hz, 4th-order Butterworth, bidirectional). EMG and marker data were segmented into each tapping cycles. Median normalized EMG (nEMG) levels were calculated for each cycle. End-point precision was calculated as the resultant of 3-D deviations of each cycle end-point from the corresponding target.

Separate repeated measures analyses of variance were performed to test the effects of device condition on median nEMG levels for each of the four target locations (Top, Bottom, Left, and Right), and end-point precision. Significant effects were followed by Tukey's HSD pairwise comparisons.

For both the UT and AD muscles, the ND condition (vs. AF and EV) yielded higher median nEMG values for all targets. In all target conditions except the Top target, EV use was also associated with higher median UT nEMGs compared to the AF device. Significant device effects were observed for the Top and Bottom targets (p=0.0067; p=0.0043). EV use was associated with a reduced precision compared to both the AF and ND conditions in the Top target condition, i.e., for movements going up from the bottom to the top target in the vertically-aligned target configuration (p=0.0126; p=0.0226 respectively). In the Bottom target condition, EV use led to significantly lower precision compared to the ND condition (p=0.0039).

Overall, use of UEXOs decreased muscle loading in the upper trapezius and anterior deltoid, but in some cases decreased precision. There was also some evidence of design-specific differences between the Airframe and EksoVest exoskeletons, with respect to both muscle loading and precision in a primarily vertical direction of movement. While muscle loading in the upper trapezius decreased with exoskeleton use during upward arm motion, the lighter-weight Levitate exoskeleton design had an increased effect compared to the heavier design EksoVest during downward and in left-right arm motions. Therefore, future research should consider design parameters and the upper-extremity motor control strategies while performing overhead work.

REFERENCES

de Looze, M. P., Bosch, T., Krause, F., Stadler, K. S., & O'Sullivan, L. W. (2016). Exoskeletons for industrial application and their potential effects on physical work load. *Ergonomics*, *59*(5), 671–681. https://doi.org/10.1080/00140139.2015.1081988

Gillette, J. C., & Stephenson, M. L. (2017). EMG Assessment of a Shoulder Support Exoskeleton During on - Site Job Tasks. In *41st Annual Meeting of the American Society of Biomechanics, Boulder, CO, USA, August 8th – 11th, 2017*.

Grieve, J., & Dickerson, C. R. (2008). Overhead work: Identification of evidence-based exposure guidelines. *Occupational Ergonomics*, *8*, 53–66. Retrieved from https://content.iospress.com/articles/occupational-ergonomics/oer00157

Huysamen, K., Bosch, T., de Looze, M., Stadler, K. S., Graf, E., & O'Sullivan, L. W. (2018). Evaluation of a passive exoskeleton for static upper limb activities. *Applied Ergonomics*, *70*, 148–155. https://doi.org/10.1016/j.apergo.2018.02.009

Kim, S., & Nussbaum, M. A. (2019). A Follow-Up Study of the Effects of An Arm Support Exoskeleton on Physical Demands and Task Performance During Simulated Overhead Work. *IISE Transactions on Occupational Ergonomics and Human Factors*, 1–12. https://doi.org/10.1080/24725838.2018.1551255

Kim, S., Nussbaum, M. A., Mokhlespour Esfahani, M. I., Alemi, M. M., Alabdulkarim, S., & Rashedi, E. (2018). Assessing the influence of a passive, upper extremity exoskeletal vest for tasks requiring arm elevation: Part I – "Expected" effects on discomfort, shoulder muscle activity, and work task performance. *Applied Ergonomics*, *70*(December 2017), 315–322. https://doi.org/10.1016/j.apergo.2018.02.025

Kim, S., Nussbaum, M. A., Mokhlespour Esfahani, M. I., Alemi, M. M., Jia, B., & Rashedi, E. (2018). Assessing the influence of a passive, upper extremity exoskeletal vest for tasks requiring arm elevation: Part II – "Unexpected" effects on shoulder motion, balance, and spine loading. *Applied Ergonomics*, *70*(December 2017), 323–330. https://doi.org/10.1016/j.apergo.2018.02.024

Nordander, C., Hansson, G.-Å. Å., Ohlsson, K., Arvidsson, I., Balogh, I., Strömberg, U., … Skerfving, S. (2016). Exposure-response relationships for work-related neck and shoulder musculoskeletal disorders - Analyses of pooled uniform data sets. *Applied Ergonomics*, *55*, 70–84. https://doi.org/10.1016/j.apergo.2016.01.010

Roquelaure, Y., Ha, C., Rouillon, C., Fouquet, N., Leclerc, A., Descatha, A., … Imbernon, E. (2009). Risk factors for upper-extremity musculoskeletal disorders in the working population. *Arthritis Care and Research*, *61*(10), 1425–1434. https://doi.org/10.1002/art.24740

Spada, S., Ghibaudo, L., Carnazzo, C., Gastaldi, L., & Cavatorta, M. P. (2019). Passive Upper Limb Exoskeletons: An Experimental Campaign with Workers. In *Advances in Intelligent Systems and Computing* (Vol. 825, pp. 230–239). https://doi.org/10.1007/978-3-319-96068-5_26

Spada, S., Ghibaudo, L., Gilotta, S., Gastaldi, L., & Cavatorta, M. P. (2017). Investigation into the Applicability of a Passive Upper-limb Exoskeleton in Automotive Industry. *Procedia Manufacturing*, *11*(May), 1255–1262. https://doi.org/10.1016/j.promfg.2017.07.252

Theurel, J., Desbrosses, K., Roux, T., & Savescu, A. (2018). Physiological consequences of using an upper limb exoskeleton during manual handling tasks. *Applied Ergonomics*, *67*(September 2017), 211–217. https://doi.org/10.1016/j.apergo.2017.10.008

U.S. Bureau of Labor Statistics. (2018). Employer-Reported Workplace Injuries and Illnesses. *U.S. Department of Labor*. Retrieved from www.bls.gov/web/osh/cd_r75.htm.

Yang, C. J., Zhang, J. F., Chen, Y., Dong, Y. M., & Zhang, Y. (2008). A review of exoskeleton-type systems and their key technologies. *Proceedings of the Institution of Mechanical Engineers, Part C: Journal of Mechanical Engineering Science*, *222*(8), 1599–1612. https://doi.org/10.1243/09544062JMES936