

# Effects of using passive back- and arm-support exoskeletons for cart pushing and pulling

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## INTRODUCTION

Occupational exoskeletons (EXOs) have recently gained substantial interest as potential ergonomic interventions. A majority of commercially available EXOs are passive (non-powered), and the two most common types are back-support (BSE) or arm-support (ASE) EXOs. While use of EXOs have been found to reduce physical demands for tasks involving lifting, trunk flexion, and elevated arm postures (e.g., Alemi et al., 2020; Baltrusch et al., 2018; Madinei et al., 2020; de Vries et al., 2021; Smets, 2019), their effectiveness for cart pushing and pulling has not been well investigated. Pushing and pulling activities are important risk factors for both low back pain (Glitsch et al., 2007) and shoulder complaints (Hoozemans et al., 2002). These activities generally involve three distinct motion phases: the initial, sustained, and ending phases (Ciriello and Snook, 1983). Understanding the phase-specific effects of BSEs and ASEs during pushing and pulling tasks may facilitate safer and more effective adoption of exoskeleton technologies. Thus, the purpose of this study was to explore the effects of different types of EXOs (i.e., ASE and BSE) during the different motion phases (initial, sustained, ending) of pushing and pulling tasks.

Fourteen healthy participants [12 males and 2 females; age: 21.6 (1.9) years, stature: 1.8 (0.09) m, and body mass: 83.8 (14.8) kg] completed the study. Note that the current report is based on ongoing data collection, and the complete study will have a larger sample size. Each participant was assigned randomly to use either an ASE (Ekso Bionics™ EVO; www.eksobionics.com) or a BSE (SuitX™ BackX™ Type S; [www.suitx.com](http://www.suitx.com)). Both devices have rigid components and incorporate passive torque generation mechanisms about the hip and shoulder, respectively. Each group had 6 males and 1 female participant. Before the experiment, informed consent was obtained from all participants following procedures approved by the university Institutional Review Board (IRB). All participants self-reported having no musculoskeletal injuries or disorders in the past 12 months.

Cart pushing and pulling was simulated in a laboratory environment using a single cart (width: 0.5 m; length: 0.74 m; height: 0.67 m including handles) that was loaded with 100 kg of mass. The cart handle was nonadjustable and was at a height of 0.12 m. Participants were asked to push the cart at a “purposeful” working speed as straight as possible over 5 m and then to pull the cart back to the starting point after reaching the 5 m mark on the floor. Participants completed 10 trials while wearing the EXO, and one trial without the EXO. A minimum of 1-minute of rest was provided between trials.

Surface electromyography (EMG) was recorded bilaterally from the lumbar erector spinae (ES) muscles, and unilaterally from the dominant-side anterior deltoid (AD) muscle. EMG

signals were sampled at 1.5 kHz during maximum voluntary isometric contractions (MVICs) and cart pushing and pulling tasks, using a telemetered EMG system (TeleMyo Desktop DTS, Noraxon, AZ, USA). For each trial, EMGs were then normalized to maximum values from MVIC trials (nEMGs). nEMG signals were analyzed separately for the cart pushing and pulling phases. Specifically, each of the pushing and pulling tasks was time normalized to 101 data points and then divided into three phases (initial, sustained, and ending phases), based on normalized time windows (~10%, 10-90%, and 90-100%, respectively). Whole body kinematics were measured at 60 Hz using an inertial motion capture system (Xsens Technologies B.V., Enschede, The Netherlands).

Difference scores were obtained by subtracting the mean outcome measure in the baseline condition (no EXO) from the EXO condition. Separate two-way, mixed-factor analyses of variance (ANOVAs) were used to assess the effects of *EXO Type* (pushing vs. pulling) and *Task Phase* (initial, sustained, and ending) on each of the difference scores ( $\Delta$ trunk ROM, and peak and median  $\Delta$ nEMG percentiles). Significant effects were followed by Tukey HSD post hoc pairwise comparisons. All analyses were performed using JMP Pro 16 (SAS, Cary, NC), using the restricted maximum likelihood (REML) method, and statistical significance was concluded when  $p < 0.05$ .

There were significant main effects of *EXO Type* on trunk ROM ( $p = 0.0017$ ) during the pushing task. There was also a significant *EXO Type*  $\times$  *Task Phase* interaction effect ( $p = 0.036$ ). During the sustained phase, using either the BSE or ASE significantly increased trunk ROM, but EXO use had no significant effects on  $\Delta$ trunk ROM during the initial and the ending phases regardless of EXO type.

Significant main effects of *EXO Type* were found on  $\Delta$ ES nEMG during both the pushing ( $p = 0.002$ ) and pulling ( $p < 0.0001$ ) tasks. Wearing the BSE significantly reduced ES muscle activity in all three phases of both pushing (~ up to 39%) and pulling (~ up to 35%) tasks. Pairwise comparisons revealed that the BSE was most effective (in terms of reducing muscle activity) during the initial phase of the pulling task ( $p < 0.05$ ) and least effective during the initial phase of the pushing task. No significant effects of using the BSE and the ASE were found for AD muscle activity.

Our results support that the effects of BSE and ASE were specific to the *Task type* (pushing vs. pulling) and *Task phase* (initial, sustained, and ending). For the task conditions examined here, using a BSE had greater overall benefits than the ASE. However, further investigation is warranted for the use of carts with varying handle heights and other task conditions. Nevertheless, these results suggest potential benefits of EXOs for at least some occupational pushing/pulling tasks.

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