Subjective Assessments of Arm-Support Exoskeletons During Simulated Static and Dynamic Overhead Tasks

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Upper extremity work-related musculoskeletal disorders continue to be an important occupational health problem (U.S. Bureau of Labor Statistics, 2020). While arm-support exoskeletons (ASEs) generally can be considered as having substantial potential as a new ergonomic intervention (de Looze et. al 2016; Kim et al., 2018a, 2018b; Smets, 2019; Yin et. al, 2020), there is limited evidence regarding the effects of ASE designs under a range of use conditions. Thus, we examined three passive ASEs in terms of perceived exertion and workload, and usability and preference, during simulated static and dynamic overhead tasks representative of those in automotive assembly. Though we have reported partial results in Ojelade et al. (2021), that work does not consider Gender differences and focused only the static task. This work presents full results using the complete sample population.

Eighteen participants (gender-balanced) completed these tasks in six different conditions, involving all combinations of three different work heights and two exertion directions (forwards and upwards). Each condition was completed using no ASE (baseline) and with three ASEs: EV = Ekso Bionics EVO, SX = SuitX shoulderX, and PX = Paexo Shoulder. The three work heights were derived using two anthropometric measures, similar to the approach in Sood et al. (2007). Static and dynamic overhead tasks were evaluated using a work target with a triaxial load cell; the static task required pushing a pneumatic nutrunner (~2.3kg) into the target with 13-20N of normal force for 30 seconds, and the dynamic task required participants to exert a force with their palm briefly onto the target with 75N in the upward direction and 53N in the forward direction at a pace of 10 pushes per minute.

Participants completed an initial training session, during which they were familiarized with the ASEs and subjective measures, and selected their preferred ASE support setting for each device at each height. Data were then collected in two subsequent experimental sessions, each on separate days. In each experimental session, participants performed the static and dynamic overhead tasks at only two *Intervention* levels (12 experimental conditions). Recorded subjective measures were obtained using: 1) the Borg CR-10 scale (Borg, 1998) for ratings of perceived exertion (RPE) for the neck, shoulder, elbow, wrist/hand, and the upper back, using; 2) the NASA-Task Load Index across its six workload dimensions (NASA-TLX; Hart & Staveland 1988); a modified 7-point System Usability Scale (SUS: Bangor et al., 2008; Brooke, 1996), which was administered after every task condition for an ASE (i.e., all combinations of directions and heights).

For each overhead task, separate three-way, mixed-factor analyses of variance (ANOVAs) were used to assess the effects of *Intervention*, *Direction*, *Height*, and *Gender* on each of the outcome measures. Statistical significance was concluded when $p<0.05$, and partial eta-squared (η_p^2) was used to quantify effect sizes for significant main/interaction effects.

In the static task, *Intervention* main effects were significant on RPEs at the neck ($p = 0.048$, $\eta_p^2 = 0.15$), shoulder ($p = 0.005$, $\eta_p^2 = 0.231$), elbow ($p = 0.025$, $\eta_p^2 = 0.179$), and upper back ($p = 0.029$, $\eta_p^2 = 0.168$). Compared to the baseline, using the EV yielded lower shoulder (29%), elbow (27%), and upper back (29%) RPEs. Neck RPE values were also significantly affected by the *Intervention* × *Height* interaction ($p = 0.003$, $\eta_p^2 = 0.205$). At the high height, using the PX significantly decreased neck RPE values (37%). *Intervention* × *Gender* interaction effects ($p = 0.05$, $\eta_p^2 = 0.15$) on NASA-TLX performance showed that the EV had the lowest performance scores among females but the best among males.

In the dynamic task, though wrist RPE was significantly affected by the *Intervention* × *Gender* interaction ($p = 0.027$, $\eta_p^2 = 0.17$), for a given gender, RPE values were comparable between the baseline and an ASE condition. There was also an *Intervention*× *Gender* interaction effect on NASA-TLX mental demand. Females generally reported about 52% lower mental demand scores than males, yet within the same gender there were no significant differences between the baseline and an ASE condition.

The main effect of ASE use on overall SUS approached significance ($p = 0.1$), whereas the main effect of gender and the interaction effect were not significant. For each ASE, mean (SD; range) overall scores were as follows: EV = 65.9 (16.9; 31.7–95); PX

= 55.7 (14.6; 30.0–85.0); and SX = 62.3 (18.3; 33.3–91.7). Gender differences in preferred ASE were found for both the static and dynamic tasks. In the static task, males did not appear to have a strong preference for a specific ASE; in contrast, most females ranked the SX first. In the dynamic task, females chose the EV or the PX as their most preferred ASE, and none chose the SX as their first, whereas more than half of the males ranked the SX first.

Results of the current study suggest rather clearly that there is no one "best" ASE that consistently provided beneficial effects across different task types (i.e., static vs. dynamic), working conditions (i.e., height and exertion direction), and genders. We find it notable that overall scores from the system usability scale (SUS) indicate that the usability of the tested ASEs needs further improvements for the tasks and task conditions considered here. Further, to support the effective adoption of ASEs in the workplace, future work should focus on how to identify an "optimal" ASE for a given job and individual characteristics.

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