Usability and user acceptance of an arm-support exoskeleton in automotive assembly: Results of a long-term field evaluation

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Work-related shoulder musculoskeletal disorders (MSDs) are an important health concern in the workplace. In the U.S., about 7.5% of all lost workday cases reported in 2019 affected the shoulder, involving a median of 22 lost workdays, vs. a median of 13 days across all body parts (Bureau of Labor Statistics, 2020). Among diverse risk factors for shoulder MSDs (Buckle & Devereux, 2002; Nordander et al., 2016), working with arms elevated repetitively or over a prolonged period appears important, and is often an unavoidable part of job tasks (e.g., for electricians, automotive assembly workers, and carpenters). Therefore, reducing shoulder MSDs remains a major practical challenge.

Use of an arm-support exoskeleton (ASE) is a promising intervention to control exposures to shoulder MSD risks (de Looze, Bosch, Krause, Stadler, & O'Sullivan, 2016; Nussbaum, Lowe, de Looze, Harris-Adamson, & Smets, 2019). ASEs are wearable system that provide on-body support about the shoulder during diverse physical activities. A number of laboratory-based studies involving simulated work tasks requiring arm elevation have demonstrated that ASE use can reduce muscle activities in shoulder and neck muscle groups (e.g., anterior deltoid, trapezius), by up to ~60%, as well as decrease perceived exertion and metabolic costs (e.g., de Vries & de Looze, 2019; Hefferle, Snell, & Kluth, 2021; Kim, Nussbaum, Mokhlespour Esfahani, Alemi, Alabdulkarim, et al., 2018; Schmalz et al., 2019). The magnitude of these beneficial effects, however, vary substantially between task conditions (de Vries & de Looze, 2019; Kim, Nussbaum, Mokhlespour Esfahani, Alemi, Alabdulkarim, et al., 2018). Several field-based studies have also been completed, suggesting that ASE use can be an effective intervention for shoulder MSDs, though based on testing of less than an hour up to a 3-month period (e.g., Hensel & Keil, 2019; Smets, 2019; Spada, Ghibaudo, Gilotta, Gastaldi, & Cavatorta, 2018, Amandels, Eyndt, Daenen, & Hermans, 2019).

Thus, the objective of this study was to understand how using an ASE affects perceptual responses over a longer, 18-month period. We used a prospective, controlled field study, and collected subjective responses related to usability from workers in several automotive final assembly facilities. Results of preliminary analyses are reported here.

All participants were recruited on a voluntary basis from automotive manufacturing facilities in Northern America, and were final assembly operators who worked daily on an overhead line at which the vehicle passed above the operators while they performed assembly work from below. A total of 65 participants were recruited for ASE use. Some participants withdrew from the study, and two facilities underwent major facility changes so that no data were obtained after the first few milestones. Data from these facilities were excluded from further analysis. Hence, final analyses were based on a total of 41 participants from six facilities. Respective means (interquartile range: Q3-Q1) of age, body mass, and stature were 38.0 (15.0) years, 83.9 (21.5) kg, and 1.79 (0.1) m.

Data were collected via questionnaires over 18 months: the day when participation began and without ASE use (Baseline), and again at 1, 6, 12, and 18 months after the baseline. The ASE used was the EksoVest^{TM} (Ekso Bionics, Inc., Richmond, CA; unit mass = 4.3 kg). This ASE included a U-shape neck pillow and back pads, along with adjustability in trunk length, waist belt length, and arm cuff size.

Participants were asked to give responses using 0–10 Likert scales to usability-related questions regarding overall comfort, thermal comfort, perceived balance, perceived range-of-motion, overall perceived job safety, perceived job performance. For each question, participants were asked to give open-ended feedback to clarify/explain their response. Additional open-ended questions included: "What do you most like about the exoskeleton?" and "What do you least like about the exoskeleton?". At the 12- and 18-month milestones, participants were further asked to report their feelings about the exoskeleton (positive, neutral and negative), and their intention to use it in the future (yes or no, though some participants reported "maybe").

Perceptions of overall comfort and overall job safety significantly differed over time. Participants reported significantly higher discomfort at Month 12 than at the other milestones. They generally reported no difference in overall job safety with ASE use until Month 12, and indicated a safer feeling at Month 18. Responses to thermal comfort and balance remained consistent, with the participants reporting a moderate level of thermal discomfort and no perceived balance concerns. Participants reported that they performed somewhat better with the ASE use and more so at Month 1, though statistically not different. This pattern may indicate that novelty effects of ASE use faded after the first month, yet the perceived benefit in job performance was still present during the remainder of the study. In Months 12 and 18, a total of 39 participants indicated their feeling about the ASE and their intention-to-use. While a large majority expressed a positive feeling about the ASE, only 61.5% reported having an intention-to-use the ASE.

Our results support that ASE use can be an effective intervention in automotive assembly. Without considerably compromising comfort, balance, ROM, and safety, using an ASE led to a slight increase in overall perceived job performance. However, just ~62% of participants (who remained at Month 12 and 18) reported having an intention to use the ASE in the future, although ~84% were positive about ASE technologies. Future work is recommended to determine

what drives ASE intention-to-use, and to better introduce an ASE in the field.

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