A data-driven approach to understand factors contributing to exoskeleton use-intention in construction

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Construction workers often perform strenuous manual tasks, which in part accounts for the high prevalence of work-related musculoskeletal disorders (WMSDs) in this population (CPWR, 2018). The problem is substantial, with almost half of construction workers self-reporting having one or more MSD-related symptoms (Dong et al., 2019). Many administrative and engineering controls can help prevent or reduce exposures to WMSD risks in construction. The continuing prevalence of WMSDs among construction workers, however, indicates a clear need for alternative intervention approaches.

Occupational exoskeleton (EXO) technologies have emerged as a new intervention in recent years (de Looze et al., 2016; Nussbaum et al., 2019). Beyond initial pilot testing however, there is little evidence that this technology is widely accepted and used on construction sites. To promote the adoption of EXOs in the workplace, understanding factors that promote user acceptance of an EXO (or use-intention) may be of substantial utility. Thus, we aimed in the current study to understand what contributes to EXO use-intention in construction, by building a data-driven, predictive model.

A self-administered online survey was completed earlier, jointly led by Virginia Tech and University of California, San Francisco. The study protocol was approved by the respective local Institutional Review Boards. Survey responses were collected between July 31, 2020 and January 9, 2021. A detailed description of the survey, including questions, procedures, and descriptive findings, can be found elsewhere (Gutierrez et al., 2023). In brief, the survey consisted of 65 open- and closed-end questions regarding EXO knowledge; work history; demographic information; job task characteristics; and perceived benefits, health and safety concerns, and facilitators for adoption and use of EXOs in construction. A total of 361 construction industry stakeholders completed the survey.

Among the survey questions, we selected 47 as potential predictors of EXO use-intention, by excluding questions that were open-ended or trade-specific. The selected questions were categorized into seven groups: 1) demographics, 2) job demands, 3) musculoskeletal pain, 4) EXO knowledge/experience, 5) perceived social implication of EXO use, 6) opinions about EXO use, and 7) perceived potential risks.

We considered responses to the following question to be indicative of use-intention: "If given the option, would you want to try an exoskeleton?". Participants responded to this question with "yes", "maybe", or "no". To address missing data (~5%), we used multivariate imputation using chained equations (MICE; White et al., 2011). Given the relatively large number of predictors (n=47), variable selection was used to identify a subset of predictors to increase efficiency in obtaining a prediction model.

A decision tree model was developed to predict responses to the use-intention question, using recursive partitioning and regression trees (RPART). To optimally select/tune three model hyperparameters, and to estimate the final tree performance, we used 10 times repeated 5-fold cross validation (CV) with an independent test set, following the procedure described by Raschka (2018). For model evaluation, we generated four common performance metrics (Alaa, 2020; Grandini et al., 2020), including balanced accuracy, Cohen's Kappa, F1-score, and Area under the receiver operator curve (AUC-ROC). The importance of a variable in the final decision tree was computed using the *vip* package in R (Greenwell & Boehmke, 2020). Note that we previously completed an initial exploratory decision tree analysis on a subset of the noted survey data (Moore et al., 2021).

Decision tree prediction performance was estimated using the repeated 5-fold CV. Respective means (SD) of balanced accuracy, Cohen's Kappa, F1-score, and AUC-ROC were 0.73 (0.03), 0.48 (0.08), 0.63 (0.06), and 0.75 (0.10). The final tree had "Standard equipment" as the root node, and 12 leaf or terminal nodes. Five leaf nodes were associated mainly with a "yes" response (i.e., *Yes* leaf nodes), two were *No* leaf nodes, and four were *Maybe* leaf nodes. Important variables were in the general category of opinions on EXO use, demographics, job demands, and perceived potential risks.

A large portion (75%) of respondents led to *Maybe* leaf nodes that are associated mainly with a maybe response. Particularly, one *Maybe* leaf node accounted for ~53% of respondents, and those who considered that EXOs will become standard equipment over time. One leaf node had mixed responses of yes and maybe. Four *Yes* leaf nodes indicated that respondents were likely to try an EXO if they thought EXOs could reduce fatigue, and/or they felt a less than moderate level (4–4.5) of physical tiredness.

Opinions about trying EXOs were influenced greatly by two variables – the degree of agreement that EXOs will become standard equipment over time and whether EXO use can reduce fatigue. We may interpret *standard equipment* as being readily available and widely used at a worksite. Given this interpretation, it is not surprising that respondents tended to indicate they would try an EXO when agreeing with the potential of EXOs becoming standard equipment. In addition, the opinion about EXO sharing with coworkers was important in the decision tree when EXOs were not expected to be standard equipment.

We developed a decision tree to predict a response to one self-reflected EXO use-intention question. Important variables identified in the decision tree were associated with opinions on EXO use, demographics, job demands, and perceived potential risks. The key influential variables identified were about EXOs becoming standard equipment over time, and fatigue reduction with EXO use. Findings from this study set a groundwork for future research to guide the effective introduction and implementation of EXOs in construction worksites.

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REFERENCE

Alaa, T. (2020). Classification assessment methods. *Applied Computing and Informatics*, *17*(1), 168–192.

CPWR – The Center for Construction Research and Training. (2018). *The Construction Chart Book. The U.S. Construction Industry and Its Workers* (6th ed.). https://www.cpwr.com/wp-content/uploads/publications/The_6th_Edition_Construction_eChart_Book.pdf

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.

Dong, X. S., Betit, E., Dale, A. M., Barlet, G., & Wei, Q. (2019). *Trends of musculoskeletal disorders and interventions in the construction industry*. stacks.cdc.gov. https://stacks.cdc.gov/view/cdc/86273

Grandini, M., Bagli, E., & Visani, G. (2020). Metrics for Multi-Class Classification: an Overview. In *arXiv [stat.ML]*. arXiv. http://arxiv.org/abs/2008.05756

Greenwell, B., & Boehmke, B. (2020). Variable Importance Plots—An Introduction to the vip Package. *The R Journal*, *12*(1), 343.

Gutierrez, N., Ojelade, A., Kim, S., Barr, A., Akanmu, A., Nussbaum, M. A., & Harris-Adamson, C. (2023). *Perceived Benefits, Barriers, Perceptions, and Readiness to Use Exoskeletons in the Construction Industry: Differences by Demographic Characteristics*.

Moore, A., Kim, S., Srinivasan, D., Nussbaum, M. A., Ojelade, A., Harris-Adamson, C., Gutierrez Contreras, N., Barr, A., & Rempel, D. (2021). A preliminary decision tree modeling of factors that determine readiness to use exoskeletons in construction. 66th *Annual Meeting Human Factors and Ergonomics Society. Meeting*, *65*(1), 419–420.

Nussbaum, M. A., Lowe, B. D., de Looze, M., Harris-Adamson, C., & Smets, M. (2019). An Introduction to the Special Issue on Occupational Exoskeletons. *IISE Transactions on Occupational Ergonomics and Human Factors*, *7*(3–4), 153–162.

Raschka, S. (2018). Model Evaluation, Model Selection, and Algorithm Selection in Machine Learning. In *arXiv [cs.LG]*. arXiv. http://arxiv.org/abs/1811.12808

White, I. R., Royston, P., & Wood, A. M. (2011). Multiple imputation using chained equations: Issues and guidance for practice. Statistics in Medicine, 30(4), 377–399