Work-Assist Exoskeleton Harness for Female Construction Workers

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The United States is currently experiencing a shortage of construction workers alongside a rapidly deteriorating infrastructure (ASCE, 2017). To address this gap, the construction industry is recruiting women at an unprecedented rate (U.S. Bureau of Labor Statistics, 2022). Despite women comprising an average of 57.1% of the workforce in other industries, men still dominate 88% of all construction jobs in the U.S. (U.S. Bureau of Labor Statistics, 2022). The low numbers of female construction workers must be corrected to address industry growth needs.

Worldwide, construction trades are notorious for their occupational risks and hazards. Construction workers in dynamic environments exert substantial physical effort and face daily safety and health hazards (Bureau of Labor Statistics, 2021). From acute injuries on-site to repetitive strain injuries (RSIs) inherent in skilled trades, work-related musculoskeletal disorders (WMSDs) account for 33% of all occupational injuries, often sidelining workers or ending careers (Boschman et al., 2012).

A persistent issue for women in construction is the lack of well-fitting personal protective equipment (PPE) and apparel (Kutz, 2023). To mitigate potential losses and labor turnover due to RSIs and to attract more women, many industries are PPE like exoskeletons to reduce biomechanical load and muscle activity during repetitive tasks (Ayodele et al., 2020; Stirling et al., 2019). Although exoskeletons are designed to alleviate RSIs, they often suffer from the same shortcomings as other PPE offerings, particularly the lack of adjustability to accommodate the anatomical differences of female workers (Stirling et al., 2019). To address this shortcoming this harness design focuses on fitting lower limb work-assist exoskeletons to the body through ergonomic patterning tailored for female anatomy, enhancing both comfort and ease of movement. This work is part of a multi-year, collaborative effort that begins with apparel designers creating a harness to house a rotary actuator exoskeleton that is being developed by engineers.

Visual Impact

Aesthetic principles were considered in relation to physical and psychological safety benefits within the design process. A bright orange color was chosen for the main harness components to provide maximum visibility and increase safety for wearers. Support fabrics in grey and black were chosen to help the leg straps become less visible, calling less attention to the overall unit as psychologically it may be uncomfortable for female construction workers to be seen as needing an exoskeleton. Curvilinear lines were favored throughout the design to create visual unity and flow along the contours of the female form.

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Methods

Prototyping for the work-assist exoskeleton harness began in Clo-3D where initial design solutions were explored. The design requirements included: ergonomic body positioning, close-to-body fit along legs for sensor accuracy, back pocket for the battery, easy donning and doffing, and load distribution (Wang et al., 2022). Some areas of the harness were required to stretch (backpack unit) while others could not move (leg braces), or sensors would not work properly. All prototypes were created on a size 12 Alvanon digital dress form to ensure proper fitting on female anatomy. The final work-assist exoskeleton harness uses a backpack-like construction on the upper body with an open mesh panel on the midback to provide adequate airflow were women sweat most (Smith & Havenith, 2012). The padded straps come over the shoulders and curve away from the breasts to improve comfort and fit. The mid and lower back is supported with a semirigid back panel that wraps around the waist distributing the exoskeleton weight over the trunk of the body. This panel has a back pocket to house the exoskeleton battery and processor and is closed with a zipper for easy access. The shoulder straps attach to the back panel via 2” wide heavy-duty elastic, allowing for height variability for wearers within the size 12 range. The entire upper body, backpack-unit of the harness is secured with more 2” elastic, adjustable straps that meet with a buckle just above the belly button.

The entire backpack-unit has bias bound edges to give durability and reduce chances of fraying on edges. The work-assist exoskeleton harness is made of polyester with a PVC no slip grip texture, .5mm neoprene, and polyester mesh in shades of black and fluorescent orange which abide by OSHA material and visibility standards (OSHA, 2024). All seams were double top stitched to ensure durability in construction settings.

Two straps extend from the anterior and posterior hip, meet and become one strap that extends down the lateral thigh. The negative space between the two straps is filled with open mesh to reduce snagging of the leg braces when sensors are attached. This nylon strap attaches to the 3D-printed leg brace that holds the mechanism for knee-hinge of the exoskeleton onto the leg. The knee-hinge is comprised of metal bars that run vertically on the lateral side of the legs and are joined together by a rotary actuator at the knee that actively assists the user in their work. In this submission, this hardware is represented by non-functioning placeholders. The braces designed in Rhino, using the Alvanon size 12 digital dress form to ensure accurate fitting. The upper thigh brace of the exoskeleton is held in place with a buckle and adjustable nylon strap. To reduce overheating, perforations were printed into the posterior of the thigh and this area is bisected with a piano style hinge for easy donning and doffing. The lower calf is braced by another 3D-printed component that closes using an adjustable strap and buckle. These rigid brace components will house future sensor components, developed for the exoskeleton.

Cohesion and Contribution

The goal of this design was to create a functional, and well-fitting lower-body work assist exoskeleton harness to be worn by female construction workers. This goal was achieved using targeted areas of stretch, rigid components to keep leg sensors stationary, weight distribution over the entire body and an effective method of attaching

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the exoskeleton to the leg. The harness abides by all available OSHA regulations for this type of equipment and focuses on ergonomic fitting for female anatomy (OSHA, 2024). The safety and psychological comfort of wearers were also considered during the design development.

The construction industry is trying to grow by increasing the number of women workers. However, women in construction with minimal PPE options that fit are subject to RSIs while on the job (Kutz, 2023). The work-assist exoskeleton harness concept demonstrates what is possible to improve fitting and ergonomics for female construction workers with purposefully designed PPE. The work-assist exoskeleton harness is original in its design as it was made for a conceptual exoskeleton at the forefront of innovation. In the future, the developed harness will be fitted with the exoskeleton unit to confirm fit and comfort for wearers. Then, the exoskeleton and harness will be tested and validated for use on a construction site to ensure that female workers do not have to sacrifice comfort or safety to reduce RSI's with exoskeletons.

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