Empowering Lineworkers: The Case for Active Exoskeletons in Utility Work

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Abstract – *Exoskeletons have evolved from early medical prototypes to advanced systems capable of addressing physical demands in various industries. This report explores the potential of active exoskeleton technology within the utility sector, focusing on its application for linemen who face significant risks of work-related musculoskeletal disorders (WMSDs). By analyzing existing literature on exoskeletons across industries such as construction, manufacturing, and military, the study identifies a gap in utility-specific applications. Task-specific design features like gravity compensation, limb support, and advanced safety measures, improve exoskeletons' potential to alleviate physical strain, reduce workplace injuries, and enhance productivity. This review emphasizes the need for targeted research and development to optimize exoskeleton designs for the utility sector to provide benefits for workers, companies, and the broader community.*

Key Words: Utility lineworkers, exoskeletons, musculoskeletal disorders

1.INTRODUCTION

History of Exoskeletons

From the fantasy of science fiction to a tangible reality, exoskeletons have transitioned from conceptual dreams to groundbreaking technologies transforming industries. Exoskeletons are categorized into two main types: passive and active. Passive exoskeletons rely on mechanical support systems, such as springs or counterweights, to redistribute loads and reduce strain on the user's body without requiring external power[1]. These systems are often light, cost-effective, and used for repetitive tasks like lifting in industrial settings[1], [2]. Active exoskeletons, on the other hand, incorporate powered components such as motors, hydraulics, or pneumatic actuators to assist and improve human movement[3]. These systems are designed to provide additional strength, reduce fatigue, and improve performance in demanding tasks, making them suitable for both medical rehabilitation and high-intensity occupational applications[2].

Exoskeleton technology has evolved significantly over the decades, transitioning from heavy and cumbersome designs to innovative, lightweight systems with a wide range of applications. Beginning in the 1960s, early prototypes focused on medical applications of exoskeletons[2], [4]. Many projects focused on gait assistance with notable contributions from the Mihajlo Pupin Institute and the University of Wisconsin-Madison[2]. In 1965, General Electric proposed Hardiman, a powered exoskeleton aimed at amplifying human strength to lift heavy loads[2]. The Hardiman project ultimately faced design challenges with excessive weight and vibrations which halted further progress on the suit[5]. Despite not coming to fruition, the research from this project, among others, was still able to pave the way for future designs.

Following the early designs of the 1960s, military-focused designs by Raytheon and Lockheed Martin, such as the XOS and HULC exoskeletons, were introduced to enhance soldiers' strength and endurance during combat and logistics tasks[2]. A few years later, the 2010s saw developments such as the Wyss Institute's textile-based exosuit for walking assistance introducing a soft style of robotic assistance[2]. While Wyss Institute's soft wearable robotic device was still focused on medical applications, industrial and military applications also began to flourish. In 2021, French startup HMT introduced a powered exoskeleton for overhead tasks and heavy lifting with the idea that workers can do more work for longer with the wearable machines[6]. The progression of exoskeleton technologies has pushed designs to address needs outside of the medical industry to find solutions across various sectors.

Solutions to WMSDs

Work-related musculoskeletal disorders (WMSDs) are among the most common occupational injuries, resulting from repetitive motions, prolonged postures, or lifting heavy loads[8], [9], [10]. These injuries often affect the back, neck, shoulders, and arms which can lead to chronic pain, reduced productivity, and increased healthcare costs[9], [10], [11]. Exoskeletons offer a promising solution to mitigate these risks by providing mechanical assistance and reducing physical strain on workers.

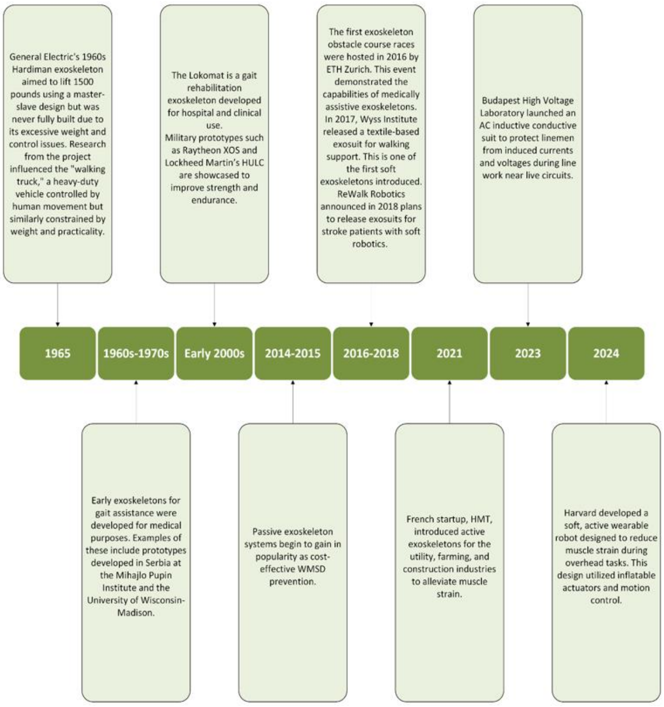

Figure 1. Key milestones in the development and application of exoskeleton technology[2], [6], [7].

These technologies can address WMSDs through functionalities such as limb support and gravity compensation to improve the ergonomics required by the worker[12], [13], [14], [15], [16]. Limb support systems help stabilize and reduce the muscular effort required for tasks like overhead work, while gravity compensation devices assist with lifting heavy objects by redistributing the weight and reducing the load the user's body experiences. These features are highly applicable to physically demanding industries like construction, manufacturing, military[17], and utilities.

In addition to improving ergonomics, exoskeletons can incorporate protective designs to improve safety conditions. An example is the AC induction suit developed by the High Voltage Laboratory at Budapest University that was designed to protect linemen from induced currents and voltages during live work near energized circuits[18]. Such innovations indicate the potential for wearable technologies to reduce workplace injuries.

The advancements in exoskeleton technology, combined with their capacity to address WMSDs and improve safety, show the growing importance of continued research and development across a range of industries. To further explore the potential of exoskeletons in the utility sector, this study evaluates a selection of articles and reports to analyze relevant literature, focusing on how exoskeletons are currently utilized in the industrial space and the gaps that exist for their application in utility work.

2. METHODOLOGY

A systematic approach was used to identify and analyze relevant literature regarding the applications of exoskeletons. The source selection process began with a broad review of general exoskeleton projects, models, and designs. This initial focus included medical, industrial, and military applications to understand the current landscape of these technologies. From there, the search was refined to emphasize industrial applications, narrowing the scope further to manufacturing, construction, military, and utility industry articles. This approach allowed the analysis to capture both the breadth and potential of these technologies in physically demanding roles.

3. ACTIVE EXOSKELETONS FOR UTILITIES

Applications

Many recent advancements in exoskeleton technology have focused on general industry or specific physically demanding occupations. Examples include Harvard's soft, active exoskeleton which uses motion prediction and inflatable actuators to assist with overhead work[7], or the agricultural exoskeleton developed in Russia in 2021, which integrates touch sensing to improve human intent prediction accuracy[19]. While these projects showcase the growing capabilities of active exoskeletons, they also show a significant gap of a lack of focus on the utility sector. Compared to industries like construction or manufacturing, the utility sector has received relatively little attention in exoskeleton development. Given the unique challenges and risks associated with utility work, this lack of targeted solutions represents a missed opportunity to improve safety and quality of life for utility workers.

Potential Benefits to Workers, Utility Companies, and Ratepayers

Lineworkers perform a wide variety of physically demanding movements and tasks as part of their job, many of which are associated with a high risk of WMSDs[11], [20]. Tasks such as hoisting feeder arms, lifting insulators and utility pole components, and performing overhead work for mounts, cables, and other power system devices place significant strain on the back, neck, and shoulders[8], [10]. Additionally, repetitive movements like pulling, pushing, and gripping while working with cables, cutting wire, or climbing ladders can lead to chronic pain and fatigue in the hands, forearms, and legs[8], [9], [10].

Figure 2. Mapping the physical demands of linemen and affected areas of the body.

According to a 2008 study, 70% of linemen reported experiencing symptomatic pain from WMSDs, with 43% citing shoulder pain, 43% reporting spine pain, and 30% reporting knee pain[9]. These WMSD statistics for linemen convey the need for ergonomic interventions tailored to the task-specific demands of utility work. Developing active exoskeleton technology specifically for this field could alleviate these injuries by providing limb support, gravity compensation for lifting, and improved stability for repetitive or prolonged tasks.

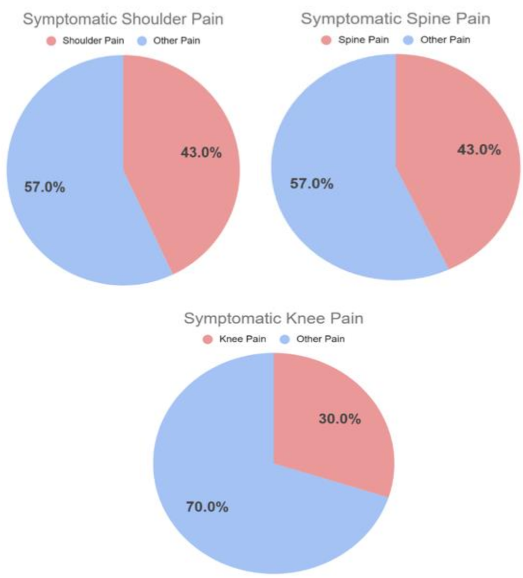

Figure 3. Distribution of symptomatic pain among linemen.

For utility companies, adopting exoskeletons could lead to reduced worker absenteeism, fewer workers' compensation claims, and improved overall efficiency in completing work[11], [20]. By minimizing injury-related downtime and improving productivity, companies can optimize operational costs and maintain more reliable service. For ratepayers, these benefits translate to fewer or shorter disruptions, cost savings passed down through reduced operational expenses, and a safer workforce for their community.

Design Recommendations

Designing an exoskeleton for linemen involves addressing many considerations to provide functionality and safety. Research by the Department of Physical Therapy in Sao Carlos, Brazil indicated that there are a diverse range of activities for utility workers, each with their own WMSD hazards[10]. Trying to create an exoskeleton that can perform every task would be a large feat so the suits would need to be task-specific for the worker. A design challenge coordinated by Harry Roman in 2012 outlined critical factors such as power source selection, safety and fire protections, balance, dexterity, ease of deployment, and environmental exposures[3]. While these considerations may initially seem daunting, task-specific design of the suits allows for targeted solutions by focusing on the most essential features and compromising on others[21], [22], [23].

Additionally, intent recognition is also critical for functionality and user acceptance of this technology. Building on the need for task-specific design, incorporating advanced intent recognition systems can improve the usability of the system[7]. In 2024, a study on ultrasound-assisted intent recognition demonstrated how the exoskeleton can provide precise control and interaction with the user, providing a more intuitive experience[7]. These advancements allow exoskeletons to respond accurately to the user's movements which is crucial for tasks requiring dexterity. By integrating intent recognition with other considerations like lifting or overhead work, exoskeletons have the potential to become the latest necessity to utility workers.

Potential Adoption Barriers

Several industries already adopting exoskeletons have faced challenges that could also be applicable to the utility sector. According to a study conducted in 2019, construction workers raised concerns about safety, usability, and the durability of the system in a real-world environment[13]. Risks such as getting caught on other objects or inability to balance were noted. These concerns could be particularly concerning the utility industry where linemen often work in dynamic and sensitive environments. Compatibility with personal protective equipment (PPE) is another issue[13]. The exoskeleton may interfere with items like fall-arrest harnesses or insulation gloves.

Additional adoption barriers can also include user acceptance and comfort [13], [22]. Discomfort from the weight of the device, the fit, or excessively warm environment were common reasons for abandonment during testing [13]. Acceptance also depends on how well the device aligns with job requirements. If an exoskeleton inhibits motion or requires extensive adjustments, they are less likely to be used consistently. Training and familiarity are methods to increase acceptance and effectiveness.

Lastly, cost is another significant barrier to adoption. There is importance in demonstrating a profitable outcome to justify the upfront costs of the purchase and maintenance of the devices. Industry companies must see the clear productivity or safety benefits to consider implementing such a system. For the utility sector, overcoming these barriers will require targeted design, adequate training, and safety protections before wearable technology is justifiable[22].

4. CONCLUSION

Exoskeletons represent an evolving landscape in technology that bridges human and machine capabilities. From early medical prototypes to modern industrial designs, their potential to mitigate WMSDs and improve safety is significant. There are underutilized opportunities for active exoskeletons to penetrate the utility sector, solving unique needs linemen face in the physical strain on their work. By focusing on task-specific features such as gravity compensation, limb support, and advanced safety measures, these systems can benefit the workers, companies, and ratepayers alike.

Adoption of such systems requires addressing user comfort, safety integration, and cost justification. Drawing lessons from other industries, utility-focused exoskeletons must prioritize compatibility with existing PPE and extensive user training. As research and technology continue to advance, the utility sector could lead in leveraging exoskeleton innovations to improve wellbeing, productivity, and efficiency.

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