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Occupational exoskeletons: Supporting diversity and inclusion goals with technology

Georgia T. Chao *, Caroline Deal, Enzo Novi Migliano

Department of Psychology, University of South Florida, 4202 E. Fowler Avenue, PCD 4118G, Tampa, FL 33620, USA

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ABSTRACT

Occupational exoskeletons are wearable devices that can augment a human worker's physical abilities. They are designed to protect the worker from physical stress and strain due to physically demanding tasks. They are also designed to increase a worker's ability to perform these tasks with less effort or to accommodate tasks with greater physical loads. There is a labor shortage for many physically demanding jobs in manufacturing, construction, agriculture, and healthcare. Occupational exoskeletons may enable more women and older workers to qualify for these jobs. Literature reviews on occupational exoskeletons and workplace diversity and inclusion were conducted to explore how this technology can facilitate diversity and inclusion goals. Future research directions are discussed for exoskeleton design and how they might affect work identities and perceptions of organizational inclusion for women and older workers who pursue vocations in physically demanding work.

Technological advances in exoskeletons are likely to change how physically demanding work is designed, staffed, and evaluated. An occupational exoskeleton is a wearable device that is designed to augment a human worker's ability to perform physically demanding jobs (de Looze et al., 2017). Also known as wearable robots, exoskeletons are designed for two major purposes: safety (Flor-Unda et al., 2023) and performance (Zhou et al., 2020). Both purposes are believed to allow more people to qualify for physically demanding jobs and to hold these jobs for longer time periods. The purpose of this article is to integrate the literatures on occupational exoskeletons and workforce diversity and inclusion, and to chart a path for future research that can advance our understanding of technology and work.

Currently, the idea that occupational exoskeletons can enable more diverse workers (e.g., women, older workers) to qualify for physically demanding work, has been expressed (Kirkwood et al., 2022; Søraa & Fosch-Villaronga, 2020), but we are unaware of any research in this area. Furthermore, these speculations are not grounded in current knowledge of diversity and inclusion (D&I) theories or frameworks. An integration of these literatures can identify opportunities to diversify workforces that utilize exoskeletons, as well as boundary conditions for effective introduction of exoskeletons to diverse groups.

The review begins with a general overview of occupational exoskeletons. We review current and future applications of exoskeletons in work settings with particular attention to how exoskeletons may expand career opportunities for women and how exoskeletons may enable older workers in physically demanding work to keep their jobs. A brief review of the D&I literature will identify likely vocational ramifications for women who enter predominantly male occupations, as well as potential reactions from current workers

* Corresponding author at: Department of Psychology, University of South Florida, 4202 E. Fowler Avenue, PCD 4123, Tampa, FL 33620, United States.

E-mail addresses: chaog@usf.edu (G.T. Chao), carolinedeal@usf.edu (C. Deal), enovimigliano@usf.edu (E. Novi Migliano).

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engaged in physically demanding jobs. The article closes with a discussion of future research needs that can help integrate D&I goals with technological advances of occupational exoskeletons. This review intends to highlight vocational issues with the implementation of exoskeletons and should be of interest to researchers, designers, and managers from many fields, including psychology, human factors, biomechanical engineering, sociology, and human resources management.

1. Overview of occupational exoskeletons

Exoskeletons have been explored since the 1960's, and most research and development on exoskeletons has been in military and rehabilitation applications (Nussbaum et al., 2019). Within the military, exoskeletons were primarily designed to help soldiers carry more weight faster and farther (Zhou et al., 2020). Although significant achievements have been made and research continues, progress has been intermittent due to funding availability, shifting military priorities, and setbacks when exoskeleton prototypes failed to meet performance expectations (Crowell et al., 2019). Within rehabilitation applications, exoskeletons have been used to advance the rehabilitation of physical abilities, such as helping arthritic hands grasp objects or aiding/enabling walking behaviors for people with spinal cord injuries (André & Martins, 2023; Chen et al., 2023). Advances in these areas have informed how exoskeletons can be designed to help people at work. Occupational exoskeletons are designed to support specific parts of the body (e.g., upper arms, back) or augment specific human capabilities (e.g., lifting / carrying objects). They range from small exoskeletons designed to protect the thumb and thumb joints (https://ottobockexoskeletons.com/thumb-new/?lang=en&lang=en) to full-body exoskeletons designed to move heavy objects (https://www.sarcos.com/products/guardian-xo-powered-exoskeleton/).

Exoskeletons can be classified as passive or active, depending on energy sources. Passive exoskeletons, or mechanical exoskeletons, rely on springs, cables, elastic bands, etc., to store or release energy derived from human body movements. For example, energy can be stored in elastic bands when a person bends over (stretches the band) to prepare to lift an object. As the person begins the lift, that energy is released to provide additional force that can enable a person to lift the object with reduced muscular effort or lift heavier objects. Rigid or hard exoskeletons provide a weight-supporting framework that can alleviate muscular stress and strain on the shoulders or back by transferring some forces from these areas to stronger, fatigue-resistant leg and torso areas (Bär et al., 2021; Smets, 2019). Soft exoskeletons are garment-like and are lightweight, more comfortable, and adjustable when compared to hard exoskeletons; however, they may be less effective with heavy-duty tasks (Park et al., 2022).

In contrast to passive exoskeletons, active exoskeletons are designed for heavy-duty tasks. Active, or powered exoskeletons, use one or more actuators (e.g., electric motor, batteries, hydraulic actuators) that provide greater strength and endurance to the user (de Looze et al., 2016) . For example, the Guardian XO exoskeleton is a full-body, battery-powered exoskeleton that enables a human operator to safely lift up to 200 pounds (Sarcos, 2020). Active exoskeletons can incorporate artificial intelligence and machine learning to optimize performance. These technologies use adaptive algorithms to detect patterns of behavior or analyze motion intentions, and then use these data to synchronize human and exoskeleton behaviors and generate corrective actions such as maintaining balance or increasing support to meet user needs (Park et al., 2022; Vélez-Guerrero et al., 2021). The external power source for active exoskeletons currently makes them heavy and/or bulky. For example, three batteries for the Guardian XO exoskeleton weigh 12 pounds each and the exoskeleton itself weighs about 200 pounds, without batteries (Yeadon, 2020). Full-body exoskeletons can transfer weight/loads to the ground (i.e., the exoskeleton legs support most of the weight of the exoskeleton itself, and exoskeleton arms carry most of the weight of objects); however, there remain concerns with mobility and maintenance capabilities (Yeadon, 2020). Currently, active exoskeletons have limited occupational applications due to their high cost, limited effectiveness, and implementation challenges with human operators (Toxiri et al., 2019).

Most exoskeletons used in occupational settings are passive exoskeletons, providing light to moderate assistance for jobs in manufacturing (Raghuraman et al., 2023), construction (Gutierrez et al., 2024), healthcare (Tröster et al., 2020), materials handling (Glock et al., 2021) and agriculture (Harith et al., 2021). Exoskeletons are primarily used to provide support for targeted body parts when engaging in physically demanding, repetitive job tasks (e.g., overhead assembly, materials handling). The added support reduces muscle strain and may decrease the frequency of work-related musculoskeletal disorders (WMSD) and fatigue that are commonly found in manufacturing and construction jobs (Ali et al., 2021). Musculoskeletal disorders involve soft tissue damage from abrupt or accumulated injuries due to repetitive motions, overexertion, and/or prolonged uncomfortable body postures. They affect bones, connective tissue, joints, and muscles, resulting in pain and loss of function (National Academies of Sciences, Engineering, and Medicine [NASEM], 2020).

From a safety perspective, exoskeletons may prevent muscle fatigue and injuries that often result in high medical costs, worker compensation claims, absenteeism, turnover, and lost productivity (Flor-Unda et al., 2023). The potential for safety benefits from exoskeletons cannot be understated. In the US alone, over 2 million nonfatal injuries were reported each year by private industry for the years 2018–2022. Of these injuries, overexertion and bodily reactions were reported as a common cause in occupations related to transportation and material moving, production, and healthcare (United States Bureau of Labor Statistics, 2023a, 2023b). Economic costs of these injuries are difficult to estimate due to the impact of non-work-related causes of musculoskeletal disorders, under-reported injuries, intangible costs (e.g., decreased productivity when working with an injury), and untreated injuries; however, NASEM (2020) reported that in 2015, musculoskeletal disorders were related to 264 million lost workdays and $131.8 billion in lost earnings.

From a performance perspective, exoskeletons can increase the strength, endurance, and performance capacity of human operators. Research on the effectiveness of exoskeletons to protect worker safety or to increase worker performance has seen increased attention, but this is an emerging area challenged by the variety of exoskeletons and methodological limitations.

1.1. Research on occupational exoskeletons

Most of the research on occupational exoskeletons has focused on the effects of exoskeletons on physiological outcomes. de Looze et al. (2016)) qualitatively reviewed within-subject repeated measures experiments that compared participant physical workloads with and without using an exoskeleton on dynamic lifting and static bending tasks. Results from ten studies that examined four passive exoskeletons found up to a 40 % reduction in amplitude of electromyographic (AMP) signals in back muscle activity. Similarly, results from two studies examining one active exoskeleton found up to a 75 % reduction in AMP signals across different muscle groups. However, results across studies varied, most likely due to small sample sizes (1–15), and the examination of different exoskeletons, different tasks, and AMP measures on different muscles.

Bär et al. (2021) conducted a meta-analysis of 48 unique quantitative studies using a variety of exoskeletons on a number of tasks. Most of these studies also involved a small number of participants performing simulated tasks without an exoskeleton, and then performing the same tasks with an exoskeleton. Outcomes included biomechanical stress or strain (e.g., muscle activity, joint moments), physiological strain (e.g., heart rate, blood pressure), and psychological strain (e.g., perceived musculoskeletal discomfort, fatigue). Results varied for back-support exoskeletons, lower-limb-support exoskeletons, and upper-limb-support exoskeletons; nonetheless, some significant reductions in objective and subjective measures of biomechanical stress and strain were found for some, but not all, targeted muscle groups or body parts that an exoskeleton was designed to support. In general, no significant differences between using and not using an exoskeleton were found across biomechanical, physiological and psychological strain measures for non-targeted areas (i.e., body areas that an exoskeleton was not designed to augment). However, there were a few exceptions where exoskeletons significantly increased muscle activity, providing some evidence of unintended negative consequences when using exoskeletons.

The above meta-analysis provided mixed evidence to support the use of exoskeletons in work tasks. Moreover, these findings are likely influenced by several limitations. Bär et al. (2021) rated all studies as having a high risk of bias due to small sample sizes. Only three studies reported a sample size of 20 or more, and none reported a power analysis or effect sizes. In addition, all studies had limited participant exposure with the exoskeleton, ranging from a few seconds to only one full working day. The majority of studies were laboratory studies that were able to standardize tasks and often included objective measures of muscle strain (e.g., electromyography); however, the reliance on healthy, primarily male college students as study participants severely limits the generalizability of these results. In contrast, field studies were constrained by nonrandomized experimental groups, more complex work tasks, and reliance on self-report measures (Baldassarre et al., 2022; Bär et al., 2021). Additional concerns for most studies in the meta-analysis include lack of randomization, selective reporting of results, and using measures with unknown reliability and validity.

Although some support was found for exoskeleton use to significantly reduce musculature strain, Bär et al. (2021) noted that the effects of exoskeletons on worker health remain unknown. The predominance of laboratory and static studies precludes the examination of longitudinal effects on safety and injuries, and the relatively few longitudinal field studies are limited by methodological challenges. An example is found in a study by Smets (2019) who observed three auto assembly workers engaged in overhead work for three months. These participants voluntarily wore an arm-support exoskeleton for about 86 % of their shift length and reported decreases in perceived discomfort in their arms and neck and little or no change in discomfort in the back and legs. All three participants indicated that they would be willing to continue using the exoskeleton every day. Results are encouraging, but the small sample size and reliance on self-report measures are a concern.

In another example, Kim et al. (2021, 2022) examined the effects of an arm-support exoskeleton across 18 months at automotive assembly plants. Although the researchers designed the study to involve adequate sample sizes (e.g., 65 participants in the exoskeleton condition compared to 133 participants in the control group), comparable jobs (final assembly operators with overhead tasks), video recordings, data collection at 4 time points, etc., practical problems resulted in a loss of over one-third of participants (many due to job transfers), participants declining to be recorded, and about 40 % missing data. Although the researchers attempted to collect data on how often exoskeletons were used voluntarily, these data were determined to be unreliable; thus, exoskeleton use was not controlled. Usage patterns were believed to be highly variable across participants, presenting a potentially severe limitation to the study. Results showed no significant differences between the exoskeleton and control groups over the 18-month period on their perceptions of musculoskeletal discomfort; however, fewer participants in the exoskeleton group made medical visits to the plant nurse (6 vs. 41 medical visits for exoskeleton and control groups, respectively). The authors cautioned that the relationship between exoskeleton use and reduction in injuries still remains an open question.

Current research on exoskeleton effects on work performance is also fraught with methodological and practical issues. The relationship between exoskeleton use and performance is task-specific and varies across individuals and exoskeleton designs (Hwang et al., 2021; Kim et al., 2021). It is likely mediated by a number of factors including fit and comfort of the exoskeleton, task demands suitable for the human and exoskeleton, psychosocial factors supporting exoskeleton use, and environmental accommodation of human-exoskeleton interactions with specific work tasks (Elprama et al., 2023; Fox et al., 2019). Furthermore, the various measures of performance (e.g. production rate, errors, production quantity or quality, endurance time, etc.) vary by type of task.

Two reviews examined exoskeleton use and work performance. Baldassarre et al. (2022) reviewed eight studies and found that exoskeletons facilitated lifting and lowering loads, but more dynamic tasks such as carrying loads, walking, or changing postures were perceived to be harder with exoskeletons. In contrast, Botti and Melloni (2024) reviewed 52 studies on exoskeletons and work performance and found that exoskeletons were more likely to decrease productivity rather than increase it or had no effect. They noted that these results were largely based on laboratory testing that did not allow participants to fully adjust to the exoskeletons or were based on prototype exoskeletons that were not ready for commercial use. More longitudinal research in field settings will be required to produce robust results for exoskeletons and work performance.

Research on exoskeletons has also identified unintended consequences of exoskeleton use. Discomfort is one of the most recurrent unintended negative consequences of exoskeleton use, identified in both qualitative (cf. Moyon et al., 2019) and quantitative (cf. Baltrusch et al., 2018) research. Exoskeleton users have reported discomfort related to the pressure, weight, and thermal characteristics of the exoskeleton (Baldassarre et al., 2022; Elprama et al., 2022). For example, some exoskeleton users, especially females, have reported discomfort in the chest region due to an exoskeleton's chest plate (Baldassarre et al., 2022; Fosch-Villaronga & Drukarch, 2023; Kozinc et al., 2021).

As noted earlier, Bär et al.'s (2021) meta-analysis found increased musculoskeletal strain on a few non-targeted areas when exoskeletons were used. Due to the mechanical characteristics of the exoskeletons, non-targeted muscles could respond in unanticipated ways, leading to possible injuries. For example, Theurel and Desbrosses (2019) reported possible negative consequences of lower back exoskeletons, such as interference with spine stability, which could increase the risk of injury. Furthermore, workers with exoskeletons may experience unintended motions, restriction of range, user error, exoskeleton interference with other equipment (e.g., construction workers may not be able to wear exoskeletons if they are already wearing a toolbelt or harness, Kim et al., 2019), exoskeleton interference with behaviors unrelated to exoskeleton use (e.g., walking, climbing), and exoskeleton misalignment, which may contribute to safety hazards and accidents (Baltrusch et al., 2018; Massardi et al., 2023). Exoskeletons may also give wearers a false sense of extra protection or strength that might encourage more risk-taking behaviors, increasing the possibility of injuries (Kim et al., 2019; Schwerha et al., 2021).

Social influences have also been found to be a potential source for unintended negative consequences of exoskeleton use. From interviews and focus groups, participants expressed concerns that using an exoskeleton may not be accepted by others (Cha et al., 2019), may negatively affect their personal appearance (Siedl & Mara, 2022), or may be perceived by others as a sign of weakness (Schwerha et al., 2021). The last concern is directly relevant to how exoskeletons might be used to enable more women and older workers to qualify for physically demanding work. If more women and older workers require exoskeletons to work in typically masculine jobs, male workers may reject the technology in order to preserve their identity as strong men and/or protect their job security.

1.2. Summary

Occupational exoskeletons are relatively new technologies designed to protect and augment the capabilities of people who work in physically demanding jobs. Not surprisingly, interest in occupational exoskeletons has been increasing, with over 80 exoskeleton companies around the world and a projected market growth estimated to be around $11.5 billion by 2030 (James, 2022). There is an emerging body of research that finds significant, albeit modest, reductions of targeted musculoskeletal strain when exoskeletons are used; however, this research is criticized for several substantial risks for biased results (Bär et al., 2021). Research results on exoskeleton use and job performance are mixed, precluding any robust conclusions at this time. More longitudinal field studies are needed to identify exoskeleton designs that can best meet work performance needs.

Although exoskeletons are designed to protect workers from injuries like WMSDs and/or help improve work performance, some unintended negative consequences of exoskeleton use have been observed. Wearing an exoskeleton may interfere with other equipment, impede some behaviors, and increase the risk of injury. Furthermore, acceptance of exoskeletons by the user, coworkers, and supervisor may depend on how exoskeletons might influence the user's self-identity as a worker, team player, or capable individual.

When workforces in physically demanding jobs become more diverse, the introduction and support of exoskeletons will be critical to their acceptance and successful implementation. A brief review of current D&I practices is presented to inform how exoskeletons can support diversity at work.

2. Overview of D&I and exoskeleton implications

Changing demographics around the world have seen increasingly diverse populations along several dimensions including age, race, ethnicity, and religion (Caplan, 2023; Poushter et al., 2019). In addition, economic, social, and organizational changes have increased vocational opportunities for women; however, their advancements have been slow due to inequalities in the workplace (e.g., the pay gap between men and women, sexual harassment and discrimination) (Flores et al., 2021). Scholars have long promoted the constructs of diversity, equity, and inclusion (DEI) and advocate their necessity to achieve a workplace with equal opportunities, involvement, and representation for all (Milliken & Martins, 1996; Roberson, 2012). Diversity can be thought of in general terms as representation in an organization of people with different group affiliations and characteristics (Cox, 1993). Diversity can be described by demographics such as race, gender, and age characteristics as well as acquired attributes such as values, education, and expertise (Harrison et al., 1998). Attention to diversity at work has evolved to include constructs of equity and inclusion (Bernstein et al., 2020; Gill et al., 2018). Inclusion refers to the degree to which members feel that they are accepted and encouraged to participate in organizational processes, which encompasses access to information and resources as well as involvement in groups and decision-making (Mor Barak, 2015; Mor Barak & Cherin, 1998). Lastly, equity is achieved when organizational practices ensure employees are treated fairly, without prejudice or harassment (Bernstein et al., 2020).

More recent derivatives of DEI frameworks add additional letters such as "B" for belongingness (Read, 2021), "N" for neurodiversity (LeFevre-Levy et al., 2023), or rearrange the order of letters to reflect priorities (Russen & Dawson, 2024). However, we focus on diversity and inclusion because they represent two distinct aspects of how more people can qualify for physically demanding jobs when exoskeletons are employed (Roberson, 2006). The diversity component is descriptive, and we identify women and older workers as diverse workers entering jobs that are traditionally held by younger men. The inclusion component is prescriptive, and we focus on organizational policies and practices, as well as informal social forces that help new and different organizational members feel that they belong. Constructs related to equity and belongingness are considered here as parts of the inclusion component because practices that enforce a fair work environment and/or promote feelings of belongingness also help individuals feel included and accepted as full organizational members.

2.1. Diversity and labor market trends

Occupational sex segregation has been observed since women and men began working in distinct jobs and remains today, despite organization, social, or cultural transformations (Reskin, 1993). For example, as of 2022, the United States manufacturing industry employs approximately 15.2 million people, of which approximately 75 % are men (USBLS, 2022b). The predominance of men in manufacturing jobs has not changed much over the past 20 years (USBLS, 2002b; USBLS, 2012b). Furthermore, this workforce is aging. The number of manufacturing workers who were 55 years old or older grew about 24 % every ten years, from approximately 2.59 million in 2002 (USBLS, 2002a), to 3.22 million in 2012 (USBLS, 2012a), and 3.97 million in 2022 (USBLS, 2022a). With exoskeletons, the longevity of manufacturing workers will likely continue to grow, but the inclusion of a more diverse workforce remains uncertain (Andrade & Nathan-Roberts, 2022).

In the past ten years, job openings in manufacturing and construction industries have not been fulfilled by the number of hires. In June of 2023, there was a surplus of 217,000 open positions for both industries combined (USBLS, 2023). Furthermore, a trend for US corporations is to return outsourced manufacturing jobs back to the US, and the growth of new manufacturers in semiconductors and new technologies will exacerbate the demand for more workers (Keilman, 2023). Exoskeletons may play a pivotal role to increase the pool of applicants and retain current workers as they age.

2.2. Understanding inclusion

Several theories have been used to define inclusion and how it affects individual and organizational outcomes. For example, Shore et al. (Shore et al., 2011; Shore et al., 2018) use Brewer's (1991)) Optimal Distinctiveness Theory to define inclusion as an individual's perception of being a valued group member. That perception is based on how the group satisfies an optimal balance between the individual's needs to belong with the group against the need to maintain a unique identity that differs from the group. This could be a challenge for a woman who joins a predominantly male group working on traditionally male jobs. Aspects of social identity theory (Brown, 2015; Tajfel & Turner, 1986) and social comparison theory (Festinger, 1954; Greenberg et al., 2007) can be applied to describe the extent to which an individual identifies as a woman and how she compares herself to men. Shore et al. (2011), Shore et al., 2018) identify an inclusive climate, inclusive leadership, and inclusive practices and processes as antecedents of perceived inclusion. Furthermore, management practices and policies should focus on promoting inclusion as well as preventing harassment, discrimination, or other negative behaviors that would threaten perceptions of inclusion. Support was found for diversity climate and leader inclusiveness to predict employee-perceived workgroup inclusion, which in turn predicted employee outcomes of helping behavior, creativity, and job performance (Chung et al., 2020).

Bernstein et al. (2020) developed the Theory of Generative Interactions to propose that adaptive contact (interactions between diverse groups that engage adaptive learning and positive attitude change), interaction frequency (high frequency of interactions over an extended time period), and interaction quality (positive experiences related to job and organizational success) could successfully counter existing barriers to inclusion (self-segregation, cross-cultural communication apprehension, and negative stereotyping and stigmatizing). Diversity goals may be achieved through recruitment and selection practices, but attention to numbers and kinds of people is not enough to sustain a diverse workforce. Organizations need to promote generative interactions that initiate and develop social connections among diverse people as they work together to achieve organizational goals. This deeper level of interaction, understanding, and adjustment is likely to overcome surface-level (demographic) differences and conflicts (Harrison et al., 2002). Some evidence-based organizationally structured practices include having a mix of diverse employees, facilitating opportunities for interactions, granting equal status and power, and encouraging collaboration and interdependence. In this way, prejudices can be gradually reduced while skills for inclusion, such as adaptive cognition, are developed (Bernstein et al., 2020).

A meta-analysis of 30 studies evaluating diversity management in human service organizations found mixed results on the relationships between demographic diversity (age, gender, race) and beneficial outcomes like satisfaction and commitment, or detrimental outcomes like absenteeism and turnover (Mor Barak et al., 2016). However, diversity management practices that promoted inclusion were consistently and positively related to beneficial outcomes and negatively related to detrimental outcomes. Thus, the effects of diversity are likely to be mediated by inclusionary processes that influence perceptions and sense-making of work experiences.

Diversity training has often been used to confront existing biases and change attitudinal, behavioral, and cognitive outcomes to support D&I goals, although the effectiveness of diversity training is mixed (Bezrukova et al., 2016). Some research finds diversity training can increase trainee knowledge and awareness of workplace diversity and may also increase performance at individual and organizational levels (Alhejji et al., 2016). A meta-analysis of diversity training evaluation research (Bezrukova et al., 2016) found cognitive learning about diversity issues had long-term effects, but changes in attitudinal/affective learning and reactions toward the training declined over time. These findings suggest that efforts to change strong biases and stereotypes of others may require long-term organizational policies and practices to support training interventions. Bezrukova et al. (2016) found stronger overall effect sizes for diversity training when it was integrated within a larger diversity curriculum or other diversity interventions.

2.3. Summary

Early research on diversity in work and organizations focused on different types of diversity and their effects on individual, group, and organizational outcomes. Results are mixed due to the complexity of how diversity is measured, the variety of organizational contexts, and methodological limitations (Bezrukova et al., 2016). More recent research has begun to examine how organizations, leaders, and employees can create a work environment where all individuals may perceive that they have access to and influence on organizational processes and resources and feel that they belong in the organization as valued and welcomed members (Roberson, 2019). Research on diversity management that focused on creating a climate for inclusion was more closely tied to positive outcomes (Mor Barak et al., 2016).

Diversity training programs are common organizational interventions to promote D&I goals. The positive effects of this training are greatest for reactions to the training and on cognitive learning. Diversity training was less effective on behavioral learning outcomes such as conflict resolution strategies, or attitudinal/affective outcomes such as attitudes toward gender or older workers (Bezrukova et al., 2016). We note that training reactions or declarative knowledge are less likely to affect inclusion perceptions than changes in attitudes or behavior with diverse individuals. Thus, the impact of diversity training programs should focus on training content, and how it meets D&I training needs. In addition, reviews on diversity training programs note that this research is hampered by small sample sizes, poor measures, and reliance on self-report measures and static research designs (Alhejji et al., 2016; Bezrukova et al., 2016). Thus, like the current research on occupational exoskeletons, there is a need for more reliable and robust research.

Recent theoretical advancements have been offered to explain how inclusion processes can be used to support diversity in workplaces (Bernstein et al., 2020; Shore et al., 2018). Early results are encouraging, and we believe many technological innovations at work will also benefit from an understanding of how D&I issues will impact the future of work. Specifically, we examine how occupational exoskeletons can empower women and older workers to meet a growing demand for workers in physically demanding occupations. An examination of current theories on vocational choice and technology acceptance can highlight common features in these different domains to better understand how different people can qualify for labor-intensive work.

3. Aligning theories on vocational choice and technology acceptance

Although there are many theories on vocational choice (Feldman, 2002) and many theories to explain technology acceptance (Venkatesh et al., 2016), an exemplar from each field is presented to illustrate how one might inform the other to promote D&I in physically demanding occupations. Holland's theory of vocational choice (1959, 1997) and the Unified Theory of Acceptance and Use of Technology (UTAUT, Venkatesh et al., 2003), are described with particular attention to gender and age differences.

Holland (1959) describes six major classes of personality types and occupational environments: Realistic, Investigative, Artistic, Social, Enterprising, and Conventional (RIASEC). Congruence between an individual's personality and a particular work environment (i.e., person-environment fit) is likely to influence that individual's vocational choice, occupational performance, and career satisfaction. A review by Nauta (2010) showed strong support for the RIASEC types and meta-analyses showed small to moderate relationships between congruence and outcomes like job satisfaction and performance (Spokane et al., 2000; Tsabari et al., 2005). In addition, gender differences were found with women scoring higher on the Artistic and Social dimensions and men scoring higher on the Realistic, Investigative, Enterprising, and Conventional dimensions (Morris, 2016). Consistent with these results, research on adolescents also found females were more likely to choose vocations that focused on working with people, whereas males were more attracted to vocations that focused on working with things (Kuhn & Wolter, 2022). These differences may be related to gender stereotypes developed in childhood. Supporting this view, Martin et al. (2012) found gender identity and roles emerged in preschool children and Woods et al. (2020) found some support that personality traits developed during childhood were related to vocational choices.

Holland's theory of vocational choice is a core theory in counseling psychology and vocational guidance (Nauta, 2010). Early research in the 1970's and 1980's revealed that many vocational counselors were biased in their guidance on appropriate careers for males and females (Helwig, 1976; Schlossberg & Pietrofesa, 1973). The attention on gender bias in vocational counseling has shifted to a broader view on school counseling, but recent research continues to document gender-stereotyping (Mulvey & Killen, 2015) systemic racism, and implicit bias (Vannest et al., 2023). For example, Francis et al. (2019) found school counselors were less likely to recommend black female students for Advanced Placement calculus courses, despite having identical transcripts with white females and black or white males. Continued biases against females for traditionally male courses in science, technology, engineering, and math (STEM) and vocations related to realistic interests (i.e., working with things) are likely to remain barriers for women who are interested in nontraditional careers.

When technological advances can enable more women and older workers to qualify for physical work, theories on technology acceptance and use can identify potential barriers and suggest strategies to improve acceptance for these groups. The Unified Theory of Acceptance and Use of Technology (UTAUT, Venkatesh et al., 2003) integrated eight theories from various fields such as social psychology, behavioral psychology (motivation theory), and information systems management. Three constructs: performance expectancy, effort expectancy, and social influence were predictors of behavioral intention to use new technology. Behavior intention was then proposed as a predictor of behavioral use, along with a fourth construct, facilitating conditions (i.e., organizational and technical supports for the new technology). In addition, four moderators of the relationships between the above predictors and outcomes were specified: gender, age, experience, and voluntariness of use. Gender differences indicated that men's behavioral intention to use new technology was more influenced by their perceptions of the technology's usefulness, when compared to other factors such as the ease in using the technology or the social support of peers and superiors. In contrast, women's perceptions of the technology's ease of use and social influences were more predictive in their intent to use the technology (Venkatesh & Morris, 2000). With regard to age differences, older workers were more influenced by social support and perceived ease of use, whereas younger workers were more influenced by their evaluation of the technology's costs and benefits (Morris & Venkatesh, 2000). These results suggest that organizational interventions designed to encourage women and older workers to accept technology may need to focus on effort expectancy

Table 1
Future research directions for occupational exoskeletons.

I. DESIGN AND PERFORMANCE OF OCCUPATIONAL EXOSKELETONS	
Topic	**Future Research Directions**
Exoskeleton Design	
Fit	Improve exoskeleton designs to fit women and a wider variety of body shapes. This may include aspects such as pressure points, weight, heat, and overall comfort levels when wearing an exoskeleton for extended periods of time.
Functionality	Improve exoskeleton capabilities to protect the worker and enhance performance. This may include aspects such as additional power and strength capabilities, supernumerary robotic limbs, and artificial intelligence. Furthermore, functionality may differ across occupations, job tasks, and work contexts.
Unintended consequences	Identify how exoskeletons might impede mobility and interfere with behaviors that were not targeted for exoskeleton augmentation.
Data integration from exoskeleton and human user	Data collection from digital twins (virtual representations of a specific exoskeleton) and biometric data from the exoskeleton user may be collected in real time, opening opportunities to monitor safety, health, and performance. Issues related to data privacy and ethical use of these data need to be understood.

II. INCLUSION OF WOMEN AND OLDER WORERS IN PHYSICALLY DEMANDING VOCATIONS	
Topic	**Future Research Directions**
Vocational Interests and Vocational Choice	Educational and organizational interventions may be designed to encourage, enable, and support more women and older workers in physically demanding jobs.
Developing interests in physical work	Explore how an individual's personality and vocational interests might develop by exposure to a variety of social cognitive processes that extend beyond gender stereotypes. Understand how technology can influence the development of social and occupational identities.
Career counseling	Understand how schools and career counselors can educate students on how exoskeleton technology can enable more people to qualify for physically demanding vocations.
Intersectionality of salient identities	Beyond simple gender and age effects, more research is needed to consider the impact of technology on multiple salient identities.
Organizational Interventions	Changes in work and organizational interventions or practices to accommodate exoskeleton use.
Work redesign	Understand how work environments may need to be redesigned to accommodate exoskeletons, particularly those that extend a human's capacity. Understand how work tasks may need to be redesigned to accommodate women and older workers.
Human resources	Understand how organizations can best recruit, select, train, and evaluate a more diverse workforce that benefits from exoskeleton use.
Ethics	Understand rights of individuals and organizations with mandatory or voluntary use of exoskeletons. Understand data privacy and use of biometric and health data in personnel decisions.
Organizational culture	Understand how an organization's culture may change when there are significant demographic changes in occupations and workgroups, due to technological advances. Implementation strategies to counteract negative attitudes as well as strategies to promote inclusivity and exoskeleton acceptance will be needed.

III. RESEARCH DESIGN AND METHODOLOGY	
Topic	**Future Research Directions**
Measure of Exoskeleton Acceptance	Develop reliable and valid measures of constructs relevant to exoskeleton acceptance and use.
Conceptualization and measurement of exoskeleton acceptance	Current extensions of technology acceptance models that were originally developed for information technology may not be sufficient for exoskeleton technology.
Individual differences	Understand key individual characteristics that influence one's acceptance and use of exoskeletons.
Team effectiveness	Understand how teamwork may change if some members use exoskeletons and others do not, whether by choice or by the type of taskwork.
Research Design	
Sample demographics	Increase the diversity of research participants beyond current samples of mostly young, able-bodied men.
Sample size	Increase the number of participants in studies for adequate power to detect effects.
Exposure to exoskeletons	More research is needed that gives participants adequate knowledge and experience with exoskeletons. Interactions with exoskeletons on tasks that are related and unrelated to exoskeleton purposes can help identify unintended consequences.
Study length	Investigate exoskeletons in longitudinal studies to examine long-term adjustment, acceptance, and use. Changes in perceptions, attitudes, and behaviors toward exoskeletons may inform better training and management interventions to promote proper exoskeleton use.
Field studies	Investigate exoskeletons within organizational settings to assess their effectiveness in specific jobs and organizational contexts. Investigate how job design and work environments may need to change to accommodate new capabilities of workers using exoskeletons.

and social influence factors.

Since the introduction of UTAUT, Venkatesh et al. (2016)) reviewed the literature and identified 37 extensions of the model, identifying additional predictors, moderators, and outcomes. However, most of the research remains focused on information systems and computers. We only found one study that tested the UTAUT model with exoskeletons (Elprama et al., 2020). Industrial workers were presented with a definition of an exoskeleton and two photos of back-support exoskeletons, then completed scales for the four UTAUT predictors and intent to use exoskeletons. Results found that about 75 % of the variance in the intent to use scale was explained by the four UTAUT predictors, however the study had several limitations. The sample was predominantly male (89 % male), had limited knowledge about exoskeletons (about 75 % of the sample had no experience with exoskeletons), and completed UTAUT scales with no direct interaction with an exoskeleton. Moreover, the study was conducted in companies that were interested in exoskeletons but had no commitment or plans to introduce exoskeletons to their workers. These limitations once again illustrate that research on exoskeletons is still in early stages with methodological and practical research challenges.

Holland's theory of vocational choice and the UTAUT are aligned by their common roots in social cognitive theory. Bandura (1986) theorized that an individual's thoughts and actions are shaped by social learning from modeling or observational learning as well as cognitive self-regulation and self-efficacy. An example of gender differences and potential effects on vocational choice is found in research examining gender differences in math abilities and interest in STEM occupations. Else-Quest et al. (2010) conducted a meta-analysis on gender differences in math abilities. Across 69 countries, they found many gender similarities in math achievement but boys reported more positive math self-concept and self-efficacy and received more parental encouragement for math achievements than girls. Bussey & Bandura, 1999) noted that perceived math efficacy can affect the level of math education pursued and subsequent vocational interests, which can contribute to occupational segregation. Levin and Gati (2015) coined the term "imagined barriers" to refer to deficits in self-efficacy that explain the occupational segregation we see today. This gap in self-efficacy may explain substantial occupational segregation despite research that supports more gender similarities than differences (Hyde, 2014).

Social cognitive theory can help explain why boys and girls develop gender stereotypes related to vocational choice. Girls may not develop particular vocational interests because they have not been exposed to nontraditional careers as serious options for them. Furthermore, Bussey and Bandura wrote: "Moreover, sociocultural and technological changes necessitate revision of preexisting conceptions of what constitutes appropriate gender conduct." (1999, p. 677). As occupational exoskeletons continue to advance, much of the human requirements for physically demanding work will level the playing field between men and women, and between younger and older workers.

Gender differences in vocational preferences and in technology acceptance can help identify developmental, educational, and organizational factors that may lower barriers for women in physically demanding work. Gender stereotypes are often reinforced by peer groups and adult-guided social activities; however, Mulvey and Killen (2015) found that children and adolescents were willing to challenge gender-stereotypic group norms and accept individuals who are interested in counter stereotypic behavior. Furthermore, there is some evidence that greater tolerance may be given to girls pursuing more masculine interests than boys drawn to more feminine activities. More research is needed to understand why there might be barriers to nontraditional work and how new and diverse entrants to labor-intensive work can learn to adjust or change current work environments.

4. Achieving diversity and inclusion goals with exoskeletons: Future research directions

The future of work is often described as the intersection of future technology and future workers. Technological advancements in exoskeletons and their implementation in workplaces are still in the early stages, but research on how people will interact with this technology is needed now to guide future technological designs, future work design, and future vocational paths. Our discussion of future research needs is summarized in Table 1 and is organized in three sections. We briefly discuss future research needs on the design of occupational exoskeletons and how they might accommodate women and older workers. This section provides a foundation for consideration in a second section on how women and older workers can choose physically demanding work and how organizations can promote exoskeleton acceptance and use. Finally, a section on improving research design and methodology is summarized to avoid limitations found in current research.

4.1. Design and performance of occupational exoskeletons

Future research should identify characteristics of exoskeletons that can help, or possibly hinder, performance on specific work tasks. This basic mapping should inform how exoskeletons can be improved to maximize effectiveness and minimize unintentional consequences. Future designs of exoskeletons should move beyond the "one-size-fits-all" approach and address how exoskeletons can be used by workers with different body shapes, job tasks, and work contexts (Andrade & Nathan-Roberts, 2022). Current research involves few women or older participants. Present limitations of occupational exoskeletons include discomfort, difficulty using and adjusting the exoskeleton, performance effectiveness, and/or interference with other work behaviors (Elprama et al., 2023). With regards to the exoskeleton itself, future research should focus on these current limitations, resulting in exoskeletons that would be more acceptable to potential users.

The design of exoskeletons for women will need to go beyond the addition of adjustable straps. Physical differences between males and females include differences in anatomy, muscle mass, biomechanical differences (e.g., less joint torque is required for shorter arms to lift a weight), and fatigue effects. In a similar vein, aging is a progressive decline in all physiological systems, including reduced muscle strength, stamina, reaction time, and balance (Preston & Biddell, 2020). Future research will need to include more women and older people to identify how exoskeletons can accommodate the physical capabilities of these groups. Specific aspects such as pressure points, exoskeleton weight, and perceived heat from wearing an exoskeleton may be concerns for exoskeleton acceptance as well as overall comfort levels (Botti & Melloni, 2024). This research should also consider how the research environment or testing facilities may need to be adjusted for people who are shorter or weigh less than the average male worker (Fosch-Villaronga & Drukarch, 2023). For example, bench height and task loads may need to be proportional to an individual's height and physical strength. Results from this research may have implications for how work environments and tasks are designed.

Many exoskeletons are envisioned to collect data on the exoskeleton and human operator to identify behavior patterns and anticipate imminent reactions. Future research should consider the types of data that are collected and how those data can be used. Continuous streams of biometric data, exoskeleton performance, and user health can provide feedback and real-time corrections. Research involving digital twins and exoskeletons is in early stages (cf. Park et al., 2024). Botín-Sanabria et al. (2022) define a digital twin as "a virtual representation of a physical object or process capable of collecting information from the real environment to represent, validate, and simulate the physical twin's present and future behavior" (p. 1). A digital twin of an exoskeleton used by a worker may be able to monitor both human and exoskeleton performance and correct any actions that may lead to unsafe or unproductive behaviors. Digital twins can also be used to predict future trends that may inform preventative maintenance on the exoskeleton. One can imagine that digital twins may also predict fatigue and risks for WMSDs on the human operator that may result in reassignment or termination decisions. Future research on the types of data that can be collected on exoskeletons will also need to consider data protection and privacy of health-related information and the ethical ramifications of this surveillance (Kapeller et al., 2020).

The design of future occupational exoskeletons includes new ways to imagine people at work. In addition to passive and active exoskeletons, hybrid or semi-active exoskeletons combine aspects of both passive and active exoskeletons, such as incorporating low-power motors into lightweight frames (Botti & Melloni, 2024; Crea et al., 2021). Nasr et al. (2024) found the hybrid exoskeleton significantly reduced energy expenditures compared to fully active or fully passive exoskeletons. More radical innovations include the design of supernumerary robotic limbs into exoskeletons (Liao et al., 2023). Extra arms can stabilize or manipulate an object that can be worked on, and extra legs can help a worker hold an awkward posture or maintain balance when working in confined spaces (Chen et al., 2023). Lastly, artificial intelligence algorithms might enable exoskeletons to provide personal feedback and corrective actions to avoid injury or maintain performance (Vélez-Guerrero et al., 2021). These developments represent exciting new ways for exoskeleton functionality to help workers in physically demanding jobs. The expanded capabilities of humans using exoskeletons may fundamentally change how physical work is designed and assessed by workers and society in general.

4.2. Inclusion of women and older workers in physically demanding vocations

Assuming exoskeletons can be designed to fit different body types, the ramifications of a more diverse workforce should be considered. Older employees could continue working in their later years, potentially without losing productivity or incurring health risks (de Looze et al., 2017; Valentin & Choi, 2022). Older people and women who do not have the physical strength of most men could match that strength when using exoskeletons. These groups could then gain access to well-paying jobs that were previously inaccessible to them. By desegregating these occupations, many people can obtain jobs potentially more suited to their interests and values as opposed to choosing jobs in line with societal stereotypes (Strober & Lanford, 1986). The opportunities to tap additional demographic groups to address the shortage of workers in physically demanding jobs should be a win-win scenario for individuals and organizations. However, there are current barriers that prevent more diverse workers in manufacturing, construction, and agriculture. Two major areas for future research are discussed. First, at the individual level, more research is needed to better understand how exoskeletons are likely to affect perceptions of self-identity and vocational choice for women and older workers. If an exoskeleton can make a woman as strong as a man, how would this change our views of masculinity and femininity? How might societal images of a male-dominated vocation change when more women enter that field? Second, at the organizational level, more research is needed to better understand how organizational practices and interventions can remove barriers to inclusion and promote a culture that welcomes, values, and involves women and older workers (Navarro-Astor et al., 2016).

4.2.1. Vocational interests and vocational choice

We frame this section with women and the construction industry to illustrate future research needs; however, the issues discussed here can apply to other male-dominated industries and to older workers. Norberg and Johansson (2021) describe the construction industry as one of the most sex-segregated industries in the world with the percentage of women in construction work varying between 9 and 13 %. The stereotype of construction workers is a masculine image of dangerous physical work in harsh climates. Long hours and construction sites that take workers away from their homes and families also contributed to the toughness of a macho culture in construction trades (Ness, 2012). The camaraderie that evolved from this male culture rewards physical skills, endurance, and resilience to hardships. Historically, labor unions and employers have worked to exclude women from construction work to preserve the status quo (Norberg & Johansson, 2021). For women who try to enter construction work, they often face a double bind when they are expected to work like a man, but be a woman (Denissen, 2010).

An important component of many vocational choice models is an assessment of an individual's knowledge, skills, abilities, and interests that are then matched to specific job requirements (Lent & Brown, 2020). Future research might address how this assessment can be expanded to include technological aids, like exoskeletons. Girls and young women may not readily exclude themselves from physically demanding jobs, if they are educated and encouraged to pursue nontraditional careers and receive school counseling on how exoskeletons can augment their physical abilities.

Future research is needed to understand how and why women can enter and thrive in male-dominated occupations. The integration of personal identity and social identity theories can help explain how inclusion efforts should examine needs for uniqueness (personal identity) and needs for belongingness (social identity) (Shore et al., 2011; 2018; Stets & Burke, 2000). Theoretical advancements may also consider the intersectionality of salient identities (Köllen, 2021). Female construction workers may view themselves as different from most women and different from most construction workers. The addition of an exoskeleton to a woman's occupational identity is likely to increase her sense of empowerment and competence. The intersection of multiple identities will provide a more comprehensive study of how women assess their fit in male-dominated vocations.

Social interactions with predominately male coworkers may threaten a woman's occupational identity if she experiences discrimination and harassment on the job. Norberg and Johansson (2021) describe how women in construction work are often confronted with misogynistic attitudes, discrimination, and unfair work demands. They describe benevolent sexism to encompass behaviors such as when men offer to help women with physically demanding tasks (i.e., carrying equipment). Although the overt behavior may be viewed as a form of supportive help, it may also communicate that a woman can't perform all tasks, they need help, and they don't belong in construction. However, with an exoskeleton, a woman's physical abilities may be viewed as being on par with her male coworkers. She does not need help. Exoskeletons may serve as visible reminders that old stereotypes regarding women as the weaker sex are no longer applicable in a work setting.

4.2.2. Organizational interventions

Meta-analytic evidence supports the proposition that inclusive practices link diversity to positive organizational outcomes (Mor Barak et al., 2016). Shore et al. (2018) describe several components of inclusion, such as psychological safety when expressing one's thoughts, having a voice in decision-making processes, feeling involved in one's work team, feeling valued and respected for one's uniqueness, being transparent in support, and respecting multiple identities. These elements, in tandem with policies and practices, work to achieve an inclusive climate with high retention of diverse individuals.

Their model divides policies and practices into two categories: practices that contribute to proactively promoting diverse employees' success and retainment, and discouraging actions that may hinder these individuals' success and deteriorate a culture of inclusion. Positive actions to promote inclusion may involve recruiting more diverse talent, mentoring or sponsorship by superiors, recognizing accomplishments, relying on peer support as part of the inclusion efforts, and leveraging diversity to promote connections and performance. Compliance practices to discourage negative behaviors that foster exclusion may involve management procedures for claims of harassment or discrimination, compliance with fair employment laws, and diversity training programs. Aspects of the Theory of Generative Interactions (Bernstein et al., 2020) may be applied here to examine the effects of a series of organizational practices. Constant communication and efforts to foster inclusion are more likely to affect long-term change than a single training program. An example may be found in government efforts to encourage women to work in factories during WWII (Santana, 2016). A fictional character, Rosie the Riveter, empowered many women to enter jobs that were once exclusively male. Organizational and societal support for real Rosies permanently changed some women's perceptions on their ability to successfully hold well-paid, physically demanding jobs. Efforts to return these women to lower-paying jobs, or to no work at all when the war concluded, were mixed. Some women resumed their pre-war identities as non-paid homemakers, but others kept their jobs or transitioned to other work (e.g., clerks) as independent breadwinners. The case of Rosie the Riveter demonstrated that deep-seated attitudes toward women and work can change, prompting organizations and society to accommodate them and their families. Future research may consider how organizations might work together to encourage more women to pursue and take satisfaction in physically demanding work.

More research is needed on organizational implementation strategies for exoskeletons. We know that some employees refuse to use exoskeletons because they don't want to appear to be weak or old (Schwerha et al., 2021), or because they are concerned with their appearance when wearing an exoskeleton and worry about what others might think of them (Siedl & Mara, 2022). How did these negative perceptions emerge and what can be done to convince employees to accept and use exoskeletons? Should exoskeletons be introduced as personal protective equipment? If so, how can an organization enforce mandatory use? If active exoskeletons dramatically increase a worker's performance, how would it change work design, performance standards, performance measurement, and compensation? More applied research is required to answer these questions.

Finally, some research on the ethical implications of exoskeletons may be warranted. Should performance with an exoskeleton far exceed what unequipped humans can do, many questions related to fair compensation, performance management, and social acceptance may be raised, challenging current human resource practices and definitions of work itself. We pose some ethical questions for consideration. Can individuals buy their own exoskeletons and use them at work? What happens if some workers have access to exoskeletons and others do not? How might exoskeletons affect teamwork? Can organizations discriminate against people who cannot fit into an exoskeleton? Who is liable if an injury occurs due to user error? If biometric data collected by exoskeletons can predict an individual's likelihood of a WMSD, can those data be used to terminate that individual? Can exoskeletons be used to expedite an injured worker's return to work? Answers to these questions can help ensure that exoskeletons will be used to enhance, rather than exploit people who use them. Now is the time to consider how occupational exoskeletons should be designed, implemented, monitored, and evaluated to improve career opportunities for a diverse workforce.

4.3. Research design and methodology

As noted earlier, current research has been criticized for many methodological weaknesses. In particular, the acceptance of occupational exoskeletons may require more research beyond extensions of models based on information technology. In addition to better experimental designs with better measures, more longitudinal field studies with larger samples have been recommended (Crea et al., 2021). Such research could address dynamic reactions to exoskeletons as workers become familiarized with what they can and cannot do. Longitudinal research is also required to understand how exoskeleton use can prevent WMSDs, particularly those injuries that occur from accumulated stress and strain. Data from large-scale longitudinal field studies can also inform human resource practices in selection, training, performance evaluation, and safety standards.

4.4. Summary

We adopt a sociotechnical systems perspective to integrate many of the future research directions described above. Trist and Bamforth's (1951) ground-breaking work in British coal mines concluded that the implementation of technical innovations alone can severely disrupt worker morale and productivity. A social organization of work processes that complements the technical system was required to restore a social balance and improve outcomes. Often, improvements in exoskeleton designs are technical, led by researchers in biomechanics and human factors engineering. From a sociotechnical systems perspective, this work must co-evolve in partnership with researchers in organizational psychology and vocational behavior. The joint optimization of technical and social systems can maximize worker acceptance of new work procedures and environments that improve the meaning of work and organizational effectiveness (Pasmore et al., 2019).

If women and older workers are forced to adapt to fixed exoskeleton designs that are based on younger male body types and physical abilities, many D&I goals will fail. Even with helpful exoskeletons, if women and older workers are asked to perform jobs that were originally designed for younger men, this vocational choice may not be sustainable. Research and practice that focus on the genuine inclusion of diverse workers may be the key for organizations to address a growing labor shortage. Given the rapid turnover of technological innovations, change will be a constant phenomenon and work redesign will be a continuous need.

5. Conclusions

Technology and diversity can be combined to better understand how technology can improve organizational processes and social climates. For example, well-developed artificial intelligence can aid unbiased decision-making in selection systems, and virtual reality technology can help train employees to be more inclusive. We are now close to a reality that will allow technology to strengthen the physical abilities of many women and older workers to qualify for jobs that are currently dominated by able-bodied men. Here, the focus is on augmenting the physical abilities of individuals to enter vocations that were once barriers to D&I goals. As opposed to technology applied to promote inclusion from the organization's perspective, exoskeletons represent technologies that enable individuals from diverse work populations to qualify for more jobs. Thus, exoskeletons have the potential to be wielded by either the organization or the individual, which differentiates it from many other technologies. Future research should include exoskeleton interactions with organizational inclusion initiatives as well as individual vocational choices (Garg & Sangwan, 2021; Shore et al., 2011).

This technology is advancing at a rapid rate, and future research is needed to improve exoskeleton design for a wide range of people, better understand how exoskeletons should be implemented, and identify psychological and sociological mechanisms related to how exoskeletons will be accepted by those who use them, as well as those who chose not to use them. These future directions should also include how work may be redesigned to best integrate exoskeletons to maximize productivity and safety goals, as well as foster a supportive environment for their continued use and acceptance (Parker & Grote, 2022). Occupational exoskeletons may open new vocational options for women and older workers. Lessons learned from how exoskeletons can advance D&I goals may enlighten our overall understanding of people, technology, and work.

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No data was used for the research described in the article.

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