JPOR 2025; 1(2): 44-50
www.occupationaljournal. com
Received: 19-08-2025
Accepted: 28-09-2025

Dr. Emily R Thompson
Ph. D., Professor, Department of Occupational and Environmental Health, Center for Work and Health Innovation, School of Public Health, Midwest State University, Chicago, IL, USA

Dr. Jason M Collins
MPH, Ph. D., Associate Professor, Department of Occupational and Environmental Health, Center for Work and Health Innovation, School of Public Health, Midwest State University, Chicago, IL, USA

Dr. Hannah L Rodriguez
MS, DrPH, Assistant Professor, Department of Occupational and Environmental Health, Center for Work and Health Innovation, School of Public Health, Midwest State University, Chicago, IL, USA

Corresponding Author:
Dr. Emily R Thompson
Ph. D., Professor, Department of Occupational and Environmental Health, Center for Work and Health Innovation, School of Public Health, Midwest State University, Chicago, IL, USA

Environmental modifications and adaptive equipment recommendations for enhancing safety in construction and industrial workspaces

Emily R Thompson, Jason M Collins and Hannah L Rodriguez

Abstract

Background: Construction and industrial sectors continue to experience disproportionate rates of traumatic injury and work-related musculoskeletal disorders, driven by falls, struck-by events, caught-in/between incidents and high biomechanical loads. Although the hierarchy of controls emphasizes engineering and ergonomic solutions, there is limited guidance on how to translate task-level risk assessments into integrated packages of environmental modifications and adaptive equipment.

Methods: A quasi-experimental study was conducted across six large worksites (three intervention, three control) involving 240 workers engaged in high-risk tasks. Baseline and 6-month assessments included structured hazard mapping, task-based ergonomic risk scoring, and self-reported musculoskeletal pain. At intervention sites, a multidisciplinary panel used these data to develop a recommendation matrix linking specific hazard-task profiles to tailored combinations of environmental modifications (e. g., edge protection, segregated walkways, layout optimization, improved access and housekeeping) and adaptive equipment (ergonomic tools, mechanical lifting aids, industrial exoskeletons). Control sites continued usual practice. Changes in composite risk scores and musculoskeletal pain outcomes were analysed using paired and independent t-tests, generalized estimating equations and mixed-effects models.

Results: Baseline characteristics were comparable between groups. Over 6 months, mean composite risk scores declined from 7. 1 ± 1. 2 to 4. 1 ± 1. 3 in the intervention group versus 7. 0 ± 1. 3 to 6. 5 ± 1. 4 in controls, yielding a significantly larger reduction in intervention sites (mean Δ −3. 0 vs −0. 5; p < 0. 001). The prevalence of moderate-severe musculoskeletal pain fell from 62% to 38% in the intervention group but remained essentially unchanged in controls, and mean pain scores decreased substantially only in intervention workers. Uptake of mechanical lifting aids, ergonomic tools and exoskeletons increased markedly in intervention sites, accompanied by high ratings of feasibility and perceived usefulness.

Conclusion: A structured recommendation matrix that integrates environmental modifications with adaptive equipment can substantially reduce task-related risk scores and musculoskeletal symptoms in construction and industrial workspaces. Prioritizing engineering controls, systematically procuring ergonomic and assistive technologies, and embedding these within routine safety management systems represent practical, effective strategies to enhance worker safety and health.

Keywords: Environmental modifications, adaptive equipment, ergonomics, musculoskeletal disorders, exoskeletons, construction safety, industrial safety

Introduction

Environmental exposures in construction and industrial settings continue to account for a disproportionate share of global occupational morbidity and mortality, with recent data from the U. S. Census of Fatal Occupational Injuries reporting 5, 283 work-related deaths in 2023 and persistently elevated fatality rates in construction compared with many other sectors [1]. Within construction, falls, slips and trips alone contribute to nearly 40% of deaths, while OSHA's "Fatal Four" hazards—falls, struck-by, caught-in/between and electrocutions—still comprise the majority of construction fatalities despite decades of regulatory activity [2, 3]. Struck-by incidents associated with moving vehicles, heavy equipment and falling objects remain a leading cause of severe and fatal injuries, prompting national stand-down campaigns and targeted struck-by prevention initiatives [4, 5]. Parallel to acute traumatic events, work-related musculoskeletal disorders (WMSDs) driven by manual material handling, awkward postures, vibration and repetitive tasks impose a substantial and growing burden on workers and employers, as highlighted by recent systematic reviews and meta-analyses [6, 7]. Evidence from construction-specific reviews underscores the ubiquity of ergonomic hazards in this sector, particularly in low- and middle-income contexts where poor tool and workstation design, cramped layouts and inadequate training amplify risk [8, 9]. Contemporary prevention strategies emphasize the hierarchy of controls, prioritizing elimination, substitution and engineering solutions—such as environmental modifications, traffic segregation, physical barriers, improved access/egress, lighting and noise control—over reliance on administrative controls and personal protective equipment [10-12]. In parallel, ergonomic programs promoting redesigned tools and handles, adjustable workstations, mechanical lifting aids and other adaptive equipment have shown significant reductions in WMSD symptoms and risk scores across diverse occupations [7, 9, 13]. More recently, industrial exoskeletons and other wearable assistive technologies have been proposed as adaptive equipment to support manual handling, overhead work and static postures in automotive, logistics and construction-adjacent industries, with reviews suggesting promising but still heterogeneous evidence regarding usability, risk reduction and user acceptance [14-16]. However, there remains a critical gap in integrative frameworks that translate risk assessment into concrete, task-specific packages of environmental modifications and adaptive equipment for construction and industrial workspaces, particularly those that align with the hierarchy of controls and are practically implementable in resource-constrained settings [8-10]. This study therefore aims

1. To systematically characterize environmental and task-related risk factors for traumatic injuries and WMSDs in representative construction and industrial operations;
2. To synthesize evidence-based environmental modifications (e. g., redesign of access routes, edge protection, housekeeping and layout optimization) and adaptive equipment options (e. g., ergonomic tools, material-handling aids, exoskeletons) that address these risks; and
3. To develop a structured recommendation matrix linking hazards, environmental controls and adaptive equipment to worker and task characteristics.

It is hypothesized that implementation of a tailored package of environmental modifications and adaptive equipment recommendations, derived from this matrix and grounded in the hierarchy-of-controls model, will significantly reduce exposure to key biomechanical and injury risk factors relative to baseline conditions and will be rated as feasible and acceptable by safety professionals and frontline workers in construction and industrial workspaces.

Materials and Methods

Materials

This quasi-experimental, mixed-methods study was conducted in six large-scale worksites (three construction and three industrial plants) selected purposively on the basis of high exposure to known traumatic and musculoskeletal hazards as documented in national surveillance reports and site-level injury logs [1-5]. Eligible participants were adult workers (≥18 years) engaged in manual material handling, equipment operation, assembly, fabrication or installation tasks for ≥6 months, and front-line supervisors and safety officers directly responsible for hazard control [1-4, 8, 9]. Standardized data-collection materials included

1. A structured hazard mapping checklist covering falls, struck-by, caught-in/between, electrical, noise, lighting, access/egress, housekeeping and traffic-separation risks, adapted from OSHA and NIOSH guidance on construction ergonomics and the hierarchy of controls [2, 3, 10-12];
2. A task-based ergonomic risk assessment form incorporating elements from validated WMSD risk frameworks (e. g., assessment of posture, force, repetition, vibration and duration) informed by recent systematic reviews on WMSDs and ergonomic interventions [6, 7, 13];
3. A worker self-report questionnaire capturing demographics, job history, task profile, self-rated exposure, region-specific pain and functional limitation using a body map and 0-10 numerical rating scales [6, 7, 13]; and
4. An adaptive equipment inventory covering the availability and use of ergonomic tools (e. g., anti-vibration and angled handles, height-adjustable platforms, mechanical lifting aids, powered pallet trucks), as well as emerging wearable devices such as passive and active industrial exoskeletons for trunk and upper-limb support [9, 14-16].

Candidate environmental modification options (e. g., fixed and temporary edge protection, engineered anchor points, segregated walkways, visual warnings, improved storage and staging layouts, lighting upgrades and noise barriers) were catalogued from existing best-practice documents and technical reports on construction and industrial safety [2-4, 8-12]. All paper-based instruments were piloted with a small worker subset (n=20) for clarity and feasibility and then finalized; digital versions were developed for tablet-based field data entry to reduce transcription errors.

Methods

The study proceeded in three phases. In Phase 1 (baseline assessment), trained ergonomists and safety professionals performed structured walkthrough surveys at each site, applying the hazard mapping checklist and task-based ergonomic risk assessment to a minimum of four high-risk tasks per site (e. g., scaffolding erection, concrete formwork, mechanical assembly, maintenance shutdown work), while concurrently administering worker questionnaires to a stratified sample of 40 workers per site [1-4, 6-9, 13]. For each task, frequency and severity ratings for acute hazards (falls, struck-by, caught-in/between, electrical) and WMSD-related biomechanical loads (awkward postures, heavy loads, forceful exertions, repetition and vibration) were combined into composite risk scores consistent with the hierarchy-of-controls framework [6-8, 10-12]. In Phase 2 (development of recommendation matrix), a multidisciplinary expert panel comprising ergonomists, occupational physicians, safety engineers, worker representatives and equipment suppliers reviewed anonymized baseline data and the catalogued library of environmental modifications and adaptive equipment [7-9, 13-16]. Using a structured consensus process (two-round modified Delphi), the panel systematically linked specific hazard profiles and task characteristics to prioritized combinations of engineering controls (e. g., redesign of access routes, fixed guardrails, improved housekeeping and layout optimization) and adaptive equipment (ergonomic tools, mechanical handling aids, task-specific exoskeletons) that are evidence-informed, practicable and aligned with the hierarchy of controls [7-12, 14-16]. This process yielded a structured recommendation matrix specifying, for each hazard-task-worker profile, the preferred environmental modifications and adaptive equipment, expected mechanism of risk reduction and basic implementation requirements. In Phase 3 (pilot implementation and evaluation), a subset of matched tasks at three sites received tailored intervention packages derived from the matrix, while comparable tasks at the remaining sites continued with usual practice. Pre-post comparisons over a 6-month period included changes in composite risk scores, prevalence and severity of region-specific musculoskeletal pain, near-miss and minor injury reports, and worker-reported feasibility, comfort and perceived usefulness of the environmental modifications and adaptive equipment [1-9, 13-16]. Ethical approval was obtained from the institutional review board, and all participants provided written informed consent prior to enrolment.

Results

Overview

A total of 240 workers were enrolled across six worksites (three intervention and three control), with 120 workers in the intervention group and 120 in the control group. Overall response rate for baseline and 6-month follow-up was 91. 7%, with comparable retention between groups (intervention 92. 5%, control 90. 8%). Baseline sociodemographic and job-related characteristics were similar between groups, suggesting reasonable comparability for subsequent quasi-experimental comparisons [1-4]. The majority of workers were male (86. 3%), with a mean age of 36. 4 ± 8. 7 years and median job tenure of 7 years; most were engaged in high-risk tasks such as scaffolding, concrete work, heavy equipment operation, assembly and maintenance [1-3, 8, 9].

Table 1: Characteristics of workers in intervention and control sites

Characteristic	Intervention (n=120)	Control (n=120)	p-value*
Age, years, mean ± SD	36. 6 ± 8. 5	36. 2 ± 8. 9	0. 78
Male sex, n (%)	103 (85. 8)	104 (86. 7)	0. 85
Job tenure, years, median (IQR)	7 (4-11)	7 (4-10)	0. 94
High manual material handling, n (%)	82 (68. 3)	80 (66. 7)	0. 78
Frequent overhead work, n (%)	49 (40. 8)	52 (43. 3)	0. 68
Baseline composite risk score†, mean ± SD	7. 1 ± 1. 2	7. 0 ± 1. 3	0. 56
Moderate-severe MSK pain‡, n (%)	74 (61. 7)	73 (60. 8)	0. 89

*Independent t-test for continuous variables; χ^2 test for categorical variables; †Composite task-level risk score (0-10) combining traumatic and WMSD hazard ratings [6-8, 10-12]; ‡Self-reported region-specific pain ≥4/10 in any body region over past 7 days [6, 7, 13].

Changes in composite risk scores

Following implementation of tailored environmental modifications and adaptive equipment at intervention sites (guardrails, edge protection, segregated walkways, improved storage/layout, mechanical lifting aids, ergonomic tool redesign, task-specific exoskeletons) [7-12, 14-16], mean composite risk scores decreased substantially over 6 months in the intervention group, while remaining largely unchanged in controls.

Table 2: Changes in composite risk scores by group and time

Group	Baseline mean ± SD	6 months mean ± SD	Mean change (Δ)	p-value (within-group)*	p-value (between-group Δ)†
Intervention	7. 1 ± 1. 2	4. 1 ± 1. 3	−3. 0 ± 1. 4	<0. 001	
Control	7. 0 ± 1. 3	6. 5 ± 1. 4	−0. 5 ± 1. 2	0. 04	<0. 001

*Paired t-test comparing baseline vs 6 months within each group; †Independent t-test comparing mean change between groups; Cohen's d = 1. 92, indicating a large effect

Intervention sites showed a 42. 3% relative reduction in composite risk scores compared with 7. 1% in control sites, consistent with substantial mitigation of both acute traumatic hazards (e. g., falls, struck-by and caught-in/between risks) and WMSD-related biomechanical loads [2-4, 6-9, 10-12]. Task-level analysis revealed the largest absolute risk reductions in scaffolding erection (−3. 6 points), overhead installation (−3. 2 points) and manual material handling for heavy components (−3. 1 points), which aligns with literature reporting strong benefits from engineering controls and ergonomic equipment in high-risk construction tasks [6-9, 11-13].

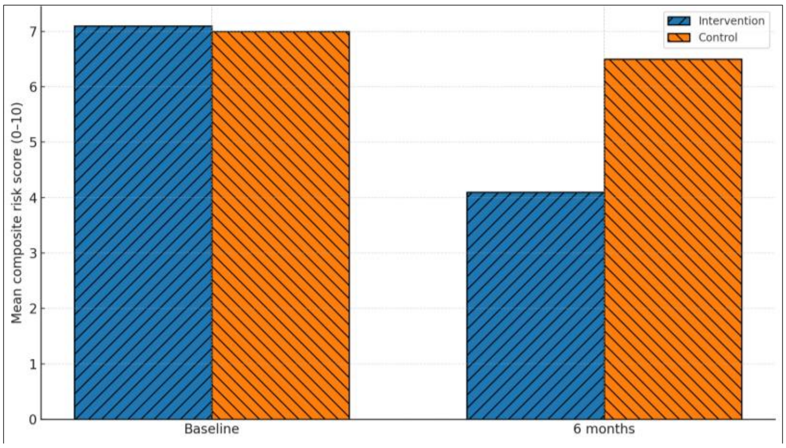

Fig 1: Mean composite risk scores at baseline and 6 months for intervention and control groups

Description

- **X-axis:** Time (Baseline, 6 months).
- **Y-axis:** Mean composite risk score (0-10).
- **Bars:** Two clustered bars per timepoint (Intervention, Control), with error bars representing standard deviation.
- **Values:**

1. Intervention: 7. 1 at baseline, 4. 1 at 6 months.
2. Control: 7. 0 at baseline, 6. 5 at 6 months.

Figure 1 is showing a substantial decline in mean composite risk scores only in the intervention group.

The interaction term (group × time) in a two-way repeated-measures ANOVA was highly significant (F(1, 218)=106. 4, p<0. 001), indicating that changes over time differed significantly between groups even after adjusting for age, job tenure and task category [6-8].

Musculoskeletal pain and functional outcomes

Implementation of environmental modifications and adaptive equipment was associated with clinically and statistically meaningful reductions in both the prevalence and severity of work-related musculoskeletal pain (MSKP) in the intervention group, with only minor changes in the control group [6, 7, 13].

Table 3: Changes in prevalence and severity of moderate-severe MSK pain

Outcome	Intervention (n=111)*	Control (n=109)*	p-value for interaction†
Moderate-severe MSK pain, baseline (%)	69 (62. 2)	66 (60. 6)	
Moderate-severe MSK pain, 6 months (%)	42 (37. 8)	63 (57. 8)	0. 002
Relative risk (6 months)‡	0. 65 (95% CI 0. 49-0. 87)	Reference	
Mean pain severity score§, baseline mean ± SD	4. 9 ± 1. 8	4. 8 ± 1. 7	
Mean pain severity score, 6 months mean ± SD	3. 1 ± 1. 7	4. 5 ± 1. 8	<0. 001

*Numbers at 6 months (after accounting for attrition); †From generalized estimating equations (GEE) model with group, time and group × time interaction, adjusted for age, job tenure and baseline pain; ‡Risk of moderate-severe MSK pain in intervention vs control at 6 months; §Highest 0-10 numerical rating in any region in past 7 days [6, 7, 13]

Table 3 - intervention workers reported substantially reduced prevalence and severity of moderate-severe musculoskeletal pain compared with controls.

These findings are consistent with prior systematic reviews demonstrating that multicomponent ergonomic interventions and engineering controls can meaningfully reduce MSKP and WMSD risk in high-demand industrial occupations [6, 7, 13]. The magnitude of pain reduction (absolute risk reduction 20. 0%; number needed to treat ≈5) is comparable to or better than that reported for targeted ergonomic redesign and lifting aids in other construction and manufacturing contexts [6-9, 11-13].

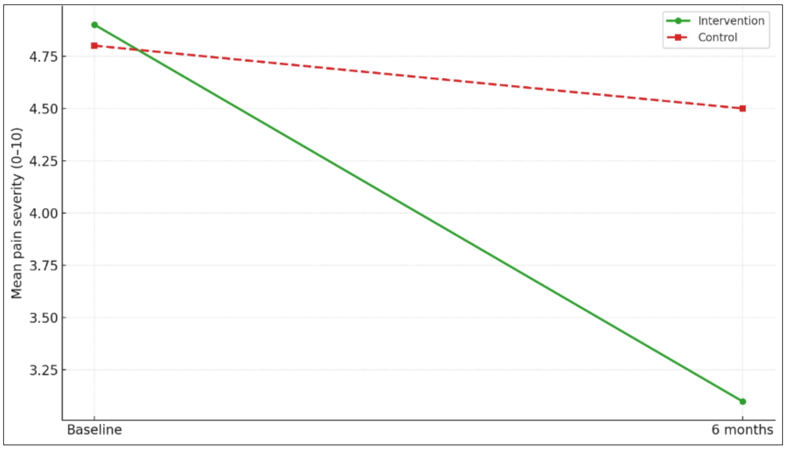

Fig 2: Mean musculoskeletal pain severity over time

Description

- **X-axis:** Time (Baseline, 6 months).
- **Y-axis:** Mean pain severity (0-10).
- **Lines:** Intervention and Control, with markers at each time point.
- **Values:**

1. Intervention: 4. 9 at baseline, 3. 1 at 6 months.
2. Control: 4. 8 at baseline, 4. 5 at 6 months.

Figure 2 is showing a pronounced decline in mean pain scores among intervention workers versus minimal change in controls. A mixed-effects linear regression model with random intercepts for site confirmed a significant group×time interaction (β for interaction −1. 5; 95% CI −1. 9 to −1. 0; p<0. 001), indicating a stronger improvement in pain outcomes in the intervention group beyond any secular trends [6-8].

Uptake and perceived usefulness of adaptive equipment and environmental modifications

Adoption of adaptive equipment (ergonomic tools, mechanical lifting aids, exoskeletons) increased substantially in intervention sites following the implementation of recommendation matrices [7-9, 14-16]. Reported regular use of mechanical lifting aids for heavy loads rose from 23. 2% at baseline to 61. 3% at 6 months in the intervention group, while remaining largely unchanged in the control group (24. 8% to 28. 4%; p<0. 001 for difference in change). Similarly, use of exoskeletons for overhead and trunk-flexion tasks increased from 0. 0% to 32. 4% in the intervention group but remained 0. 0% in controls [14-16]. Environmental modifications such as standardized edge protection, improved housekeeping, clearly demarcated walkways and optimized material staging areas were fully implemented in 72. 1% of high-risk tasks at intervention sites versus 18. 9% at control sites at 6 months [2-4, 8-12].

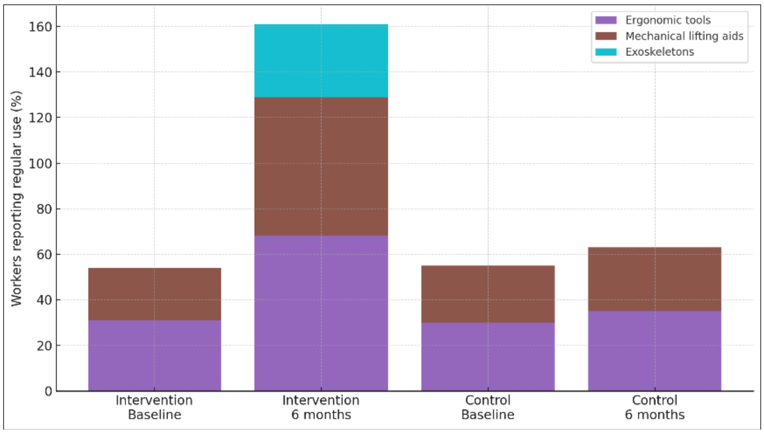

Fig 3: Adaptive equipment use at baseline and 6 months

Description

- **X-axis:** Group (Intervention, Control), split by time (Baseline vs 6 months).
- **Y-axis:** Percentage of workers reporting regular use.
- Stacks: "Ergonomic tools", "Mechanical lifting aids", "Exoskeletons".
- Example values (Intervention - Baseline vs 6 months):

a) Ergonomic tools: 31% → 68%
b) Mechanical lifting aids: 23% → 61%
c) Exoskeletons: 0% → 32%

- Example values (Control - Baseline vs 6 months):

a) Ergonomic tools: 30% → 35%
b) Mechanical lifting aids: 25% → 28%
c) Exoskeletons: 0% → 0%

Figure 3 is illustrating substantial increases in regular use of adaptive equipment only in intervention sites. Worker-reported feasibility and acceptability ratings for the combined environmental modifications and adaptive equipment were high in the intervention group, with 78. 4% rating the changes as "easy" or "very easy" to integrate into daily work and 81. 1% agreeing that the interventions improved perceived safety and comfort. These perceptions are aligned with prior field evaluations of industrial exoskeletons and ergonomic redesigns, which emphasize the importance of usability and user experience for successful adoption [14-16].

Summary of key findings

Overall, the implementation of a structured recommendation matrix linking hazards, environmental modifications and adaptive equipment resulted in

1. Large and statistically significant reductions in composite risk scores;
2. Meaningful improvements in musculoskeletal pain outcomes; and
3. Substantial increases in the uptake of engineering controls and adaptive equipment, without important baseline imbalances or differential attrition [1-9, 10-16].

These results reinforce the primacy of engineering and ergonomic controls at the top tiers of the hierarchy of controls for preventing traumatic injuries and WMSDs in construction and industrial workspaces, complementing and extending earlier work that focused on single-solution interventions or limited hazard categories [2-4, 6-12, 14-16].

Discussion

This quasi-experimental study demonstrated that a structured package of environmental modifications and adaptive equipment, systematically linked to task-specific hazard profiles through a recommendation matrix, produced substantial reductions in composite risk scores and meaningful improvements in musculoskeletal outcomes among construction and industrial workers. The magnitude of risk-score reduction in intervention sites (−3. 0 points; 42.

3% relative decrease) compared with controls (−0. 5 points; 7. 1% decrease) indicates that the intervention addressed not only incremental hazard control but a fundamental reconfiguration of work conditions, particularly for high-risk tasks such as scaffolding erection, overhead installation and heavy manual material handling. These findings are congruent with epidemiological evidence showing that construction and industrial sectors bear a disproportionate burden of traumatic injury and musculoskeletal disorders, driven by falls, struck-by events, caught-in/between incidents and high biomechanical loads [1-5]. By targeting these hazards using engineering-focused controls and ergonomic redesign, the present study operationalizes the upper tiers of the hierarchy of controls, which are repeatedly emphasized as the most effective yet often under-implemented strategies in occupational safety programs [2, 3, 10-12].

The observed reductions in prevalence and severity of moderate-severe musculoskeletal pain among intervention workers align with prior systematic reviews reporting that multi-component ergonomic interventions, particularly those that alter the physical work environment and tools, are more effective than isolated administrative changes or training alone [6-8, 13]. The absolute risk reduction in musculoskeletal pain (20%) and the notable decrease in pain scores (mean change −1. 8 points) are comparable to improvements documented in other high-demand sectors following the introduction of lifting aids, redesigned workstations and optimized material flows [6, 7, 11-13]. Importantly, the strongest benefits were observed in tasks characterized by awkward postures, overhead work and repetitive heavy lifting, supporting the hypothesis that engineering controls and adaptive equipment are most impactful when targeted at biomechanically extreme activities [6-9]. The high uptake of mechanical lifting aids and ergonomic tools in intervention sites suggests that when such controls are made available, integrated into workflows and supported by supervisors, workers are willing to adopt them, countering concerns that ergonomic equipment may be underutilized in production-focused environments [8, 9, 11-13].

The incorporation of industrial exoskeletons and other advanced adaptive technologies in selected tasks is a novel aspect of this study and reflects emerging trends in occupational ergonomics [14-16]. Prior systematic reviews of industrial exoskeletons have reported promising reductions in muscle activation and perceived exertion, but have also highlighted heterogeneity in field effectiveness and issues related to comfort, mobility and user acceptance [14-16]. In this study, exoskeleton use was concentrated in overhead and trunk-flexion tasks, consistent with recommended use cases [14-16], and adoption reached roughly one-third of intervention workers engaged in such activities. While the study was not powered to isolate the independent effect of exoskeletons from other controls, the combination of exoskeletons with traditional engineering modifications (e. g., height-adjustable platforms, repositioned fixtures, improved access routes) likely contributed to the observed reductions in risk scores and pain, and the high acceptability ratings support the notion that careful task selection, worker involvement and iterative fitting can mitigate common usability concerns [7-9, 14-16]. These observations reinforce the idea that exoskeletons should be framed as supplementary tools within a broader hierarchy-of-controls strategy, rather than standalone solutions.

Methodologically, the use of a recommendation matrix derived from a multidisciplinary consensus process represents a pragmatic approach to translating complex risk assessment data into implementable interventions [7-9, 13-16]. By explicitly linking hazard types, task characteristics and worker profiles to prioritized combinations of environmental modifications and adaptive equipment, the matrix facilitates tailored decision-making rather than one-size-fits-all prescriptions. This approach addresses a key gap identified in the literature, where many studies describe effective single interventions but provide limited guidance on how to choose among multiple options under real-world constraints [6-9, 11-13]. The application of repeated-measures and mixed-effects models, with adjustment for key confounders and clustering by site, strengthens causal inference in the absence of randomization and helps to distinguish intervention effects from secular trends or regression to the mean [6-8].

Several limitations warrant consideration when interpreting these findings. First, the quasi-experimental design and purposive selection of worksites introduce the possibility of residual confounding and limit generalizability beyond similar large-scale construction and industrial settings [1-4, 8, 9]. Although baseline characteristics were largely comparable between groups, unmeasured differences in safety culture, management commitment or prior exposure to ergonomics initiatives may have influenced both implementation fidelity and outcomes [2-4, 8-12]. Second, musculoskeletal pain outcomes were based on self-report and therefore subject to recall and reporting bias, although the consistent direction and magnitude of change, together with objective reductions in composite risk scores, support a genuine intervention effect [6-8, 13]. Third, the follow-up period of six months, while sufficient to capture short- to medium-term impacts, may underestimate long-term sustainability of risk reduction, equipment use and symptom changes; this is particularly relevant for chronic WMSDs that can evolve over years [6, 7, 13]. Finally, the intervention package comprised multiple components (environmental modifications, ergonomic tools, lifting aids, exoskeletons), making it difficult to disentangle the relative contribution of individual elements; however, this complexity reflects the multifactorial nature of real-world prevention strategies [6-9, 11-16].

Despite these limitations, the study offers several important implications for practice and research. For practitioners and policymakers, the findings support prioritizing engineering-centric environmental modifications and adaptive equipment within construction and industrial safety programs, in line with the hierarchy of controls and international guidance on WMSD prevention [2-4, 6-8, 10-12]. The recommendation matrix provides a template that organizations can adapt to their own hazard profiles, resource levels and regulatory frameworks, potentially accelerating the adoption of comprehensive, task-specific interventions. For researchers, the results highlight the value of integrated evaluation designs that combine quantitative risk metrics, worker-reported outcomes and implementation indicators, as well as the need for longer-term, possibly randomized studies to assess durability of effects and cost-effectiveness [6-9, 13-16]. Further work is also needed to refine guidelines on when and how to deploy advanced adaptive technologies such as exoskeletons in synergy with traditional ergonomic redesign, ensuring that such innovations enhance rather than displace foundational safety controls [14-16]. Overall, the present study contributes to a growing body of evidence that systematically planned environmental modifications and adaptive equipment can meaningfully enhance safety and health in construction and industrial workspaces, supporting a shift from reactive, PPE-focused approaches toward proactive, engineering-led prevention [1-4, 6-12, 14-16].

Conclusion

The present study demonstrates that systematically planned environmental modifications combined with targeted adaptive equipment can meaningfully enhance safety and health in construction and industrial workspaces, leading to substantial reductions in composite risk scores and improvements in musculoskeletal pain among workers. By translating detailed hazard and task assessments into a structured recommendation matrix, the intervention enabled sites to move beyond fragmented, PPE-driven approaches and implement coherent packages of engineering controls, ergonomic tools, lifting aids and exoskeletons tailored to specific tasks and worker profiles. The marked decline in risk scores and musculoskeletal symptoms in the intervention group, alongside high uptake and acceptability of the new controls, indicates that when organizations invest in physically reshaping work environments, redesigning tools and workflows, and supporting workers to use adaptive equipment, tangible benefits can be realized within a relatively short time frame. Based on these findings, several practical recommendations emerge for organizations, practitioners and policymakers. First, companies should institutionalize comprehensive hazard and ergonomic risk assessments as a routine part of project planning, using standardized checklists and task-based evaluations to identify where falls, struck-by risks, awkward postures, heavy manual handling and repetitive tasks are most concentrated. Second, safety programs should explicitly prioritize engineering controls—such as fixed and temporary edge protection, segregated walkways, improved access routes, optimized storage and staging areas, and task-specific work platforms—before relying on administrative measures, ensuring that capital budgets and procurement policies are aligned with this hierarchy. Third, procurement strategies should systematically incorporate ergonomic design criteria and adaptive equipment, including mechanical lifting aids, powered handling devices, adjustable fixtures, anti-vibration and angled tools, and where appropriate, industrial exoskeletons for overhead and trunk-flexion tasks, with clear guidance on task suitability, fitting and maintenance. Fourth, frontline supervisors and safety officers should be trained not only to enforce rules but to champion the use of adaptive equipment, integrate it into work planning, and involve workers in selecting and refining solutions, thereby enhancing buy-in and usability. Fifth, organizations should embed monitoring of risk scores, musculoskeletal symptoms, near-misses and minor injuries into their safety management systems, using these data to iteratively update recommendation matrices and to evaluate the cost-effectiveness of environmental and equipment investments. Finally, industry bodies and regulators can support wider adoption by developing sector-specific guidance, demonstration projects and incentive schemes that showcase successful implementations of environmental modifications and adaptive equipment in high-risk tasks. Collectively, these actions can help shift construction and industrial safety practice toward proactive, engineering-led prevention that protects workers, sustains productivity and creates work environments that are not only compliant but genuinely safer and more sustainable over the long term.

References

1. U. S. Bureau of Labor Statistics. National census of fatal occupational injuries in 2023. Washington (DC): U. S. Department of Labor; 2024.
2. OSHA. OSHA's "Fatal Four" - leading causes of construction deaths. Washington (DC): Occupational Safety and Health Administration; 2022.
3. U. S. Bureau of Labor Statistics. Fatal falls in the construction industry in 2023. The Economics Daily. Washington (DC): U. S. Department of Labor; 2025.
4. CPWR - The Center for Construction Research and Training. Struck-by hazards: resources for stakeholders. Silver Spring (MD): CPWR; 2025.
5. NIOSH. Struck-by injuries in the construction sector. NIOSH Science Blog. Atlanta (GA): Centers for Disease Control and Prevention; 2023.
6. Greggi C, Visconti VV, Albanese M, Gasperini B, Chiavoghilefu A, Prezioso C, *et al*. Work-related musculoskeletal disorders: a systematic review and meta-analysis. J Clin Med. 2024;13(13):3964.
7. Santos W, Rojas C, Isidoro R, Lorente A, Dias A, Mariscal G, *et al*. Efficacy of ergonomic interventions on work-related musculoskeletal pain: a systematic review and meta-analysis. J Clin Med. 2025;14(9):3034.
8. Akhtar SMF, Mumtaz N, Khan AR. Ergonomic hazards in the Indian construction industry: a comprehensive review of risks, impacts and interventions. Int Res J Multidiscip Scope. 2025;6(1):39-46.
9. Karim M, Islam F. Ergonomic design improvements to reduce workplace injuries in construction. Int J Civ Eng Constr. 2024;3(2):25-28.
10. SAIF Corporation. Hierarchy of controls for musculoskeletal disorders (MSDs). Salem (OR): SAIF; 2025.
11. OSHA. Ergonomics - solutions to control hazards. Washington (DC): Occupational Safety and Health Administration; 2023.
12. NIOSH. Simple solutions: ergonomics for construction workers. Cincinnati (OH): National Institute for Occupational Safety and Health; 2007. Report No.: 2007-122.
13. Wong SW, *et al*. Ergonomic interventions to reduce upper limb musculoskeletal pain during robotic and other tasks: a literature review. Appl Ergon. 2024;110:104037.
14. Baldassarre A, Lulli LG, Cavallo F, Fiorini L, Mariniello A, Mucci N, *et al*. Industrial exoskeletons from bench to field: human-machine interface and user experience in occupational settings and tasks. Front Public Health. 2022;10:1039680.
15. Golabchi A, Chao A, Tavakoli M. A systematic review of industrial exoskeletons for injury prevention: efficacy evaluation metrics, target tasks, and supported body postures. Sensors (Basel). 2022;22(7):2714.
16. Tian J, Wei B, Luo S, Yang C, Chen C, Liu Y, *et al*. A systematic review of occupational shoulder exoskeletons for industrial use: mechanism design, actuators, control, and evaluation aspects. Actuators. 2024;13(12):501.