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Applying implementation science to evaluate participatory ergonomics program for continuous improvement: A case study in the construction industry

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ABSTRACT

While participatory ergonomics (PE) presents numerous benefits, its empirical effectiveness remains elusive due to the lack of transparency in implementation contexts and processes. This hinders our ability to discern the reasons behind a program's success or failure and to determine optimization and adaptation strategies. To unravel this "black box," we present a case study using implementation science to evaluate a PE program and illuminate the mechanisms linking process to outcome. The study examines a 4.5-year PE program at a construction company, targeting musculoskeletal disorders (MSDs) from material-cart handling. Using the RE-AIM framework and Implementation Causal Pathway Model, we evaluated implementation process and catalogued contextual factors through worker surveys (n = 106), safety document review (27 training sessions and 7 construction projects), and key informant observations. We assessed the program's impact using a 42-worker survey and an analysis of 8-year injury data, and determined the return-on-investment (ROI) by monetizing the collected data. The program achieved significant impact: Workers' ergonomic knowledge improved from 73% in baseline to 86% in follow-up; 97% of workers reported at least one positive change in their crews; and no cart handling injuries occurred after the first program change, resulting in a ROI rate of 1.99. Implementation process evaluation revealed that seamless integration, tailored intervention, and ongoing adjustments contributed to the success. Five organizational factors necessary for the effective functioning of these three strategies were identified, along with three moderators that amplified their influence. Finally, this case study demonstrates that implementation science offers a coherent structure for evaluating PE programs, uncovering mechanisms of change, and informing future improvements and adaptations. Our research facilitates knowledge transfer from implementation science to ergonomics, eventually leading to more cost-effective PE programs that are faithfully implemented across various industrial settings to prevent MSDs.

1. Introduction

Participatory ergonomics (PE) is a widely adopted approach to prevent work-related musculoskeletal disorders (MSDs) by involving practitioners in the ergonomic modification of their work activities (Tappin et al., 2016; van der Molen et al., 2005). The rationale for PE lies in the notion that practitioners, with their firsthand knowledge of their work, have the capacity to influence change processes and outcomes (Hignett et al., 2005). In practice, a wide variety of PE models with numerous variations in program characteristics can be implemented (Broberg et al., 2011; Schmidt et al., 2021). The original PE model falls under the category of microergonomics and is reactive, where teams comprising workers and management collaboratively address existing ergonomics issues (Hess et al., 2004). Wells et al. (2003) further introduced a proactive model outlining steps to anticipate and prevent ergonomic issues from arising in the first place. While many PE programs documented in the literature are externally regulated by researchers, the integration of organizational learning into the PE program offers the potential for a gradual transition towards internal regulation by the company's own staff (Haims and Carayon, 1998). Moreover, recent years have witnessed the emergence of PE programs operating at a macroergonomics level, with a focus on enhancing the overall well-being of workers alongside a company's health initiatives (Henning et al., 2009; Nobrega et al., 2017; Punnett et al., 2009). Alongside these

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advancements, however, current studies present inconsistent evidence regarding the effectiveness of PE in promoting ergonomic changes and reducing MSDs injuries and symptoms (Burgess-Limerick, 2018; Cole et al., 2005; Rivilis et al., 2008).

The mixed health outcomes of PE programs could be a result of the diversity of program implementation, as poor fidelity can negatively impact PE programs performance (Van Eerd et al., 2018). Rasmussen et al. (2018) found that most PE studies do not explicitly describe and evaluate implementation components, making it difficult to gauge the full impact of the PE intervention. Furthermore, the inconsistent evidence on the effectiveness of PE could also be explained by varying contexts faced by PE implementers (Burgess-Limerick, 2018). For example, companies with varying organizational cultures and management systems may not implement an ergonomic program with equal faithfulness and consequently, may not achieve the same result (Yazdani and Wells, 2018). Thus far, there has been limited research on cataloging contextual factors and examining their influence in PE intervention programs, despite the potential benefits for intervention adaptation and improvement.

Implementation science can provide PE implementers with scientific methods to measure and manage implementation fidelity and contextual factors (Nilsen, 2020). This field seeks to understand how to get "what works" to the people who need it, with greater speed, fidelity, efficiency, quality, and relevant coverage (Kemp et al., 2018). For example, RE-AIM is a framework developed by implementation scientists to consider important contextual factors when planning interventions (King et al., 2020) and to evaluate the components of the implementation (Balis and Strayer, 2019). The framework has become mature after two decades of application and refinement in public health (Glasgow et al., 2019). Although not yet widely applied in ergonomics, implementation science can significantly enhance the understanding of processes and conditions that lead to successful interventions, thereby advancing PE theory and practice.

This paper presents a case study of a successful PE program in the construction industry, employing implementation science concepts and methods. The case study evaluates the program's implementation process, intervention effectiveness, and return on investment (ROI). Based on the evaluation outcomes, the case study identifies contextual factors and change mechanisms affecting implementation fidelity. The goal is to devise strategies for continuous improvement and future expansion. To this end, the research provides insights on structuring a PE program and demonstrates the novelty of integrating implementation science into a PE program evaluation. The study also conducts an in-depth economic assessment, addressing the existing gap in cost-benefit knowledge for ergonomic interventions (Sultan-Taieb et al., 2017; Tompa et al., 2010, 2013). Ultimately, this paper aims to foster knowledge transfer from implementation science to applied ergonomics, resulting in cost-effective PE programs that are faithfully implemented across industries to prevent MSDs.

2. Description of the participatory ergonomics program

The PE program described in this study was implemented within a family-owned, privately held commercial roofing and waterproofing company with over a century's history, based in the Pacific Northwest of the United States. The company employs over 150 field staff and 30 office personnel and provides full roofing and waterproofing services for large construction projects. The company is dedicated to safety and has consistently been rated among the top safest roofing contractors in Washington State during the study period. However, prior to the PE program, their existing ergonomic program was rudimentary, comprising only a stretching routine and training on lifting techniques, such as 'watch your back' and 'lift with your legs'. The company had a general awareness of MSDs as a severe problem in its workplace but lacked technical knowledge about risk factors and possible solutions. Almost 50% of the reported injuries were attributable to MSDs. This alarming fact motivated the safety team to upgrade their ergonomics program to further improve the company's safety records. Notably, this company had an interest and prior experience in safety research at the time of the PE program's inception.

The program, which was led by the authors and the company's safety team between June 2018 and December 2022, can be divided into three phases: participatory partnership initiative, research and development (R&D), and ergonomic intervention. The timeline of the PE program is shown in Fig. 1. The logic model—2SAFE—underlying the PE program was detailed in the authors' prior study (Zhang, 2021; Zhang et al., 2022). 2SAFE functions as a reactive, microergonomics model, facilitating the resolution of existing ergonomic issues within the company. This aligns seamlessly with our program's purpose. The model underscores excellence in the implementation process by laying out clear steps for researchers to communicate with industry partners, ensuring their sustained engagement throughout the program. It also offers guidelines for researchers during the R&D phase, guaranteeing streamlined implementation that both furthers scientific insight and resolves real-world ergonomic issues.

The first phase of the PE program, the participatory partnership initiative, commenced with the goal of preventing MSDs caused by material-cart handling. This issue was identified in the summer of 2018, when one author, a doctoral student at the time, interned with the company and noticed that many cart handling injuries could have been prevented had there been a set of evidence-based principles to address ergonomic hazards involved in manual material handling. The field investigations prompted senior management to take immediate action by purchasing new carts (Fig. 2(a)) and establishing a university-business partnership between the authors and the company to address safety deficiencies through a participatory approach.

The second phase of the PE program, the R&D, aimed to generate evidential guidance for material-cart handling. This phase included laboratory experiments (Fig. 2(b)) and field studies, during which the company used 14 experimental carts in day-to-day operations at no cost. The participatory process and research results were described in detail in prior studies (Zhang, 2021; Zhang et al., 2021). As a result, the PE program developed a range of implementation-ready ergonomic resources (Fig. 3). These resources were subsequently evaluated and refined in 2020 through feedback from more than 105 company staff members (Fig. 2(c and d)) and 12 safety trainers or union representatives external to the company. The evaluation process and results have been described extensively elsewhere (Lin and Zhang, 2022).

The third phase of the PE program, the ergonomic intervention, aimed to systematically adopt the ergonomic resources developed during the R&D phase at the company. The intervention was implemented between August 2021 and June 2022, followed by a 6-month post-intervention evaluation. The intervention was comprised of four components, each involving multiple activities.

- Awareness Campaign (August 2021–June 2022). The PE program began the intervention by showing animated stories and providing a 1-h presentation training at the company's all-hands meeting (Fig. 4(a)). The same animated stories were presented in safety orientations and foreman meetings. The goal of the awareness campaign was to increase frontline workers' awareness and motivation to participate in the intervention.
- Skill Training (January 2022–June 2022). Company foremen discussed the training handouts with the PE program team during monthly foreman meetings (Fig. 4(b)) and then led toolbox talks using the same materials. The goal was to help workers recognize ergonomic hazards associated with cart handling and ways to control them.
- Policy Intervention (August 2021–June 2022). The company's existing safety document templates were updated to include information on how to reduce cart handling injuries on each project. The

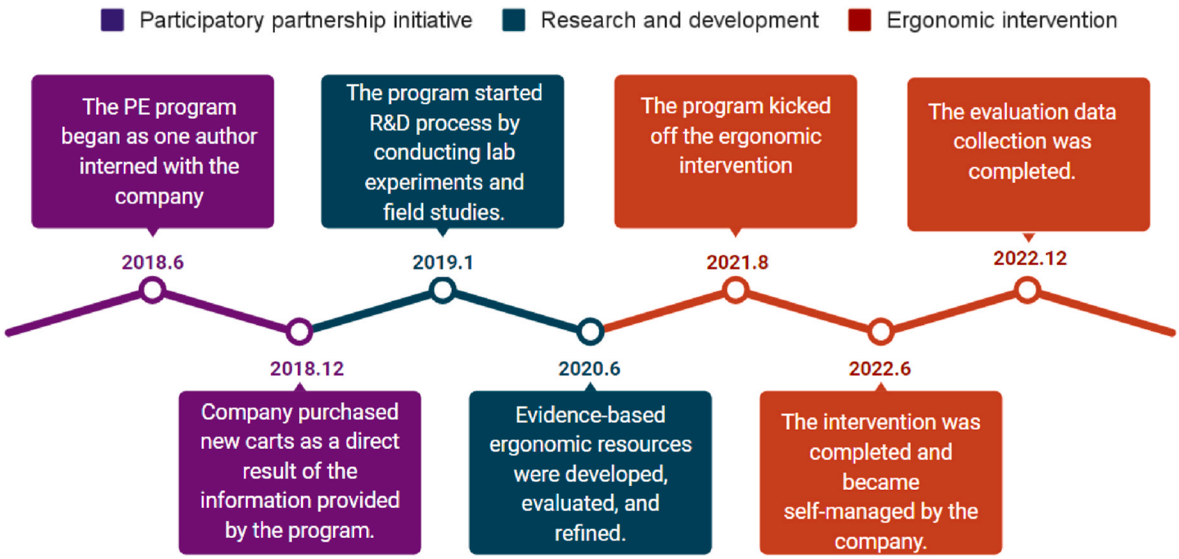

Fig. 1. Timeline of the PE program.

Fig. 2. Snapshots of the PE partnership: (a) new carts (insulation carriers) purchased by the company; and (b) an experimental ramp set up in the company's warehouse; (c) a focus group held in the company's meeting room to evaluate an animated story with 13 roofers; and (d) a group discussion held in the foreman meeting to evaluate another animated story.

goal was to help the safety team provide site-specific instructions and support (Fig. 4(c)) on manual cart handling.

- Working Environment Redesign (January 2022–June 2022). The company mechanic and the authors jointly modified carts by installing a handle to allow easy push from behind. The prototypes were presented at a foreman meeting to gather participatory feedback before the final launch. In addition, warning signage were attached to the carts (Fig. 4(d)) to offer an explicit point-of-choice prompt for ergonomic good practices that were covered in the skill training.

Since the completion of the four-component intervention in June 2022, the intervention became self-managed by the company with the routine consultation provided by the authors.

3. Methods

3.1. Study design

The aim of this paper is to evaluate the process and effects of the PE program to illustrate the value of implementation science in ergonomic

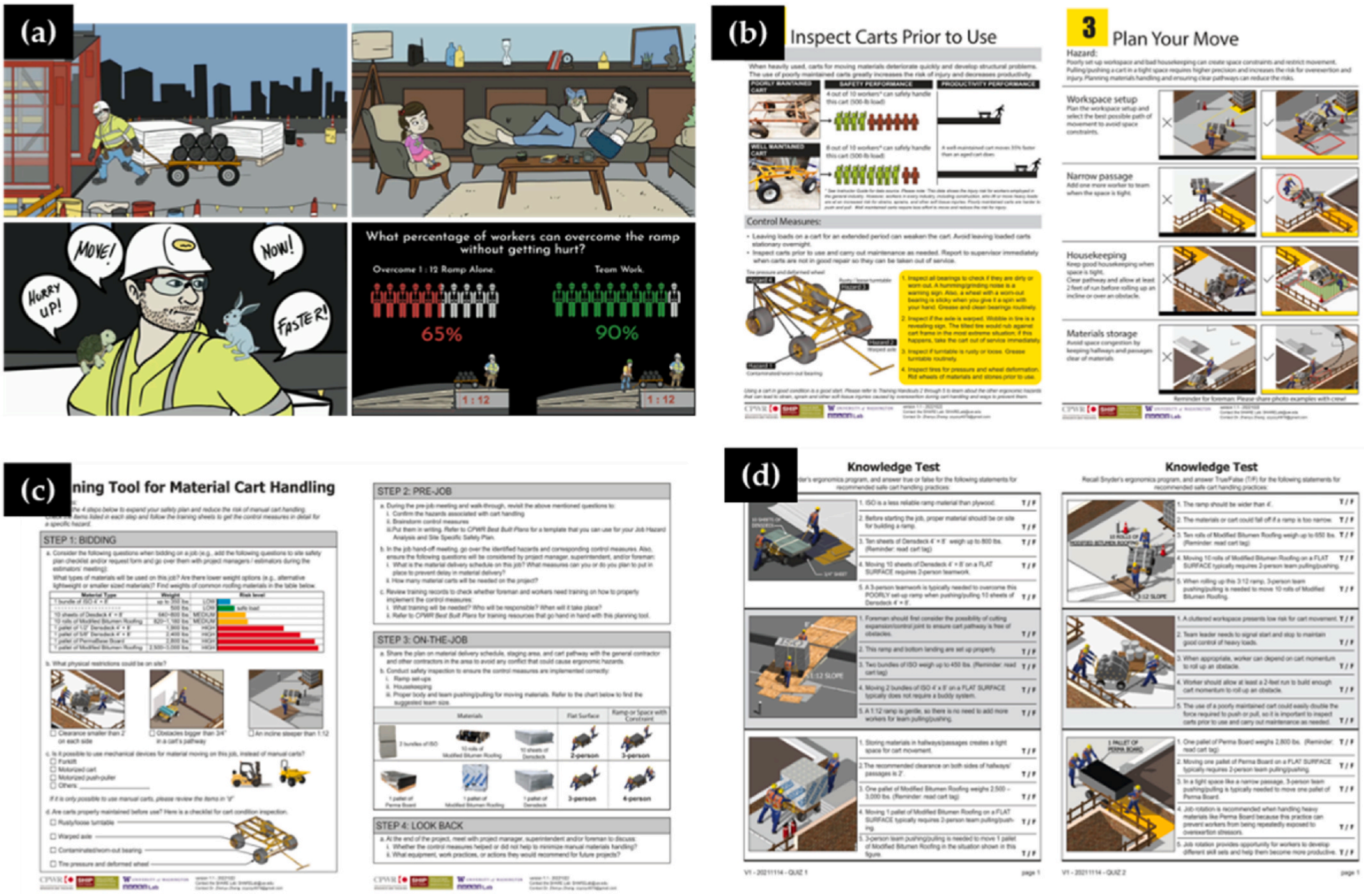

Fig. 3. (a) Screenshots of animated stories; (b) Sample training handouts; (c) Planning tool; and (d) Sample knowledge tests.

Fig. 4. Snapshots of the intervention: (a) 150 roofers watched an animated story at an all-hands meeting; (b) three roofers volunteering for hands-on practice during skill training; (c) 11 roofers filling out a program survey during lunch break; and (d) a remodeled cart with warning signage.

intervention studies. To achieve this, we adopted an effectiveness-implementation hybrid design, a commonly selected study design in implementation science (Kemp et al., 2019; Landes et al., 2020). This design allows researchers to gather information on the process of implementing an intervention while pilot testing its effectiveness, so that researchers do not wait until it is too late to consider the "implementability" of the intervention (Landsverk et al., 2012). This design allowed us to explore the most promising ways of implementing an intervention before testing it extensively in full-scale randomized controlled trials (Lewis et al., 2021).

The underlying methodology for this paper is a case study, in which a wealth of qualitative and quantitative evidence was obtained for the crucial examination of how implementation science contributes to PE theory and practice. Case study is considered suitable for testing and demonstrating the values of applying theoretical knowledge in real-world contexts (Flyvbjerg, 2001; Yin, 2017). In addition, the PE program selected for this case study constituted an exemplary case. As shown in the remainder of the paper, the case program successfully achieved desirable outcomes through spearheading some promising ways of structuring a PE program. In this light, this paper develops a ROI of the case program from the company perspective: The positive results about implementation costs versus financial merits can encourage more company representatives to emphasize and engage in PE studies and inform them of the program design and budgeting.

3.2. Outcome measures

The evaluation of the case program in this study focused on three key areas: process outcomes, intervention outcomes, and ROI. This comprehensive evaluation approach was employed to gain a thorough understanding of the program's implementation and effectiveness.

3.2.1. Process outcome measures

To evaluate the process outcomes, the RE-AIM framework was applied. The RE-AIM framework (Harden et al., 2018) is a widely-used method for evaluating the implementation of health programs. It identifies five key dimensions for evaluation: adoption (i.e., where and when the intervention was conducted); reach (i.e., who received it); implementation (i.e., the extent to which it was delivered as intended); efficacy (i.e., the observed impact of the intervention); and maintenance (i.e., the extent to which the intervention was continued after the study period). Specific outcome measures were adapted from previous studies and are summarized in Table 1.

3.2.2. Intervention outcome measures

Intervention outcomes were measured by evaluating the health and behavioral outcomes of the program's participants. The logical model for PE program evaluation (Jaegers et al., 2014) was applied to determine the outcome measures that gauged the effectiveness of the PE program. This model posits that intervention evaluation can be grouped into short-term impacts (e.g., skills, awareness, knowledge, and attitudes), intermediate impacts (e.g., behavior, practice, and decision-making), and long-term impacts (e.g., symptoms, risk factors, and MSDs). Table 2 lists the measures selected in this study for measuring program effectiveness. It should be noted that the terms efficacy (one dimension of the RE-AIM framework) and effectiveness could be interchangeable. To differentiate them in this paper, we refer to effectiveness as overall impact of the program resulting from a combination of multiple intervention components, while efficacy is defined as direct observed effect of a specific intervention component.

3.2.3. ROI measures

Finally, the ROI analysis described the program's mechanism in monetary terms to make a business case for the case program. The ROI Calculator developed by CPWR – The Center for Construction Research and Training (2013) was used to determine the cost structure of the ROI analysis. For each cost type, the cost items were catalogued by referring to the Classification of Implementation Costs proposed by Raghavan (2012). Table 3 presents a list of the cost and saving outcomes used in this study for the ROI analysis.

Table 1
Outcome measures and data collection plan for process evaluation.

Dimensions	Outcome measures	Data source and collection methods	Key source
Adoption	***A-1:*** Number of job sites that participated ***A-2:*** Portion of job sites that participated	Document review of project logs, signature and/or timesheets sheets for intervention activities, and safety documents	Beer-Borst et al. (2019)
Reach	***R-1:*** Number of individuals that participated ***R-2:*** Portion of individuals that participated	Same as Adoption	Beer-Borst et al. (2019)
Implementation	***I-1:*** Intervention elements not delivered as intended ***I-2:*** Contextual factors influencing an intervention ***I-3:*** Adaptations made	Participation observation by program implementers gathered through group discussions	Estabrook et al. (2012)
Efficacy	***E-1:*** Perceived benefits by participants ***E-2:*** Satisfaction ratings (applicable to Awareness Campaign & Skill Training) ***E-3:*** Scores on 15-question knowledge test (applicable to Skill Training)	Participation ratings and/or feedback gathered through survey and individual interview; participation observation by program implementers gathered through group discussion; knowledge tests	Adams et al. (2017)
Maintenance	***M-1:*** Interventions being continued or not	Semi-structured interview with program implementers; safety documents review	Welch et al. (2020)

3.3. Data collection

3.3.1. Process outcome data collection

Both qualitative and quantitative methods were employed in the process evaluation. To quantify adoption (A-1 and A-2) and reach (R-1 and R-2), we gathered and reviewed the company's timesheets, signature sheets, project logs, and safety documents from August 2021 to June 2022. Our review of company documents included a total of 27 training sessions and 7 construction projects. Deviations from the original protocol (I-1) were identified through discussions amongst program implementers during monthly intra-intervention meetings, which typically took 30 min. These meetings included the authors and two safety personnel from the partnering company. Program implementers further analyzed the contextual factors impacting implementation (I-2) and adaptations made (I-3), subsequently classified them into preconditions and moderators using the implementation causal pathway model (Lewis et al., 2021) as a guiding framework. Here, precondition refers to contextual factors that are necessary for the effective functioning of an implementation strategy, while a moderator refers to contextual factors or adaptations that increase the level of influence of an implementation strategy.

To measure the efficacy of the four intervention components, we used a variety of methods and data sources. For Awareness Campaign,

Table 2
Outcome measures and data collection plan for intervention evaluation.

Effectiveness	Outcome measures	Data source and collection methods	Key source
Short-term impacts	***ST-1:*** Usefulness of the program provided ***ST-2:*** Brevity of the program activities ***ST-3:*** Overall satisfaction of the program ***ST-4:*** Contribution to company's safety commitment ***ST-5:*** Contribution to company's safety value ***ST-6:*** Willingness to recommend	Program debrief questionnaire administered on site	Hess et al. (2020)
Medium-term impacts	***MT-1:*** Perceived improvement in crews' teamwork ***MT-2:*** Perceived improvement in crews' housekeeping ***MT-3:*** Perceived improvement in crews' task planning ***MT-4:*** Perceived improvement in crews' job rotation ***MT-5:*** Perceived improvement in equipment inspection	Program debrief questionnaire administered on site	Schwatka et al. (2019)
Long-term impacts	***LT-1:*** Incident number associated with cart handling ***LT-2:*** Injury costs associated with cart handling	Document reviews of injury log	Dale et al. (2016)

we undertook post-training surveys to evaluate participants satisfaction (N = 77), complemented by program implementers' perceived efficacy derived from their participation observations (E−1 and E−2). The survey was seamlessly integrated into the regular training debrief and sign-out process, allowing participants to complete it in less than 3 min. For Skill Training, we surveyed three foremen and four roofers after each round of the delivery to gauge their perceived benefits (E−1) and satisfaction levels (E−2). Each survey was scheduled on the same day as Skill Training sessions, and it took approximately 5 min to complete. To ensure convenience, the surveys were conducted over the phone after work, while workers were on their way home.

To measure knowledge retention and thereby further ascertain the intervention's effect (E−3), we administered knowledge tests during field visits both before (N = 42) and after (N = 40) the Skill Training sessions. The test questions were vetted by the company's safety team and employees at a safety committee meeting, and the process accounted for 10 min of the 60-min gathering. Baseline scores were collected before Skill training (October 2021–January 2022); follow-up scores were gathered after Skill Training (June 2022–October 2022). Typically, it took workers between 5 and 10 min to complete a knowledge test. Policy Intervention and Working Environment Redesign were examined through post-intervention interviews (June 2022–October 2022) with selected receivers of the intervention delivery, including one safety director, two safety managers, three foremen and three workers. Each interview was conducted in-person during routine field visits and typically lasted between 10 and 20 min.

Finally, a semi-structured, 1-h interview with the company's safety team, along with the review of safety documents was conducted after the program was completed to evaluate the maintenance of all four intervention components (M-1). All data on adoption, reach,

Table 3
Outcome measures and data collection plan for economic evaluation.

Cost or saving type	Cost or saving items	Data source and collection methods
Cost to purchase and maintain carts	***C1-1:*** Investments in new carts made by the company ***C1-2:*** Inspection and maintenance costs for carts	Document review of purchase orders and maintenance records
Cost to support research & development	***C2-1:*** In-house resources for laboratory experiments ***C2-2:*** Office and field staff's time cost in field data collection ***C2-3:*** Field staff's time cost in translating results into intervention materials ***C2-4:*** Safety team's time cost in coordination and administration	Document review of laboratory records, project timesheets, signature sheets for translation activities and in-kind contribution documents; survey shop workers for self-reported time data
Cost to training & deploy	***C3-1:*** In-house resources for creating intervention materials ***C3-2:*** Field staff's time cost in intervention participation ***C3-3:*** Participation incentives provided by the company ***C3-4:*** Safety team's time cost in implementation and administration	Document review of in-kind contribution documents, signature sheets for intervention activities, safety incentive tracker sheet; and survey safety team for self-reported time data
Saving in worker productivity	***S1-1:*** Saving from reduced labor time after cart replacement	Literature review of research article (Zhang et al., 2021) and field cart operation survey
Saving in injury costs	***S2-1:*** Saving from workers' compensation premiums ***S2-2:*** Saving from reduced indirect costs	Document review of compensation worksheets provided by insurance company
Compensation	***S3-1:*** Compensation for the company to use experiential carts at no cost	Document review of purchase orders

implementation, and efficacy was collected after each delivery. Methods and data sources used in measuring the process outcomes are described in Table 1.

3.3.2. Intervention outcome data collection

We collected quantitative data to evaluate the short-term, intermediate, and long-term outcomes of the PE program. First, an attitude survey (N = 42) was conducted as part of program debrief questionnaire to assess workers' perceptions toward the PE program and its contributions to the company (ST-1 to ST-6). The survey questions were adapted from the study by Hess et al. (2020). The program debrief questionnaire was administered on site within the four months following the completion of the interventions (June 2022–October 2022). To ensure convenience, the surveys were conducted during lunch breaks and took approximately 15–20 min to complete.

Second, five behavior-based questions were also incorporated into the program debrief questionnaire to measure perceived changes in behavior, practice, and decision-making (MT-1 to MT-5). All questions were in response to key messages of the training curriculum used in the program, as well as the behavioral change goals defined at the beginning of the program. This survey used a referent-shift approach and invited participants to reflect on to what extent they believe their co-workers made desired changes, which is found more accurate in predicting safety performance and improvement (Probst et al., 2019; Wallace et al., 2016).

Finally, to measure the reduction in MSDs from cart handling since the program's inception (LT-1 and LT-2), we reviewed the company's injury logs and workers' compensation worksheet to track claim numbers and claims costs. Injury data from the four years prior to the program (January 2015–December 2018) were used as the baseline to compare with the data gathered since the first ergonomic change led by the PE program in January 2019. Methods and data source used in measuring the intervention outcomes are described in Table 2.

3.3.3. ROI data collection

As shown in Table 3, the cost data for the ROI analysis was collected through a combination of document review and survey methods. The document review mainly involved various business documents and records tracked by the company, such as purchase orders, maintenance orders, and signature sheets, to track costs for resources and time commitment provided by the company (C1-1, C1-2, C2-1, and C2-3), such as time allocated to research translation and participation in intervention activities. These costs are considered “tangible” as they are easily quantifiable and are directly related to the project. To gather information on time not reflected in business records, such as shop workers’ time spent on setting up experiments and safety team coordination activities, we surveyed program implementers and individual participants to gather self-reported data on their time commitment to the project (C2-2 and C2-4).

The saving data for the ROI analysis was gathered using a multi-faceted approach that included literature review, survey, and document review. We combined field data with research evidence to estimate the productivity gain after cart replacement (S1-1). The field data was collected by the PE program through daily surveys at seven job sites from April 2019 to June 2020, and the results recorded the routine patterns of operating carts in the field. We also consulted the literature, specifically the study by the authors in the roofing industry (Zhang et al., 2021), which provides applicable experimental evidence on unit productivity improvement after adopting preventative replacement. To estimate savings in injury costs (S2-1 and S2-2), we used the same data sources and collection methods that were described earlier in Subsection 3.3.2. Additionally, we reviewed purchase orders to estimate participation compensation (S3-1). All ROI data was gathered and analyzed after the program was completed.

3.4. Data analysis

Descriptive data were summarized using percentages for all numerical process and outcome measures. Scores on knowledge test were treated as continuous variable, and the data collected from the baseline and follow-up tests were treated as independent samples. Student’s t-test was conducted to compare if the difference between the pre-test and post-test is statistically significant. Qualitative data gathered for process evaluation was analyzed using content analysis with R Project. The ROI data was tabulated and calculated using the ROI Calculator developed by CPWR (2013). We estimated the workers’ compensation premium paid by the company for cart handling injuries pro rata, based on the relative portion of medical costs resulting from cart injuries. Indirect

Table 4
Results of the process evaluation.

	Awareness Campaign	Skill Training	Policy Intervention	Working Environment Redesign
Adoption: • *A-1 & A-2*	• Safety orientations: 17/17; 100% • All-hands meetings: 1/3; 33% • Foreman meetings: 1/6; 17%	• Foreman meetings: 2/3; 67% • Toolbox talks: 5/5; 100% • All-hands meetings: 1/1; 100%	• Projects that used carts in routine operation: 7/7; 100%	• Remodeled carts: 3/7; 43% • Warning signages: 6/7; 86%
Reach: • *R-1 & R-2*	• Safety orientations: 77/77; 100% • All-hands meeting: 143/184 (78%) • Foremen meeting: 17/27; 63%	• 1st foreman meeting: 12/27; 44% • 2nd foreman meeting: 11/27; 41% • All toolbox talks: 170/170; 100% • All-hands meeting: 133/170; 78%	• Site-specific instructions: 80/170; 47%	• Remodeled carts: 42/170; 25% • Warning signages: 63/170; 37%
Impl.:	I-1: • Successful with good worker engagement I-2: • Changed orientation format • Covid-19 social distancing measures I-3: • All-hands meeting moved earlier due to company’s request • Presentation adapted to include other ergonomics topics	I-1: • Foreman meetings and all-hands meeting implemented as planned • Implementation of toolbox talks varied I-2: • Pandemic absence • Foremen’s instruction skills and commitment to safety • Lack of hands-on practice • Language barriers I-3: • Added two hands-on practice sessions and one session on instruction skills • Turned core training curriculum into contests using game format	I-1: • Successfully implemented, 8 out of 13 suggested changes made I-2: • Facilitators: successful execution of other intervention components, effective cross-department communication; • Barriers: lack of information, slow cross-department execution, instability within the safety team I-3: • N/A	I-1: • Remodeled carts: not successful, Warning • Signages: overall satisfactory I-2: • Remodeled carts: preferred original carts, raised safety concerns. • Warning signages: delivery delayed to align with reordered sequence of Skill Training I-3: • Rollout of warning signages performed in conjunction with problem-based training
Efficacy	E−1: • Perceived increased in awareness E−2: • 71 out of 77 workers perceived an increase in knowledge • 68 out of 77 perceived an increase in confidence	E−1: • Usefulness of the information, practical relevance, ease of learning E−2: • Mean rating of 4.74/5 from 29 responses E−3: • Knowledge test scores increased significantly	E−1: • Awareness raised, comprehensive planning	E−1: • Helpful visual cues/prompts
Maint.: • *M-1*	• Orientation internalized, • All-hands meeting repeated annually • Foreman meeting stopped	• Foreman meetings and toolbox talks repeated • All-hands meeting continued as needed	• Continued and institutionalized	• Warning signages continued

costs were calculated using the Safety Pays Program developed by OSHA (2015). The overall ROI ratio was calculated using formula provided by Raghavan (2012).

4. Results

4.1. Process evaluation

The PE program conducted a total of 27 training sessions between August 2021 and June 2022, along with site-specific interventions on 7 construction projects. Overall, the intervention activities were implemented faithfully and effectively, and the company plans to continue most of them in the future. The results of the process evaluation are summarized in Table 4.

4.1.1. Awareness campaign

Adoption: The numbers (A-1) and portions (A-2) of job sites that participated in the Awareness Campaign were as planned, with the exception of one scheduled delivery at an all-hands meeting that was replaced last-minute by a business-related presentation.

Reach: Due to the fact that all intervention activities were conducted in conjunction with the company's existing training events, the numbers (R-1) and portions (R-2) of individuals that participated reflected typical turnover rates and were satisfactory.

Implementation: The program implementers reached consensus that the implementation was successful with good worker engagement (I-1). However, two contextual factors negatively impacted implementation (I-2). In January 2022, the company changed the orientation format from a slide-based lecture to a multimedia video, which resulted in the loss of the safety team's ability to introduce the story and facilitate discussions. Additionally, due to Covid-19 social distancing measures, the all-hands meeting was held outdoors and the screen became too bright to look at towards the end of the training. To accommodate the company's requests, two adaptations were made (I-3). The all-hands meeting was moved from December 2021 to August 2021, as the safety team believed ergonomics was a timely topic during the summer when most overexertion-related MSDs occur. For the same reason, the presentation was adapted to include other topics related to manual materials handling. The all-hands meeting awareness training was completed within an hour, while the intervention-specific segment only occupied 10–15 min during both the safety orientation and foreman meetings.

Efficacy: Anecdotal evidence was obtained to demonstrate perceived benefits by participants (E−1). For example, when the safety director attempted to reach personal protection equipment on the top of a closet during a safety orientation, she was reminded by new hires: "Did you forget to ask for help? We just learned it from the animation. We should always work as a team!" Satisfaction ratings (E−2) received were promising: 71 out of 77 workers perceived an increase in ergonomic knowledge and 68 out of 77 reported an increase in confidence in addressing hazards due to the Awareness Campaign.

Maintenance: Two of the Awareness Campaign activities, the safety orientation and all-hands meeting, have been institutionalized as part of the company's safety program and are being continued (M-1). No plan was made to continue the Awareness Campaign at foreman meeting trainings, but the animated story was planned to be delivered at new foreman orientations.

4.1.2. Skill training

Adoption: The number (A-1) and proportion (A-2) of job sites that participated in Skill Training were as planned, with the exception of two scheduled deliveries at foreman meetings that were canceled due to increased absences during the Covid-19 pandemic. To mitigate the impact of these canceled meetings, the training topics were reordered (I-3) to allow foremen to self-learn two "easier" topics before leading toolbox talks.

Reach: As a result of the canceled meetings, the number (R-1) and proportion (R-2) of individuals who participated in foreman meetings was lower than expected. Every round of toolbox talks, however, reached every frontline worker.

Implementation: The foreman meetings and all-hands meeting were implemented as planned (I-1). However, the implementation quality and duration (ranging between five to 20 min) of toolbox talks varied (I-1) depending on the foremen's instruction skills and commitment to safety (I-2). Additionally, workers reported a lack of hands-on practice as a barrier to effective implementation (I-2). To address these barriers, the program implementers added two hands-on practice sessions and one session on instruction skills (I-3). Additionally, the PE program turned the core training curriculum of Skill Training into contests using a game format to make the training more engaging and memorable (I-3). Altogether, Skill Training occupied 20 min during the 1-h all-hands meeting.

Efficacy: Workers reported various benefits (E−1) from Skill Training, such as the usefulness of the information, its practical relevance (e.g., "*The training goes hand in hand with what is done on the site.*"), and ease of learning (e.g., "*They are easier than the old trainings where we would get a huge textbook and have someone read through it. These are easier to remember.*"). The training also received an overall mean rating of 4.74/5 from 29 responses (E−2). Furthermore, the program led to an improvement in workers' ergonomics knowledge. As shown in Fig. 5(a), a statistically significant increase in mean scores was found from 73% in baseline tests (42 responses) to 86% in follow-up tests (40 responses) (E−3).

Maintenance: Skill Training materials would be integrated as part of orientation program for new foremen; deliveries at toolbox talks and all-hands meeting will be repeated at least biannually.

4.1.3. Policy intervention

Adoption: The numbers *(A-1)* and portions *(A-2)* of job sites that participated in Policy Intervention were satisfactory but slightly lower than expected with seven projects using carts during the study period compared to the average of nine projects during the same time interval in the past three years.

Reach: Due to the lower adoption rate, the number (R-1) and percentage (R-2) of individuals who participated in the intervention were also lower than expected.

Implementation: The company successfully implemented eight out of the 13 suggested changes (I-1). Two factors were identified as facilitators for successful implementation: successful execution of other intervention components (e.g., *Cart training creates criterion and shared understanding and makes it easier for policy intervention*) and effective cross-department communication (e.g., *The communication comes full circle from estimating through job handoff, down to the crew*). Five suggested changes were not implemented as intended. The first two recommendations—suggesting lower weight options and considering hazards related to physical restrictions—were not adopted due to a lack of project information available during the bidding phase. The safety team's suggestion on proper maintenance of manual equipment was not fully implemented due to slow execution across different departments (e.g., *That's a different department, so the change will happen a little more slowly*). Two other suggestions—brainstorming ergonomic solutions during the pre-construction phase and soliciting recommendations upon project completion—were not pursued due to the absence of established business procedures for such activities within the company. Moreover, the safety team's increased confidence in the working knowledge of field staff following our Awareness Campaign and Skill Training led them to perceive a lesser need for changes in these areas. Finally, the instability within the safety team, caused by the departure of one safety manager during the intervention and the training of its replacement, further delayed the adoption of these five suggestions (I-2).

Efficacy: The safety team found the intervention enlightening and helpful (E−1), with one example provided of how it caused the team to

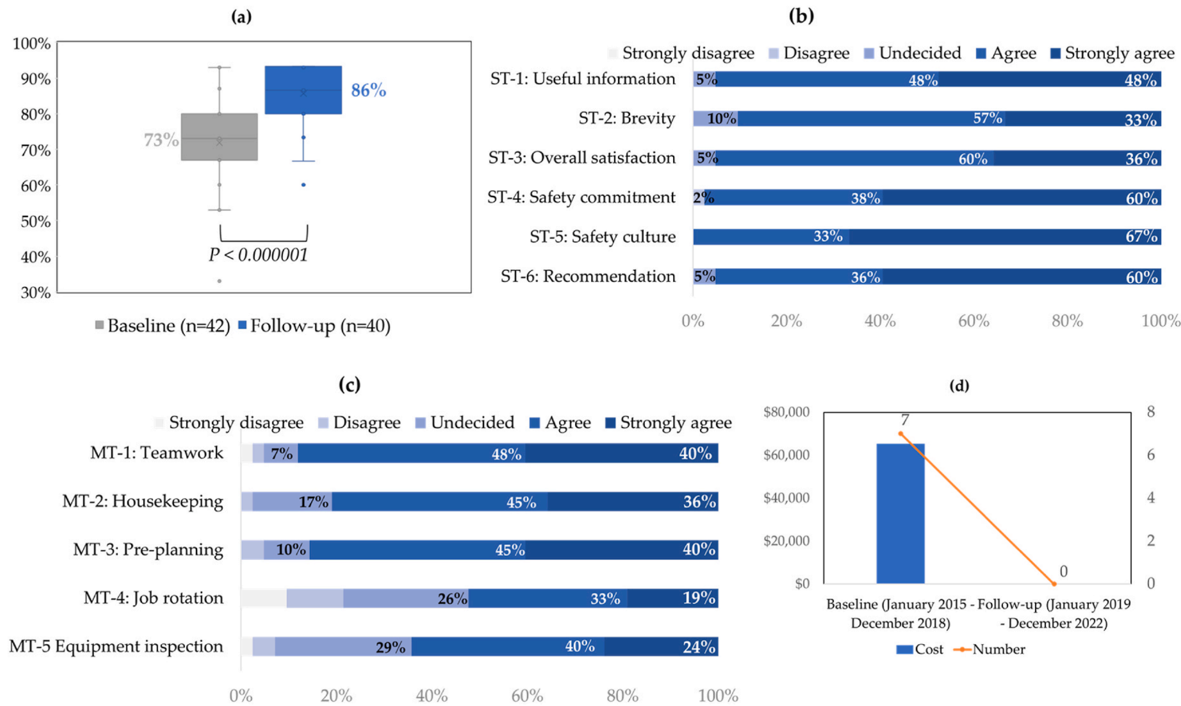

Fig. 5. (a) The difference in knowledge test scores between baseline (n = 42) and follow-up (n = 40) groups: The bottom and top of the box represent the 25th and 75th percentiles, respectively, and the line within the box is the median (73% versus 86%); (b) Short-term impacts of the PE program based overall program satisfaction (n = 42); (c) Medium-term impacts of the PE program based on perceived changes in crews' behaviors (n = 42); (d) Long-term impacts of the program based on the company's injury data.

think more seriously about every aspect of cart handling: "*It did cause me to overall think more seriously about every aspect of cart handling. Before this program, I would not have even asked whether carts are going to be used on a roof or not*".

Maintenance: All eight policy changes that were made have been continued, as they have become common knowledge within the company (M-1).

4.1.4. Working Environment Redesign

Adoption: The number (A-1) and percentage (A-2) of job sites that received the opportunities to use redesigned working environments: remodeled carts and warning signage were slightly lower than expected due to a decrease in the number of projects that used carts during the study period.

Reach: Similarly, the number (R-1) and percentage (R-2) of individuals that participated in this intervention were also lower than expected.

Implementation: The implementation of remodeled carts was not successful (I-1) as the field workers did not accept the changes and preferred to use the original carts they were familiar with (I-2). During the prototype feedback session of the remodeled carts, foremen raised safety and quality concerns, including the potential for tip-over and the susceptibility of extra handle to wear and tear, especially when the carts were fully loaded. However, we were unable to promptly address their concerns due to the absence of loads during the presentation. To rectify this, a subsequent demonstration was performed. Unfortunately, the improper setup of the remodeled cart by a warehouse worker resulted in a failure to highlight its advantages over the original carts, indicating that the carts could be problematic when workers were not adequately informed about their correct usage. Eventually, negative field feedback, coupled with the company mechanic's increased workload due to the departure of his coworker, led to the decision to discontinue this aspect of the intervention. On the other hand, the implementation of warning signages was overall satisfactory (I-1), although the delivery was delayed for 3 months to align with the reordered sequence of Skill Training (I-2). One adaptation (I-3) was made based on the safety team's suggestion: the rollout of warning signages was performed in conjunction with problem-based training on-site to help workers develop the habit of reading safety labels before using any equipment.

Efficacy: The warning signages were well-received by workers and found helpful by the safety team (E−1). The safety team reported that the signages gave workers permission to ask for help when the load was heavy, which they viewed as a positive aspect.

Maintenance: The safety team intended to continue using the warning signages, as they expected strong benefits from their maintenance (M-1). A member of the safety team stated, "I would like to continue using those. They're a great reference. Even if people have seen the tag once and know what's on it, the fact that it's hanging there, even if they don't look at it again, it's a constant reminder of asking for help."

4.1.5. Mechanism of change underlying the implementation

When linking the process evaluation results to key implementation strategies, mechanism of change underlying the PE program implementation surfaced (Fig. 6). The program's success hinged on three crucial implementation strategies.

- **Seamless integration of the PE program into the company's existing safety program.** All intervention activities were designed to coincide with the company's regular training and planning activities, facilitating reach, adoption, and institutionalization of the intervention at a low cost.
- **Tailoring intervention materials to the specific context of use.** For example, toolbox talks were designed with bullet-pointed tips and talking points for crew discussions, while legible visual cues were used on-the-job as a reminder for ergonomic practices. This strategy ensured the accurate implementation of activities and achievement of desired outcomes.
- **Consistently monitoring feedback from both field and office staff, allowing for adjustments to intervention activities.** This reduced potential resistance to adoption, continuously enhanced

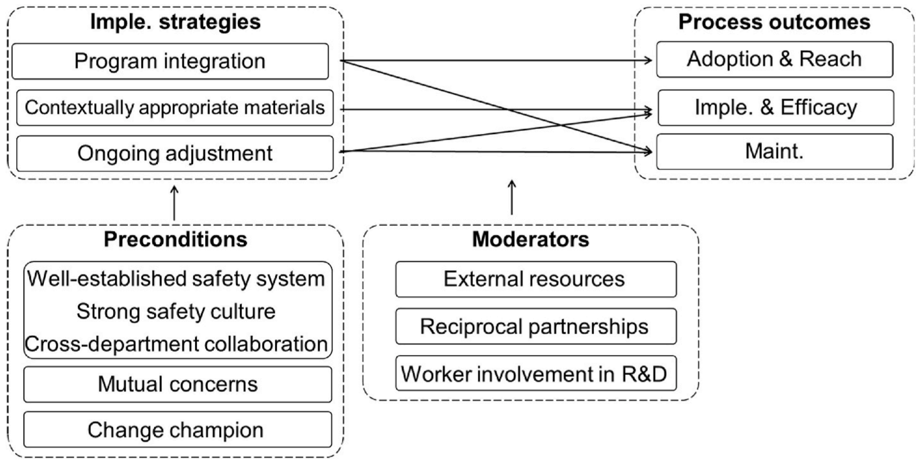

Fig. 6. Implementation strategies and contextual factors influencing the implementation of the PE program.

efficacy, and fostered co-ownership and commitment to maintaining the intervention.

Five organizational preconditions were instrumental in the effective functioning of these implementation strategies. The company had a well-established safety system, a robust safety culture, and efficient cross-departmental collaboration, which all synergized with the intervention as the PE program was integrated into the existing safety program. Furthermore, at the partnership's inception, both parties were driven by mutual concerns: the researchers recognized knowledge gaps in cart-handling ergonomics, while the company had long-standing concerns about MSDs. The safety director, in particular, was motivated to make ergonomic changes. As a change champion within the company, the safety director's dedication bolstered management and field staff commitment, contributing to the initiative's overall success.

Three key moderators enhanced the impact of the implementation strategies. First, external research grants funded the program, relieving the company of the financial burden and incentivizing staff engagement in executing the strategies that led to process excellence and desired outcomes. Second, mutually beneficial partnerships cultivated from the onset of the PE program improved group dynamics and created supportive interpersonal relationships for executing the implementation strategies. Lastly, the participation of company staff in R&D provided them with a deeper understanding of the research findings, enabling them to make better suggestions on tailoring the findings into implementation-ready materials. This participation experience also increased their sense of co-ownership of the program implemented at their job sites, encouraging proactive involvement during implementation to avoid failure and ensure success.

4.2. Intervention evaluation

The PE program achieved promising intervention results, as evidenced by the results of the program debrief survey (n = 42) in Fig. 5(b and c) and the injury data (2015–2022) in Fig. 5(d).

4.2.1. Short-term impact

According to Fig. 5(b), most workers surveyed (n = 42) reported positive attitudes towards the PE program and its contributions to the company, with high agreement that the program delivered useful information (ST-1: 96%), was presented in a concise manner (ST-2: 90%), and was overall satisfactory (ST-3: 96%). Additionally, the majority agreed that the program demonstrated the company's commitment to improving safety (ST-4: 98%) and care for worker safety and wellbeing (ST-5: 100%). As a result, most workers recommended the adoption of similar programs in the future (ST-6: 96%).

4.2.2. Medium-term impact

According to Fig. 5(c), 34 of 35 surveyed workers reported at least one positive change in their crews' behaviors as a result of the program, with high agreement that their crews were more likely to assist each other (MT-1: 88%), maintain good housekeeping (MT-2: 81%), and plan ahead before starting a job (MT-3: 85%). However, job rotation (MT-4: 52%) was not widely adopted, possibly due to a lack of detailed action plans at the company and project levels. Additionally, only 64% of surveyed workers perceived an improvement in equipment inspection (MT-5), which may have been hindered by slow cross-department execution and human resource challenges.

4.2.3. Long-term impact

As seen in Fig. 5(d), there were zero injuries from cart handling after the first change brought by the PE program (January 2019 to December 2022), compared to 7 injuries four years prior between January 2015 and December 2018. It is estimated that the program saved the company a total of $65,323 b y preventing cart handling injuries, including $23,866 from workers' compensation premium and $41,457 from indirect costs.

4.3. Return on investment

The ROI analysis, shown in Table 5, demonstrates a positive impact of the PE program on the company. The total investment made by the company in the program was $51,806, and the total return was $102,857, resulting in an ROI rate of 1.99. In other words, $1.99 were saved for every dollar invested. The main costs were for R&D ($24,040) and training and deploying staff ($20,410), with 48% of the total investment being the safety team's time (C2-4 and C3-4). The main savings were from injury prevention, amounting to $65,323. The assumptions and breakdown of the ROI analysis are explained in Table 5's notes.

It is important to note that these results are conservative as they do not take into account indirect benefits such as safety culture and employee satisfaction that were shown in Fig. 5(b). It was evident from interviews that workers perceived management's recognition of the positive impact of even small ergonomic changes on their satisfaction and productivity during the program (e.g., *The company can definitely notice how well we work with good materials and machinery … If they're [materials and machinery] crappy and not working, we're gonna be feeling crappy and not want to work.*) As a result, management has shown increased support in exploring ergonomic innovations through participatory processes, such as conducting trials of stair climbing carts and assigning a new dolly to each propane bottle. This significant shift in management mindset and action is anticipated to have profound effects on various aspects of the workplace. Additionally, the time horizon used

Table 5
ROI analysis results for the PE program.

Cost or saving type	Cost or saving items	PE Program	w/o PE Program	Difference
Cost to purchase and maintain carts	***C1-1***	$11,856[a]	$0	$11,856
	C1-2	$1,500[a]	$6,000[b]	-$4500
Cost to support research & development	***C2-1***	$3550	$0	$3550
	C2-2	$9,500[c]	$0	$9500
	C2-3	$1,240[d]	$0	$1240
	C2-4	$9,750[e]	$0	$9750
Cost to training & deploy	***C3-1***	$5100	$0	$5100
	C3-2	$26,328	$26,328[f]	$0
	C3-3	$100	$0	$100
	C3-4	$15,210[g]	$0	$15,210
Saving in worker productivity	***S1-1***	$39,208[h]	$60,320[i]	-$21,112
Saving in injury costs	***S2-1***	$0	$23,866	-$23,866
	S2-2	$0	$41,457	-$41,457
Compensation	***S3-1***	$0	$16,422[j]	-$16,422
		Total investment		**$51,806**
		Total return		**$102,857**
		ROI rate		**1.99**

Notes.
[a] The company spent $11,856 on 15 new carts of three types: four-wheel carts, dollies, and insulation carriers. The estimated cost to maintain these carts over four years was $1500.
[b] Without the intervention, the company would have had to continue using old carts and spend $6000 to maintain the old carts over four years.
[c] The company invested approximately 190 h in field data collection over the course of a year. This includes the time spent on tasks such as incorporating surveys into daily timecards, coordinating between the field and office, as well as the time taken by foremen to fill out the surveys on a daily basis.
[d] A combined total of 26 workers committed 1 h each, while 23 managers and foremen devoted 15 min each, to participate in focus groups aimed at refining intervention materials.
[e] Safety team dedicated 195 h over 18 months to project coordination and administration during the R&D phase.
[f] Safety team dedicated 304 h over 21 months to project coordination and administration during the intervention phase.
[g] Without the intervention, the company would still have had to allocate $26,328 for ergonomics trainings, equivalent to 874 training hours for safety orientations, foreman meetings, toolbox talks, and all-hands meetings.
[h] The labor cost without replacing aged carts was estimated based on field observation and survey reported in (Zhang, 2021).
[i] Labor time savings of 35% after cart replacement was estimated based on evidence from Zhang et al. (2021).
[j] 14 four-wheel carts were purchased with grant funds for laboratory and field experiments. Their use was complimentary for the company.

(Jan 2019–Dec 2022) is short, however, the effectiveness of the program in preventing injuries can be expected to be long-lasting as it focuses on safety culture, healthy behaviors and ongoing training. Plus, the company has already finished investing in research and development, and maintaining and sustaining the intervention only requires minimal investment.

5. Discussions

5.1. Lessons learned from the case study on structuring a PE program

This case study presents the implementation and evaluation of a 4.5-year ergonomic program aimed at improving ergonomic awareness, knowledge, and behaviors to reduce cart-handling injuries in a large specialty contractor in the construction industry. The program evaluation results demonstrate success in achieving the program's goals in a cost-efficient manner. The results also reveal three innovative and promising aspects of the program's structure that contribute to its effectiveness and set it apart from other ergonomic programs reported in the literature (Burgess-Limerick, 2018; Cole et al., 2005).

5.1.1. Integrating PE program into the partner Company's management system

A key strength of the program was its full integration into the partner company's management system. Unlike many existing PE programs implemented as stand-alone initiatives (Yazdani et al., 2015), our program was not perceived as a 'side-car' function but was instead fully aligned with the company's business processes and practices. For example, the company's safety management procedures were updated through Policy Intervention. The safety team simply incorporated a selection of pertinent ergonomics-related questions into their regular meetings with project teams. This strategy preserved the flow and original function of these gatherings, thereby facilitating the institutionalization of intervention activities. Furthermore, Skill Training was delivered in manageable portions during toolbox talks, foremen meetings, and all-hands meetings. This not only ensured effective adoption among the target audience but also minimized the administrative burden on the company. Our study supports the argument put forth by Yazdani and Wells (2018) that incorporating ergonomic programs into a company's existing safety initiatives can help overcome significant barriers faced by ergonomic professionals in preventing MSDs. Our study not only confirms this argument but also provides an exemplary case of the benefits of integrating ergonomic programs and insights on how to do so effectively.

Indeed, this synergistic approach has been instrumental in dismantling departmental 'silos' and fostering a culture of collective responsibility for workplace ergonomics. The genuine commitment to improving safety lies at the core of the company's managerial ethos. Yet, tangible efforts were previously limited, as each department focused heavily on its own specialized duties. The introduction of this integrated program has provided an accessible avenue for managers to actualize their commitment to ergonomics. The program's ease and effectiveness, in translating genuine interest into concrete action, has been widely appreciated. It is widely agreed that this PE program marked the company's very first initiative where field staff, office personnel, and safety professionals have worked in unison, realizing a shared responsibility for worker safety within the company. The resounding success of this program has proven to be a valuable asset to the safety director, who perceived an increase in confidence while securing top management commitment and fostering cross-departmental buy-in for safety initiatives.

5.1.2. Combining PE and researcher-in-residence models

Our program uniquely combines the PE and researcher-in-residence models (Vindrola-Padros et al., 2019), unexplored in most ergonomic programs. One of the authors served as a researcher-in-residence throughout the program, which enabled him to become familiar with the company's management, identify opportunities for integrating PE program into the company's management system, and establish connections with staff. This relationship was also strengthened through reciprocal support beyond the scope of the PE program, such as researchers' assistance with the company's summer internship recruitment and volunteering for orientations while the safety director was out of the office. These efforts were seen as goodwill that top management explicitly wanted to reciprocate. The hybrid model facilitated group dynamics and allowed for more effective collaboration between the company and the research team, leading to better program outcomes. This approach has the potential to encourage more fruitful collaborations between universities and companies to reduce MSDs and enhance business performance.

5.1.3. Utilizing external funding

The use of external funding played a crucial role in the success of the program, addressing the longstanding challenge of resource commitment from company management in preventing MSDs (Boatman et al., 2012; Dasgupta et al., 2017; Entzel et al., 2007; Village and Ostry, 2010). External funding alleviated the company's financial burden for

R&D and ergonomic changes while providing financial incentives to garner company-wide support and engagement. Our study emphasizes the benefits of utilizing external research grants as seed money, incentivizing key stakeholders like the safety team to invest their time and expertise during the ideation phase, rather than requesting company investment initially. The successful execution of the initial phase can naturally lead to further company investment. This funding strategy is powerful and complements other approaches, such as recruiting internal champions and external experts and selecting achievable initial objectives (Burgess-Limerick, 2018). However, relying on external funding might also have its challenges, such as potential fluctuations in funding availability or changes in funding priorities.

5.2. Value of using implementation science to enhance PE

Despite the popularity of PE programs to prevent MSDs, there are criticisms about the lack of scientific methods to measure and manage their implementation (Rasmussen et al., 2018). This has led to a limited understanding of why PE programs succeed or fail and how to improve their effectiveness (Burgess-Limerick, 2018; Van Eerd et al., 2018). Our case study addresses these concerns by uniquely employing mixed tools from implementation science including the RE-AIM framework (Harden et al., 2018), the implementation causal pathway model (Lewis et al., 2021), and the Classification of Implementation Costs (Raghavan, 2012), which have not been widely used in previous ergonomic studies. As a result, our study highlights the benefits of using implementation science in the PE context: enabling a coherent structure for reporting complex programs, uncovering mechanisms of change, and informing future adaptations and study designs.

5.2.1. Evaluating complex PE programs with a coherent structure

Our case study demonstrates the usefulness of implementation science in evaluating complex PE programs. The multi-component nature of our intervention, such as involving R&D, policy upgrades, worker training, and site-specific instructions, made it more challenging to evaluate than simpler programs, such as stakeholder committee-led training reported in the literature (Dale et al., 2012; Driessen et al., 2010; Van Eerd et al., 2018). By using implementation science, we provided a coherent structure for reporting the processes of a complex program, enabling meaningful comparison of intervention effectiveness across cases.

5.2.2. Uncovering mechanisms of change with coherent evaluation

Our study underscores the value of using implementation science to uncover the mechanisms of change underlying PE programs. Unlike prior research that focused solely on process evaluation (Nobrega et al., 2017; Visser et al., 2018), this study synthesized the program's process evaluation results with its implementation strategies and contexts. By classifying contextual factors according to their distinct roles, such as precondition and moderator, in influencing strategy effectiveness, we gained insights into the mechanisms of change. For example, our analysis revealed that the success of the "ongoing adjustments" strategy relied on preconditions, such as an open culture within the company and change champions. Fostering mutually beneficial relationships with change champions enhanced their engagement and strategy efficacy, acting as a moderator.

By documenting and assessing the impact of contextual factors on implementation quality, we have gained insights that shed light on potential enhancements for future programs. A prominent issue that emerged in this case study was that two out of three suggested policy changes for the company's bidding phase were not adopted. The challenge stemmed from the unfavorable precondition of the traditional design-bid-build delivery methods in the construction industry. In these methods, specialty contractors, like our partner company, are typically not involved in project conception and design. As a result, they often lack critical project information necessary to consider ergonomics when preparing a bid for the job. Our lesson learned from this experience is that such suggestions should be provided exclusively for design-bid projects, where information sharing is transparent between contractors involved. Otherwise, we should shift our focus towards proposing more changes during the pre-construction phase, where potential ergonomic considerations can be better integrated.

Another notable issue that surfaced during our PE program was worker pushback against the remodeled carts. The global context of implementing this component was the instability of mechanic team. Staff shortages were partially responsible for the suboptimal setup of the demonstrations. The remodeling project experienced a delay of over three months, leaving limited time for ongoing adjustments based on participatory feedback. Mechanics constantly expressed time pressure due to an increased workload caused by the departure of a coworker, which diminished our implementation team's confidence in continuing the intervention and addressing workers' feedback. In hindsight, we still perceived the in-house mechanic's design as having potential advantages. However, hiring external mechanics with greater availability could have resulted in more effective implementation. By having additional resources, we could have addressed the time constraints and ensured a smoother and more ideal setup for the carts.

Additionally, understanding the underlying mechanisms of change can be instrumental in adapting future PE programs for broader impact and guiding study design when scaling up. For instance, if our partner company already had established business procedures for pre-construction and project debrief meetings, certain suggested policy changes could be more fully implemented. A readiness intervention program may, therefore, be introduced when transferring our program to a company with an inadequate safety system. This readiness intervention should involve strengthening the company's safety system before implementing the PE program. Our case study also shows that identifying change champions and building relationships with them could be a valuable addition to the readiness program.

5.2.3. Dispelling concerns around PE with implementation science lens

Concerns persist about the effectiveness and sustainability of PE, particularly when it is introduced as a standalone program that heavily relies on ongoing commitment and consistent investment from the company (Bohr et al., 1997; Yazdani et al., 2015). Without these, PE runs the risk of becoming a transient, unproductive venture (Albers et al., 2005; Dale et al., 2016; Peters et al., 2018). This paper extends beyond presenting a successful case study to legitimate PE as a means to address MSDs. Instead, it scrutinizes the success through the lens of implementation science. This viewpoint reveals that the perceived shortcomings of PE, including its transient nature and peripheral role, are not inherent attributes. Instead, they are operational challenges that can be overcome by carefully devised implementation strategies. Our case study illustrates that when properly integrated, PE can become a fundamental component of a company's system, yielding lasting and positive impacts. The core value of PE—promoting worker empowerment and a culture of transparency—is irrefutable across any workplace context and should be a target for every company. Thus, the research question should never be about the legitimacy of PE as a management strategy for MSDs. Instead, the scientific probe should focus on how to overcome the challenges associated with the effective execution of PE to maximize its benefits. In this regard, implementation science can provide the key to resolving this conundrum, paving the way for more effective PE programs that introduce not only emerging technologies (Golabchi et al., 2023) but also work arrangements (Cheyrouze and Barthe, 2023) geared towards promoting the health and wellbeing of workers.

5.3. Limitations and future research

This study offers valuable insights into the implementation process and evaluation outcomes of a complex and uniquely structured PE program. However, it is important to acknowledge the limitations and identify areas for future research. First, our case study employs a qualitative approach to examine the underlying mechanisms of change in the PE program instead of resorting to a quantitative analysis. While a qualitative approach is legitimate given the nature of the study, future research can benefit from conducting randomized controlled trials (RCTs) to possibly quantify the mechanisms of change and investigate causal pathways. Second, this study connects implementation strategies with process evaluation results to highlight factors influencing the implementation process. In future large-scale RCTs, researchers should also link implementation strategies and process evaluation results to program impact and ROI. This would enable a comprehensive exploration of factors contributing to the effectiveness and cost-efficiency of PE programs, as well as an examination of the impact of different program components on outcomes. Third, our study documents the PE program's implementation process, but it does not explicitly measure and track the execution of implementation strategies. Future research should address this gap by systematically examining the execution of implementation strategies and providing a clearer understanding of each strategy's effectiveness or areas for improvement.

The intervention evaluation results are drawn from a single company's eight-year injury data, thus emphasizing the need for further research involving larger sample sizes to corroborate and expand upon these findings. Moreover, the COVID-19 pandemic affected two of the four years in the post-intervention phase, leading to a 25% reduction in the company's total production hours. This inevitably impacted the number of projects that utilized carts. Despite this, workers reported a heightened usage of the carts during this period, owing to improved cart conditions and well-planned operation compared to the pre-intervention phase. While we acknowledge that the pandemic may have added complexity to the implementation of the PE program, we diligently ensured the program remained on course with effective adaptations. We believe our efforts practically minimized confounding effects during the evaluation of the intervention. Similarly, we documented and reported organizational changes that occurred over the study period, which could potentially impact the implementation of the PE program. However, we did not observe any significant organizational changes that substantially affected the program's intervention. Factors such as turnover rate, company structure, policies, and practices remained relatively consistent. Furthermore, it is worth noting that the company did not receive any ergonomic assistance beyond this PE program during the study period.

6. Conclusions

This study presents a comprehensive case study on structuring a PE program in the construction industry, demonstrating its effectiveness in improving ergonomic awareness, knowledge, and behaviors, as well as reducing injury rates in a cost-efficient manner. Our innovative approach integrates the program into the partner company's management system and combines PE with a researcher-in-residence model, highlighting the potential for improving PE program effectiveness and fostering collaboration between academia and industry. Furthermore, the application of implementation science principles in our study offers valuable insights into the underlying mechanisms of change, as well as future refinement and adaptation of the program for continuous growth. This study also provides an in-depth economic evaluation regarding the financial costs and benefits of our PE program and emphasizes the role of external funding in its success. While our study has limitations, such as the qualitative nature of the change assessment affecting our ability to quantify the effect of each implementation strategy, our findings pave the way for future research to address these gaps and further explore the value of implementation science in PE programs across industries. Ultimately, these efforts will contribute to the development of more effective and cost-efficient PE programs to prevent MSDs and improve worker well-being in the construction industry and beyond.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

The authors declare the following financial interests/personal relationships which may be considered as potential competing interests.

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